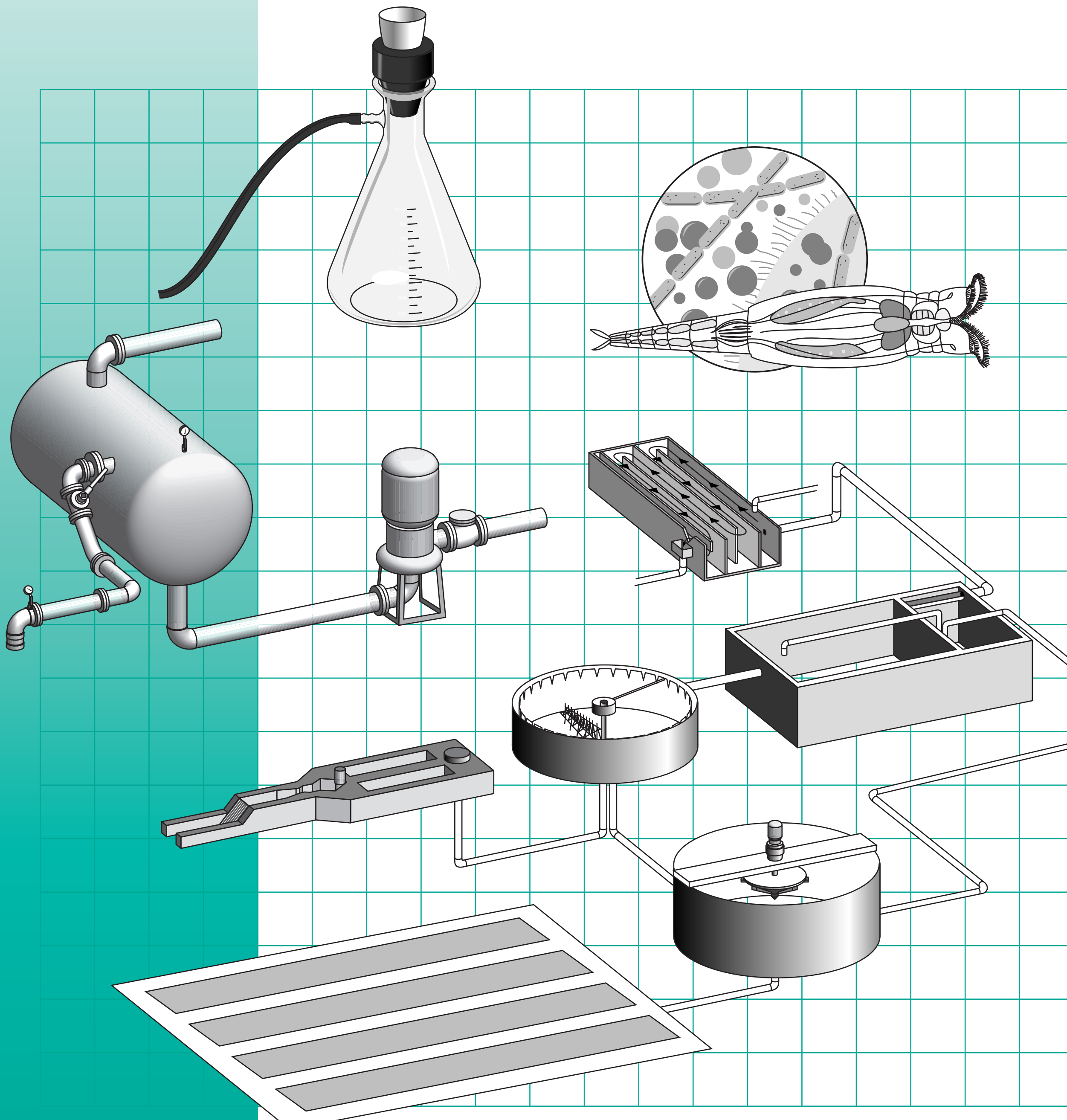
Introduction to Small Wastewater Systems



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Introduction to Small Wastewater Systems

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Introduction to Small Wastewater Systems

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Foreword

This material was developed for a four-day training course to provide owners and operators of small public wastewater systems a basic understanding of the principles and practices involved with collecting, treating and disposing of wastewater and wastewater sludge.

The course and text material are narrowly focused on communities with a population of less than 3,300. However, we believe that an entry level through level II operator at any treatment or collection facility of any size will find the material helpful.

Developing an understanding of the concepts discussed in this text should provide all of the necessary information needed to be successful with the wastewater treatment or wastewater collection OIT or Level I examination.

Operator Responsibilities

The job of wastewater system operator is an important one and is looked upon by EPA as a key to the health of the community. Therefore, it is assumed that a wastewater system operator must know their job and will perform their responsibilities in a way that indicates that knowledge. Failure to perform the responsibilities of the plant operator can lead to the loss of an operator's certification, or an even worse consequence.

Printing of this Manual

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Key Words

- Aquifers
- Contamination
- Environment
- Forest canopy
- Hydrologic cycle
- Infiltration
- Lithosphere
- Percolation
- Pollution
- Primary Treatment
- Receiving Stream
- Secondary Treatment
- Transpiration
- Vector
- Contaminants
- Effluent
- Evaporates
- Graywater
- Hydrosphere
- Influent
- Microorganisms
- Permafrost
- Precipitation
- Receiving Water
- Runoff
- Sewage
- Topography
- Wastewater

Introduction to Wastewater Systems

Introduction

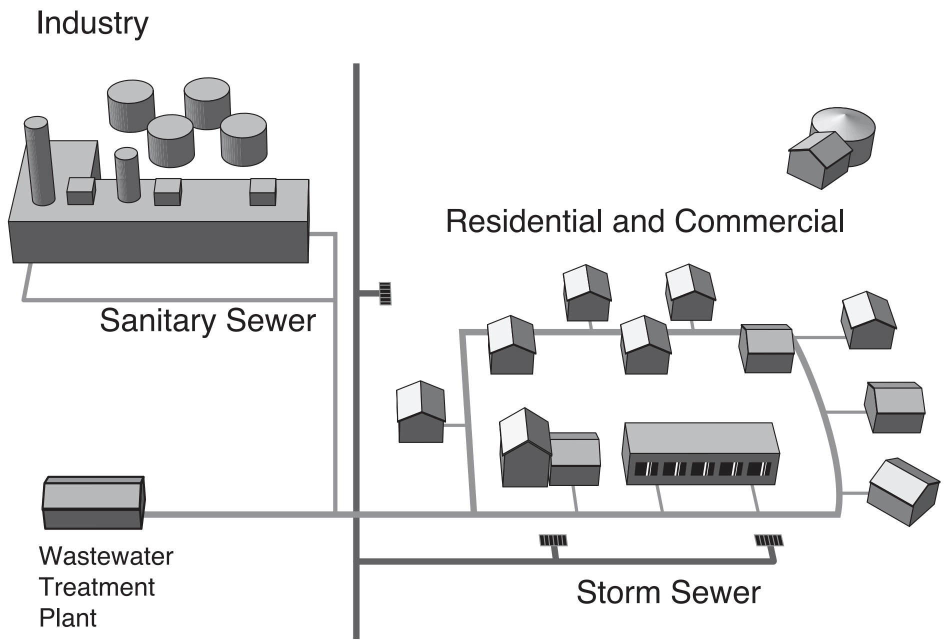
What is Wastewater?

We use water to wash our hands, wash the dishes, take a shower and flush the toilet. Water may also be used to clean the streets and to process foods such as fish. The water picks up material associated with its use called **contaminants**[1]. The water then carries the material away from houses and other buildings to a treatment plant or **receiving stream**[2]. This used water is called **wastewater**[3].

Sources of Wastewater

Three Categories

The used water (wastewater) is placed into one of three categories. The categories are based on the source of the wastewater. The three categories are; domestic wastewater, storm water and industrial wastewater.



Domestic Wastewater

Domestic wastewater is the wastewater produced by homes, businesses, schools, hospitals, clinics and other typical buildings found in any town or village. Domestic wastewater includes human waste and **graywater**[4].

Storm Water

Storm water includes surface **runoff**[5] from streets, the ground and roof drains.

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1 **Contaminant -** (Kun-TAM-uh-NAY-nt) - Toxic material, bacteria, or other deleterious agents that make the water unfit for its intended use.

2 **Receiving Stream -** A stream, river, lake or ocean into which treated or untreated wastewater is discharged.

3 **Wastewater** - The used water and solids from a community that flow to a treatment plant or receiving stream.

4 **Graywater** - Wastewater from kitchen sinks, showers and laundry, excluding human toilet wastes.

5 **Runoff** - Water that is the result of precipitation which is flowing over the earth's surface to rivers, streams, lakes and oceans.

Industrial Wastewater

Industrial wastewater is water coming from common industries such as fish hatcheries, fish processing, mining, pulp mills and other similar sources. Industrial wastewater contains contaminants other than human waste.

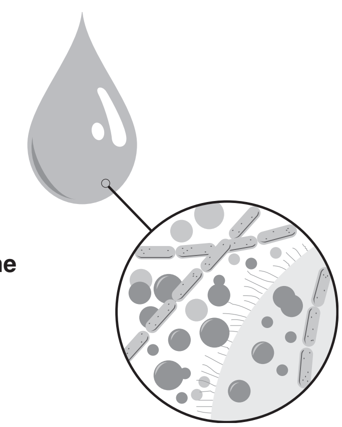
Impact of Wastewater

Introduction

The impact of using water to carry away contaminants depends on the source and quantity of the wastewater and how it is handled, collected, transported and method of disposal.

Disease & Human Waste

For instance, human waste contains **microorganisms**[6] that can cause disease. These microorganisms are commonly called germs, but more technically should be called **pathogenic organisms**[7]. One drop of wastewater containing human waste can contain millions of these disease-causing microorganisms.



Example of the quantity of pathogenic organisms in one drop of human waste

Disease and Graywater

Graywater can also carry these same disease-causing microorganisms. However, their numbers are usually less than wastewater containing human waste.

Disposal in a Stream

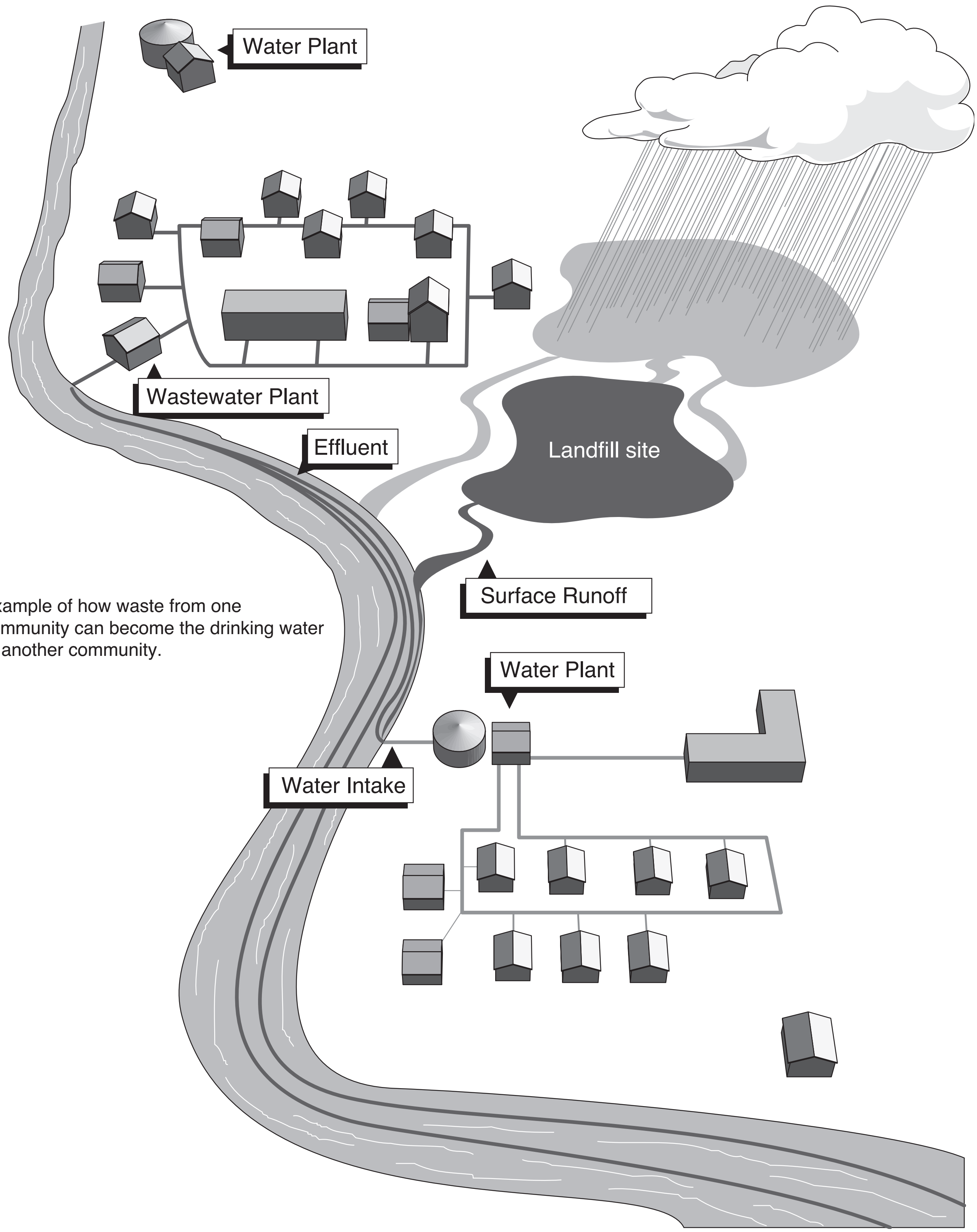
When domestic wastewater is disposed of in a stream or river, the disease-causing microorganisms are carried downstream and may be taken into the water intake of another village or city or hauled home by villagers using the stream for drinking water.

Disposal on the Land

When domestic wastewater is disposed of on the land, it can seep into the groundwater supply contaminating it and thus causing disease. The waste in the wastewater can also be tracked into the home by children, adults or dogs that walk through the wastewater and pick up the microorganisms on their feet or clothing. Because this waste is exposed, it can also be picked up by birds, flies, and other vectors and deposited directly on humans, their food, or places where it can contact humans.

[6] **Microorganisms** - Minute organisms, either plant or animal, invisible or barely visible to the naked eye.

[7] **Pathogenic Organisms -** Bacteria, virus and protozoa which can cause disease.



Example of how waste from one community can become the drinking water of another community.

How Can This Be?

Most people would not deliberately walk through a deposit of human waste. Children and dogs are less concerned about where they walk and play. Consequently, when waste is placed on the ground, the liquid portion seeps into the ground leaving behind small amounts of waste containing large numbers of pathogenic organisms. Because the microorganisms are so small, we walk on them without even knowing that they are there.

Storm Water and Disease

Storm water runoff contributes to the disease problem in a village or city in two ways. First, storm water may transport wastewater and garbage that have been deposited on the land into a receiving body of water. This contributes to the **pollution**[8] of the stream and increases the possibility of disease being transported to downstream users. Second, when ditches and culverts overflow, wastewater and garbage that have been deposited on the land can end up on walks and roadways. From here it can be tracked into the home.

Industrial Waste

While the collection and treatment of industrial waste is not a high priority in this text, the overall impact of this waste material is of importance to the wastewater operator. Industrial waste does not normally contribute to an increase in disease in a community because it contains materials other than human waste. However, when these materials enter a stream, they may contribute to the **degradation**[9] of the stream and its aquatic population.

Summary

Using water, contaminates the water, turning it into wastewater. If not properly collected, treated and disposed of, this wastewater can contribute to an increase in disease in the community. In addition, improperly treated waste that enters a receiving stream, can adversely affect the water quality of the stream impacting fisheries and can carry disease downstream to people that use the stream for drinking water.

[8] **Pollution** - (puh-LEW-shun) A condition created by the presence of harmful or objectionable material in water.

[9] **Degradation** - (degg-rah-DAY-shun) - Water Quality - The reduction of the quality of the water. (Chemistry - The conversion of a substance to a simpler compound. For example, the degradation of organic matter to carbon dioxide and water.)

The Spread of Disease

Introduction

As was stated above, untreated wastewater can be a major contributor to disease in rural villages such as those in the Arctic and the Pacific Islands. The question is, how does this happen? The following is a brief overview of a few common ways that disease can be transmitted in a rural village.

Personal Hygiene

Symptoms

It is important to understand that even though a person does not appear sick, they may still carry a disease. Many people can carry disease and not show any symptoms. However, carriers still pass disease-causing organisms in their waste. Therefore, we must assume that all human waste and graywater contain disease-causing microorganisms.

The Process

We get disease-causing microorganisms on our hands when we go to the restroom, change the baby's diapers or handle a honey bucket. Once our hands are contaminated, we transfer the microorganisms into our body. For instance, when we touch food, a cigarette, our mouth or, in some cases, just our face, and cause our own illness. The solution to this problem is to wash our hands with soap and hot water after each of these activities. However, in many villages in the Arctic and subarctic, the lack of an adequate supply of running water makes proper personal hygiene more difficult.

Honey Buckets

Handling

When honey buckets are hauled by hand to a disposal site they come in contact with a persons clothes, hands and gloves. The clothing items are then worn back into the home where they come in contact with children and adults. Simply touching a pair of gloves or pants that are contaminated can pass thousands of microorganisms to an unsuspecting individual. Once on the hands, the microorganisms can then be transferred to food, cigarettes or our mouths infecting us with the disease.

Spills

Spills from honey buckets occur during transportation and dumping at a collection site. Adults, children and dogs walk through the spill and pick up the microorganisms on their feet. These microorganisms can be tracked directly into the home or deposited where they are picked up on the feet of a second person or dog. Once they are tracked into a home, it is easy for children, who typically play on the floor, to pick up the microorganisms on their hands and transfer them to their mouth.

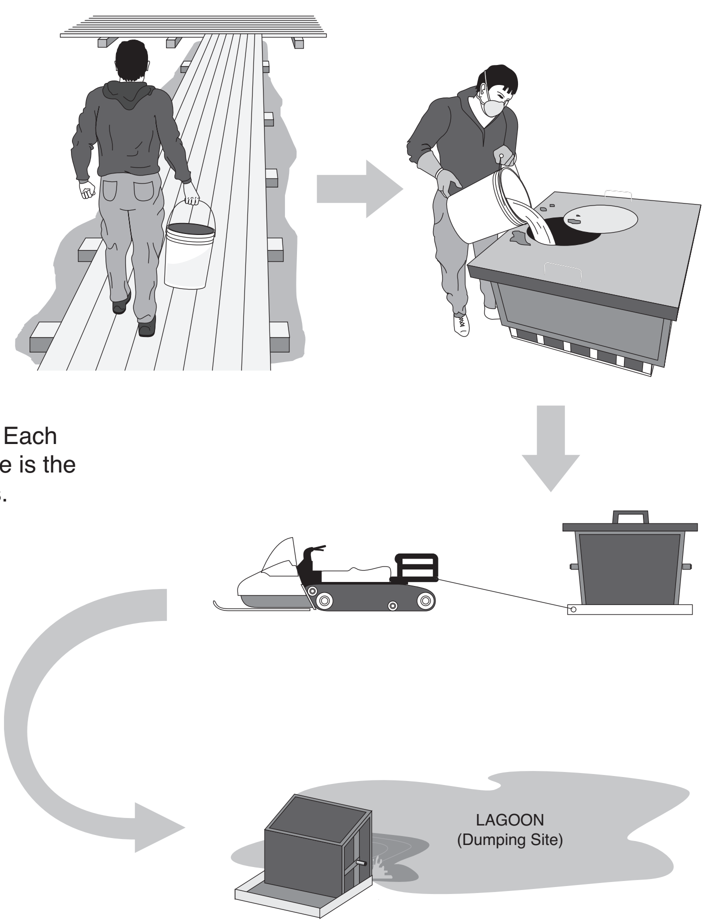
Disposal Pits and Sewage Lagoons

Disposal Sites

In some villages, honey buckets are disposed of in individual disposal sites. In other villages, honey bucket contents and individual home waste holding tanks are collected and hauled to a disposal site. While both of these practices reduce some exposure to disease, they can also be major contributors.

Spills

One of the major problems with these systems is accidental spills. No matter how careful the handler is, there will always be spills. The material that is spilled can be washed downstream into another village's water intake. In addition, the spill may be spread about the community by humans, dogs, snowmobiles, ATV's, birds and flies. Once it has been spread, it is very easy for the material to make it into a home on the shoes of adults and children or feet of dogs. The



Typical disposal sequence - Each time sewage is handled there is the potential to pick up diseases.

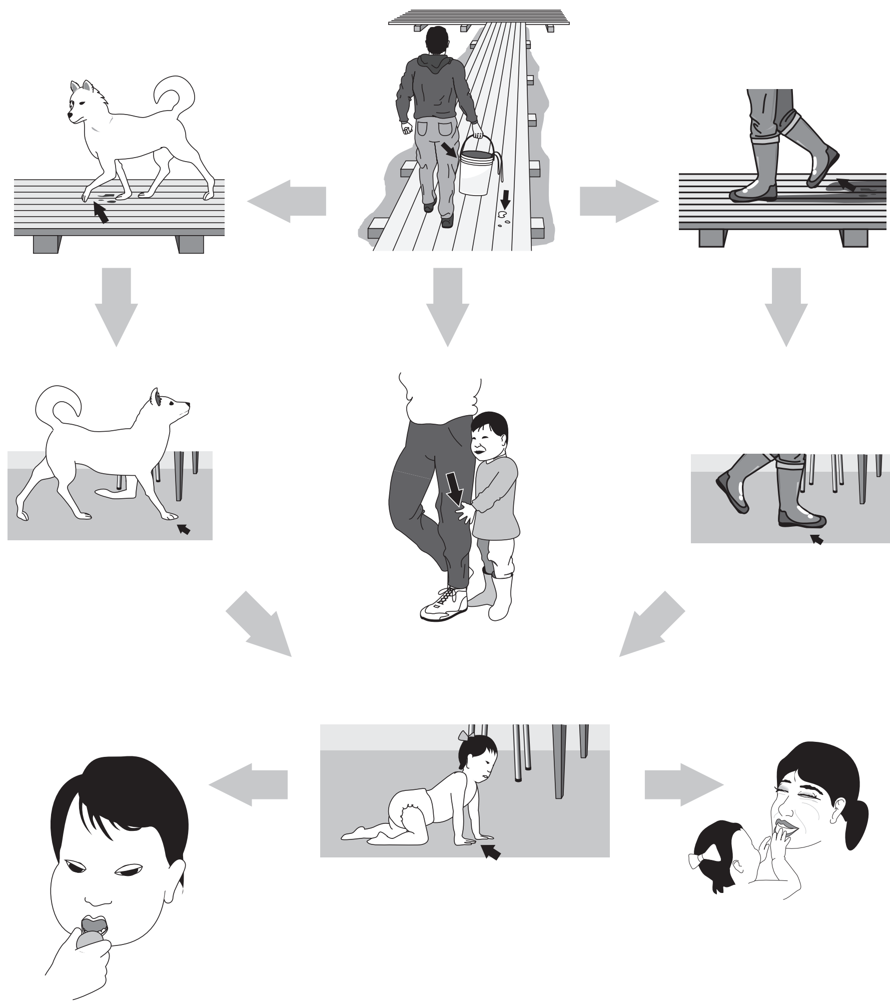
following is a brief description of how humans, dogs, and **vectors**[10] such as birds and flies can be major contributors to the transportation of disease-causing material.

Humans

As discussed above, humans are natural major carriers of disease. We carry common disease-causing germs inside of our body and deposit them in our waste. We transport disease when our clothing comes in contact with wastewater. Once on our clothing, it is easy for it to be transported to our hands and then to our mouth. We can cause disease in others by tracking **contamination**[11] into a home on our clothing or shoes where it is picked up by others.

Dogs

Dogs care little about where they walk. They can easily walk through a disposal site or spill and pick up germs on the bottom of their feet. As they travel around the village, they can deposit these germs for



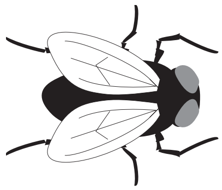
Cycle of disease as a result of handling human waste

[10] **Vector -** An agent who transmits pathogenic organisms from one organism to another. In a sewer this includes birds, mice, rats, flies and other insects.

[11] **Contamination** - (Kun-TAM-uh-NAY-shun) The introduction into water of toxic materials, bacteria, or other deleterious agents that make the water unfit for its intended use.

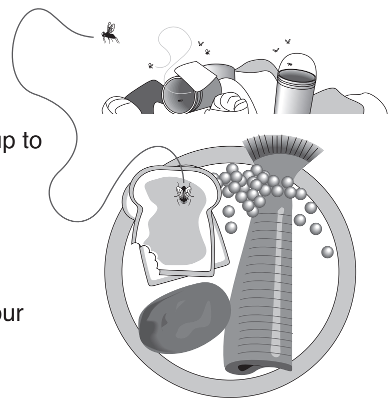
others to pick up or they can track them into the house. As a dog licks its feet and then other parts of its body, it can move the germs so that they may easily be picked up on the hands of anyone petting the dog or when the dog licks a child or adult,

Flies



Flies can be a major carrier of disease. They are born and live in waste products. They feed on rotting garbage and untreated or partially treated human waste. In the process of feeding on the disease-ridden material, they pick up the microorganisms on their legs and body. One fly may carry up to 6,500,000 microorganisms on their legs and body. They also carry disease-causing microorganisms in their digestive track.

Flies - Eating Habits



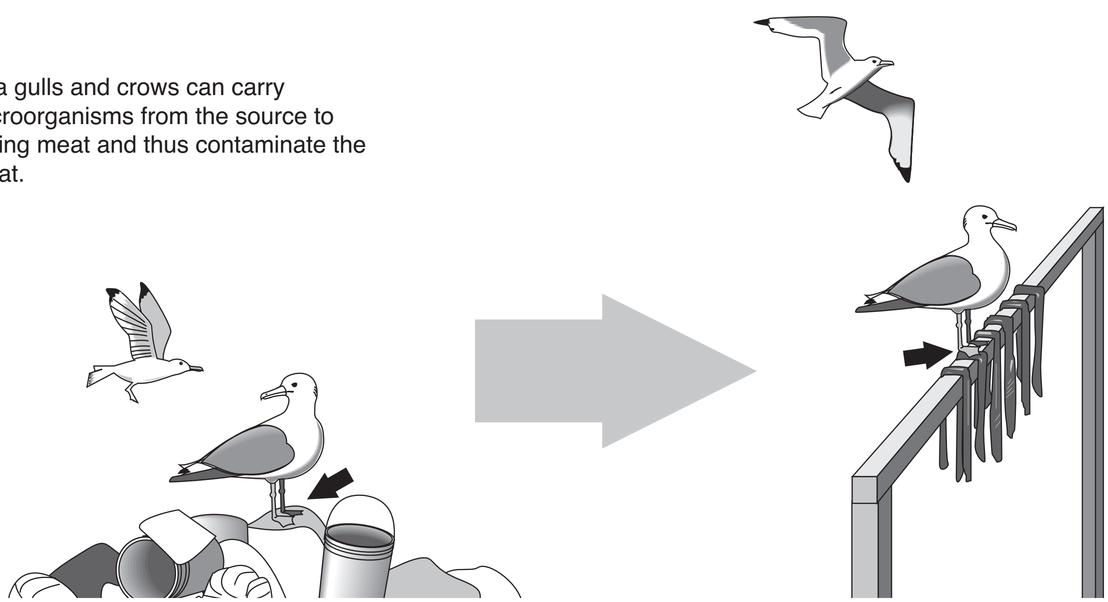
A single fly can carry up to 6,500,000 disease causing organisms from their source to our food

Flies travel a great distance to find food. They may start their day by feeding on human waste and then land on food, drying meat or land on the face of an individual. In order for a fly to eat food such as your cake, sandwich, or drying fish, they must spit some saliva onto the material. The flies saliva turns the material into a liquid that can then be eaten by the fly. In placing their saliva on your food, they deposit disease-causing microorganisms on the food. In addition, they deposit germs in their fecal matter.

Birds

Birds such as crows and sea gulls delight in feeding on garbage and untreated human waste. In doing so, they ingest germs into their digestive tract and pick them up on their feathers or feet. From this feast they may travel to your drying meat where they deposit a few of these germs, thus contaminating your meat. In

Sea gulls and crows can carry microorganisms from the source to drying meat and thus contaminate the meat.



addition, bird droppings on walk ways contain germs that are picked up on the feet of people and carried into the house.

Summary

The key to preventing the spread of disease is to minimize the possibility that humans, dogs, birds, and flies can come in contact with human waste and wastewater.

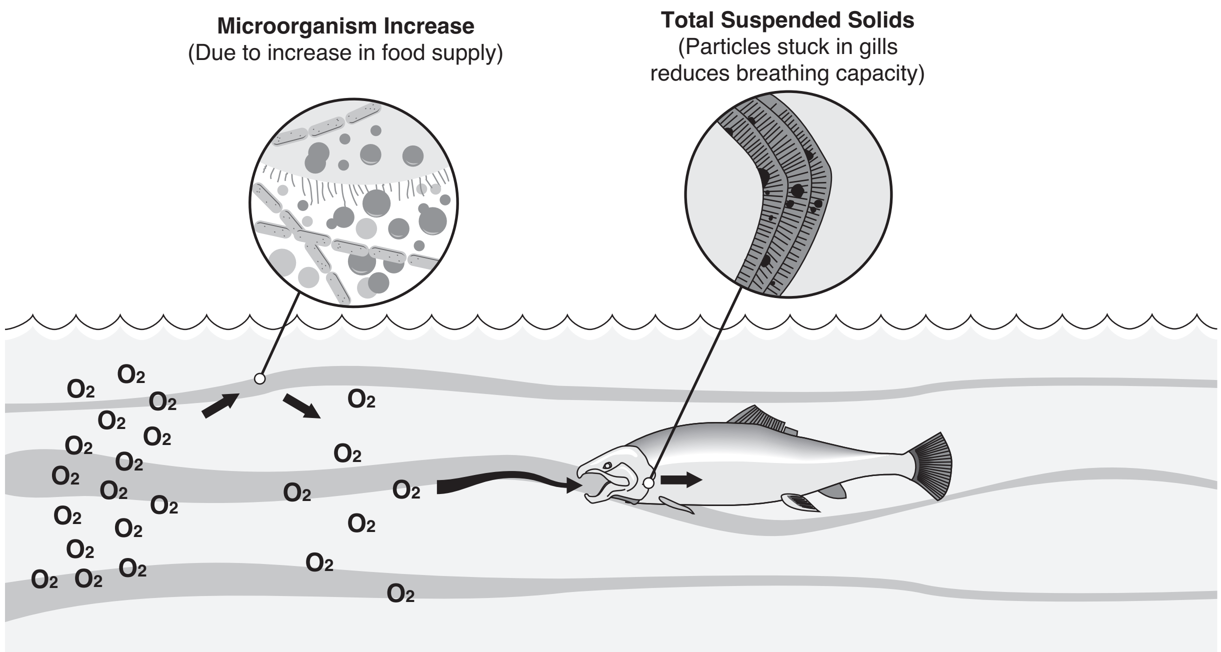
Other Water Quality Considerations

Water Quality

Besides the health problems associated with untreated or partially treated wastewater there are other considerations that have to do with the degradation of the quality of the receiving stream.

The Aquatic Environment

When waste is placed into a stream it becomes an additional food source for the microorganisms in the stream. This addition of food to the stream causes an increase in the number of microorganisms. They multiply in response to the added food supply. As they consume this food, they also consume oxygen from the stream. It is possible for the food supply to be so great that the increased numbers of microorganisms use more oxygen than the stream can supply, reducing the oxygen content of the stream. The result is a deterioration of the quality of the water and the death of fish and other aquatic life.



Solids in the Stream

Some material that is deposited into a stream is suspended in the water. This material is commonly called solids. These solids can become lodged in the gills of fish making it difficult for them to breathe.

Recreation

Along with the food and solids are the disease-causing organisms that we have spent so much time discussing. Besides the contamination of a downstream users water supply, these same organisms can pollute the beach and swimming area near where the wastewater enters the stream and further down stream. As a result, individuals using this area can become infected with the diseases carried by the wastewater.

The Solution

What is the Solution?

The solution to human contamination within the village or community is to reduce contact with human waste. The solution to deterioration of water quality and preventing contamination of a downstream users water supply is proper treatment. Treatment can be natural or manmade.

Natural Treatment

Natures Way

Nature has three ways of naturally dealing with waste. One is the process of **dilution**[12]. The second is the movement of waste and the cleansing of water through the **hydrologic cycle**[13] and the third is the biological process of reducing the waste to harmless material.

Dilution

Past Practices

In previous generations, the peoples of the Arctic and subarctic were migratory. They were hunters and gatherers. As such, they moved throughout the year to find game and food that could be harvested. As a result, they left a small amount of waste in each area where they camped. The great volume of water and expanse of the land mass diluted the impact of this waste material. The material was then reduced by natural degradation so that by the time people revisited an area there was no sign of them having previously been there.

Concentration of Numbers

Today almost all of the people of North America are gathered together in small areas called villages, communities or cities. This results in a high volume of wastewater being concentrated in a small area. Consequently, the natural treatment processes can no longer clean the land or water adequately and they become contaminated.

Hydrologic Cycle

Introduction

The hydrologic cycle is the key to maintaining our supply of fresh water. The cycle is made up of four key components.

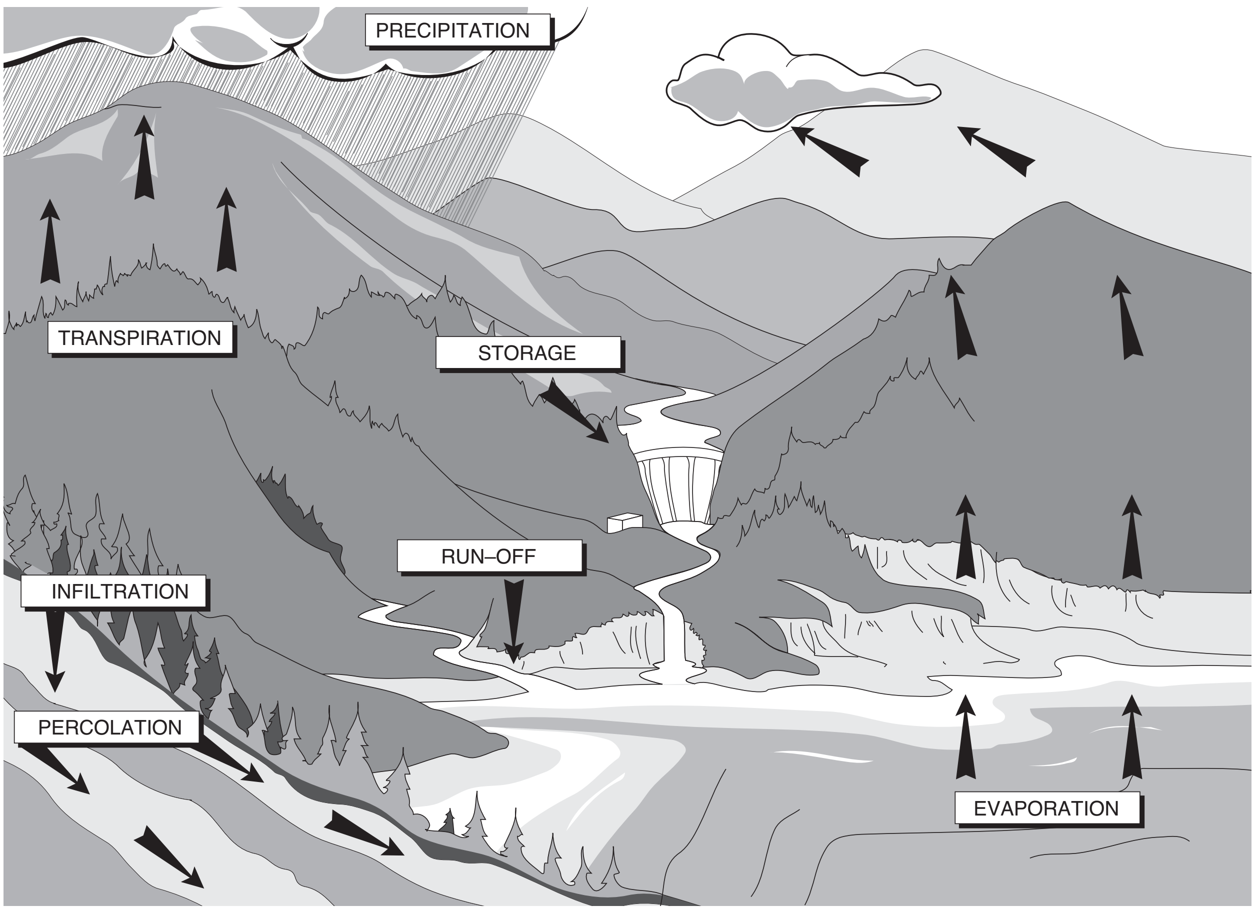
[12] **Dilution** - (Dih-LEW-shun) - The process of making weaker by adding water.

[13] **Hydrologic cycle** - (HY-druh-LOJ-ik SY-kul) - Nature's method of continuously recycling between the earth and atmosphere the earth's limited water supply, making it possible to use this water over and over again.

- The atmosphere
- The **lithosphere**[14] - the crust of the earth
- The **hydrosphere**[15] - the water on the earth
- The sun - the energy source used to drive the hydrologic cycle

Available Water Supply Recycled

The amount of water available in the atmosphere, lithosphere and hydrosphere remains constant. It was formed during the creation of the earth. There will never be any more or any less than there is today. This water is continually recycled between the lithosphere and the atmosphere by the action of plants and the sun. In order to understand this process, lets follow the cycle.



Precipitation

You can start the cycle anywhere because it is continuous and has no beginning or ending. So lets pick up a droplet of **precipitation**[16] and follow it through the cycle. Precipitation in the form of rain, snow, hail or sleet falls towards the earth.

[14] **Lithosphere** - (LITH-o-sfer) - The solid crust of the earth. It consists of the thin, loose layer known as soil and the mass of hard rock, several miles in thickness, upon which soil lies.

[15] **Hydrosphere** - (HY-druh-sfer) - All of the water on the earth.

[16] **Precipitation** - The process by which atmospheric moisture is discharged onto the earths crust. Precipitation takes the form of rain, snow, hail and sleet.

Fall Toward Earth

As the precipitation falls toward the earth, it can pickup contamination in the form of minerals and toxic materials from industrial air pollution and natural pollution such as dust from a volcanic eruption. On its fall toward the earth, some of the precipitation **evaporates**[17] leaving behind contaminants.

Hits the Forest

Some of the precipitation hits the trees, brush and grass. Some of the precipitation evaporates directly from the leaves and grass.

Hits the Ground

Some water flows down the outside of the trees and grass onto the ground, and some strikes the ground directly. As water accumulates on the ground it runs downhill. The water that runs down the hill is called runoff.

Surface Water

This runoff water accumulates in lakes, streams, muskeg ponds and rivers. Most rivers will eventually empty into the ocean. This portion of the water supply is called surface water. A large quantity of this water will be evaporated back into the atmosphere.

Groundwater

Some of the water that is running along the earth's surface seeps into the soil where some contaminants are filtered from the water. This process is called **infiltration**[18]. As the water infiltrates the soil and moves downward some is taken up by the roots of trees and other plants. The water that is taken in by plants is given off into the atmosphere through the leaves of the plants in a process called **transpiration**[19].

Groundwater Movement

The water not taken up by plants continues to move downward in a process called **percolation**[20]. As water percolates downward, contaminants in the soil are picked up or dissolved into the water. This water continues to move downward until it collects in gravel and sands called **aquifers**[21] and is called groundwater. There the water continues to slowly move toward adjacent lakes, streams and the ocean where it collects with the surface water and is evaporated back into the atmosphere.

Back to the Atmosphere

As you can see, all of the water is eventually evaporated back into the atmosphere and forms water vapor. This vapor is condensed by atmospheric conditions and forms precipitation which falls to the ground and the cycle continues, providing us with clean fresh water.

[17] **Evaporate** - (ee-VAP-o-rate) - The process of conversion of liquid water to water vapor.

[18] **Infiltration** - (In-fil-TRAY-shun) - The initial movement of water from the earths surface into the soil.

[19] **Transpiration** - (TRAN-spur-RAY-shun) - The process by which water vapor is lost to the atmosphere from living plants.

[20] **Percolation** - (PUR-cuh-LAY-shun) - Movement of water into and through the ground.

[21] **Aquifer** - (AK-wuh-fur) - A porous, water-bearing geologic formation.

Biological Process

Food

The third natural treatment process is called the biological process. When wastewater enters a stream or lake, the microorganisms in the **receiving water**[22] eat material in the wastewater. In the process of eating this material, they increase their numbers and consume the oxygen that is dissolved in the water.

Oxygen

In the natural process, the oxygen is replenished by the water flowing downstream over rocks where it is aerated. In addition, oxygen is added to the receiving water by the action of the wind on the surface.

Overload

When the quantity of oxygen used by the microorganisms in the receiving water exceeds the quantity of oxygen that is entering the water, the quality of the water starts to deteriorate. The result is an unfavorable condition which may cause the death or reduction of aquatic life including fish.

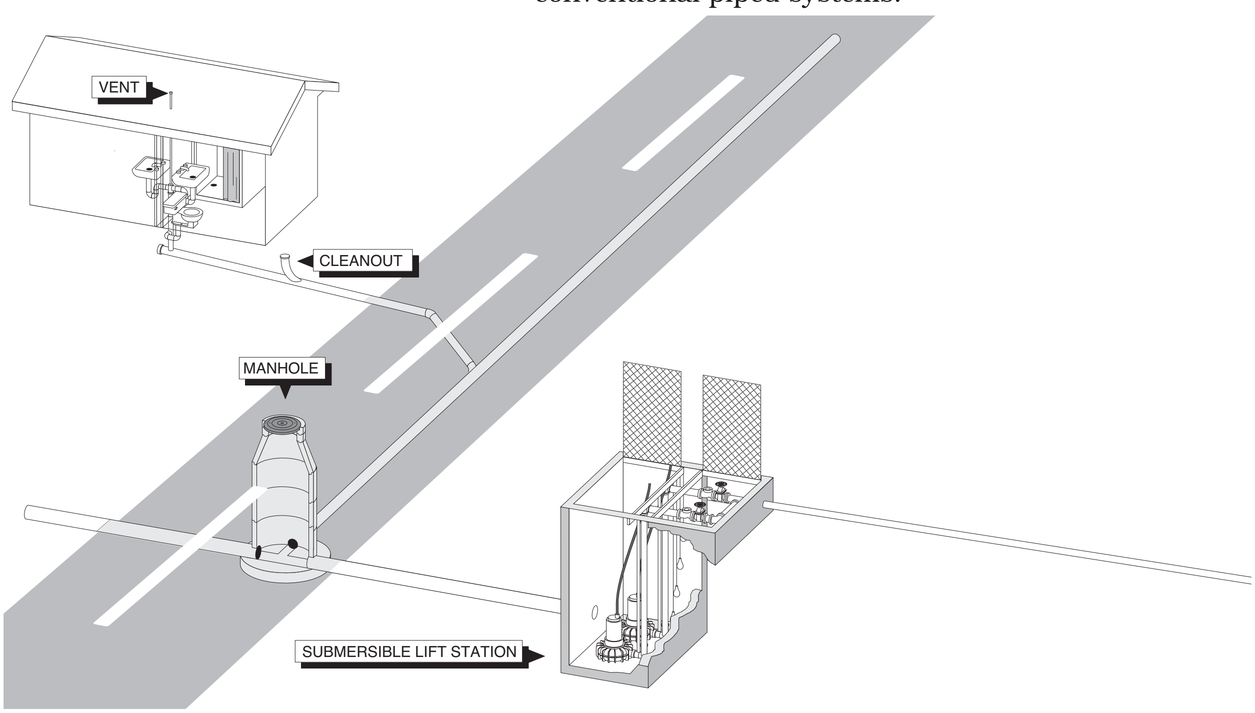
Manmade Treatment

When natural treatment is not sufficient, we must turn to manmade treatment systems in order to prevent disease and protect the receiving waters. These systems are commonly called sanitary facilities and are composed of two general groups of components; the collection system and the treatment plant.

The Collection System

Individual System

The collection system may consist of individual holding tanks that are pumped and hauled or more conventional piped systems.



[22] **Receiving Water** - A stream, river, lake or ocean into which treated or untreated wastewater is discharged.

Piped System

A piped system is composed of a network of pipes that collect the wastewater and move it to the treatment plant. Most piped systems work by gravity, that is, they are sloped downhill from the house to the treatment plant. When the **topography**[23] does not allow this type of system to be used, pressure and vacuum collection systems can be utilized.

Lift Station

The topography of most communities do not allow a collection system to work entirely by gravity. Pumping stations called lift stations are often needed to pump the wastewater over hills or to just lift it up and move it along its way.

Manholes

To allow access into the collection system for maintenance, manholes are installed at specific locations in the system.

Utilidors

In Arctic and subarctic climates, the presence of **permafrost**[24] and other ground conditions do not allow the use of buried pipe systems. In some locations, above or below ground utilidors, which are heated enclosures, are required in order to prevent the wastewater from freezing in the pipes.

Treatment Facilities

The Basics

Influent and Effluent

A treatment plant utilizes a combination of physical, biological and chemical processes in order to treat the wastewater. The wastewater stream that enters a plant is called the **influent**[26]**.** The flow out of the plant and into a receiving stream is called the **effluent**[26]**.**

Wastewater Content

The material contained in domestic wastewater can unscientifically be divided into five categories.

- Material that sinks
- Material that is dissolved in the water
- Material that floats
- Material that is suspended in the water
- Pathogenic microorganisms

Physical Treatment

Treatment processes designed to remove those items that sink or float are generally physical processes and are called **preliminary treatment**[27] and **primary treatment**[28].

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23 **Topography** - A description of the surface features of the land.

24 **Permafrost** - (PER-ma-fra-st) - Soil, bedrock or other material that has remained below 0°C for two or more years.

25 **Influent** - (IN-flew-unt) - Sewage, water, or other liquid, raw or partly treated, flowing into a treatment plant or part thereof.

26 **Effluent** - (EF-lew-unt) - Sewage, water , or other liquid , partially or completely treated, or in its natural state, as the case may be, flowing out of reservoir, basin, or treatment plant, or part thereof.

27 **Preliminary Treatment** -The process of grinding material that can clog equipment, removing rags with screens and the removal of grit. Preliminary treatment is commonly a part of primary treatment.

Biological Treatment

Processes designed to convert the material that is suspended into material that will either sink or float are usually biological processes and are called **secondary treatment**[29].

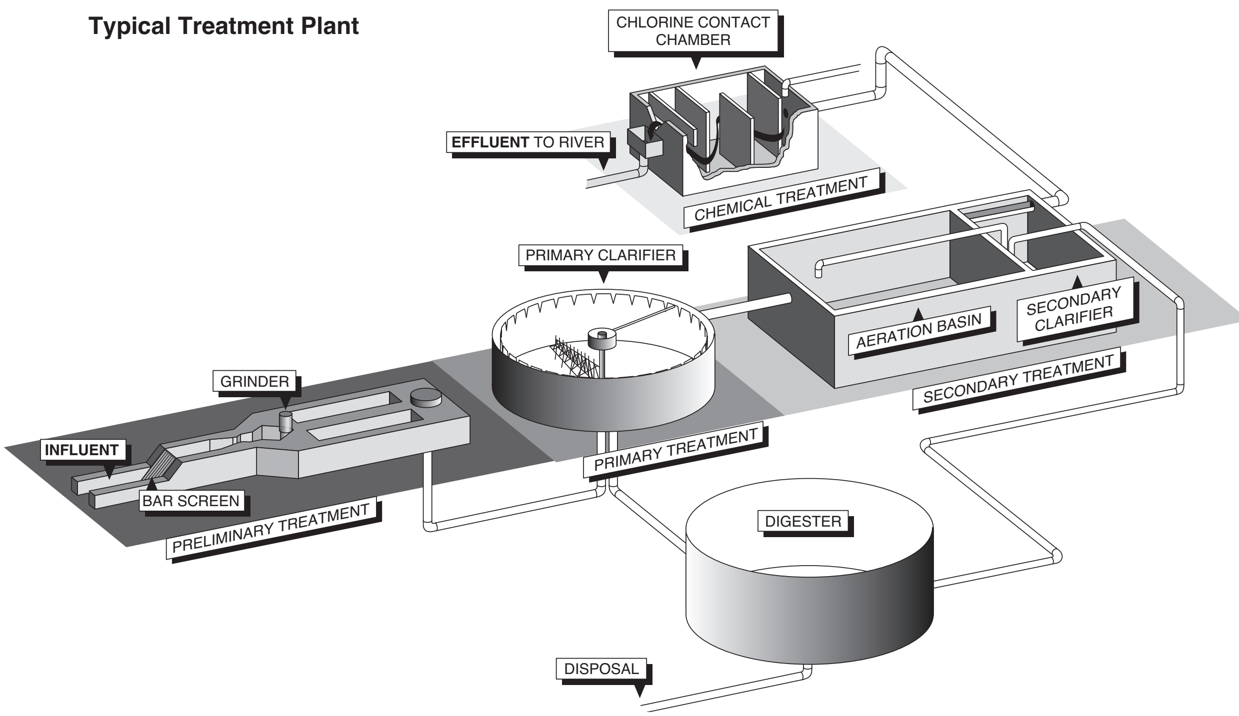
Chemical Treatment

While each of the processes removes some pathogenic organisms, it is the disinfection process that is the most effective in this action. This is normally a chemical process.

Summary

The treatment process does not destroy the material that is in the wastewater, it only removes it from the water. Material that is removed is called sludge, it is not harmful and can be disposed of in landfills or incinerated.

Typical Treatment Plant



Preliminary Treatment

First Process

The first treatment process in most treatment plants is preliminary treatment. This process is used to remove rags and grit that could damage other equipment in the plant.

Equipment

The equipment used to do this are screens, grinding devices and grit removal devices.

28 **Primary Treatment** -The first major (sometimes the only) treatment in a sewage treatment works. This process takes place in a rectangular or circular tank and allows those substances in wastewater that readily settle or float to be separated from the water being treated.

29 **Secondary Treatment -** A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated. Usually a biological treatment process.

Primary Treatment

Second Process

The second stage of the treatment process is called primary treatment. This process is used to remove those materials that either float or sink. The major component in the primary treatment process is a circular or rectangular basin called a clarifier. Not all small plants have primary treatment.

Biological Treatment

Natural Treatment Expanded

The third stage of treatment is a biological treatment unit. This process is an adaptation of the natural biological treatment process found in streams. This process uses microorganisms that occur naturally in the wastewater to reduce the waste material to a product that can be disposed of without causing harm to people or the **environment**[30].

Secondary Treatment

This biological treatment process is called secondary treatment and includes the use of lagoons, tundra ponds and mechanical plants.

Package Plants

The mechanical plants that are used in small communities are typically called package plants. This is because in the smallest sizes they are sold as a package. While there are various types of package treatment plants, the most common uses a process called activated sludge.

Activated Sludge Plant

After the preliminary and primary treatment processes, the wastewater is placed into a rectangular or circular basin, called an aeration basin. Here, air or oxygen is added by a mechanical blower. The blowers provide the air necessary for the microorganism to convert the waste material into products that will settle or float. (Most is converted into material that will settle).

Settling

After mixing with air and allowing biological action to take place, the contents of the aeration basin flows to a circular or rectangular tank called a secondary clarifier. Here the solids settle to the bottom and clear liquid flows to the top and out of the clarifier.

Sludge Return

Some of the solids, called activated sludge, that settles in the secondary clarifier is returned to the aeration basin to help maintain the population of microorganisms. The majority of sludge is sent to a second basin where it is mixed with air and further biological action is allowed to take place. In this stage of treatment, the waste material in the sludge is stabilized, so that it can be disposed of on the land without causing harm to humans or the environment. This treatment stage is called digestion.

[30] **Environment** - (in-VI-row-ment)-The surroundings, material and spiritual influences which affect the growth, development and existence of a living being.

Chemical Treatment

Chlorine

The clear water from the secondary clarifier is sent to a rectangular basin called a chlorine contact chamber. Chlorine is added to the flow as it enters the basin. The basin allows for sufficient contact time for the chlorine to drastically reduce the remaining number of pathogenic microorganisms.

Lime

While not a part of the standard treatment plant processes, lime is commonly placed on spilled raw **sewage**[31]., in sewage pit bunkers, pit toilets or outhouses, and sewage dumps in order to reduce odor and kill disease-causing microorganisms.

Treatment Considerations for Arctic and Subarctic

Vast Area

The Arctic and subarctic of Alaska and Canada provide unique challenges for the design, installation and operation of sanitary facilities. This area is composed of a vast frozen land that stretches for over 3000 miles from Davis Strait in the east to the Bering Sea in the west. It extends approximately 1600 miles from the northern part of Canada to the North Pole.

Sparsely Populated

While there are a few large communities in this area, Anchorage, Fairbanks and Yellowknife, the majority of the communities have populations of less than 500. In most cases a single community is only connected to another by river or overland travel with a snow machine or dog sled. Access to many communities is limited to the short summer months. The others are fortunate enough to be provided with routine (at least once a week) plane flights with small single engine planes.

Transportation Cost

The remoteness and lack of standard transportation routes that are taken for granted in most of the U.S. creates an extremely high cost for transporting equipment, spare parts and supplies. This single cost alone can drive construction cost above what is reasonable for the community.

Economic Base

Throughout the Arctic and subarctic, the standard life style is that of hunters and gatherers. This subsistence lifestyle, while providing a high quality of life, provides no economic base. The lack of this base makes payment for the collection and treatment of wastewater difficult to nearly impossible for some communities.

Climate

Long cold winters reduce the construction season to a short three months in good years and less than two months in bad years. These same climactic conditions cause freezing problems with piped systems increasing operating costs to two or three times what they are in the continental U.S.

31 **Sewage** - Largely the water supply of a community after it has been contaminated by various uses.

Geology

Most of the Arctic and subarctic is subject to permafrost. Besides the frozen ground problem, there is excessive settling and ground movement when the top layer of the earth thaws during the summer months. As a result, septic tanks and below ground piped wastewater collection systems are often not feasible. One alternative is to place the pipes above ground in a heated utilidor. This increases construction and operating costs and impacts the aesthetics of the community.

Planning

Many of the communities in the Arctic and subarctic were established without consideration for roads or utilities. Individual lots and homes were located based on survival and personal preference. Streets and property lines do not follow straight paths. This results in increased costs for providing water and wastewater service in these communities.

Water Use

In most of this area, water is not easily obtained. A large number of the communities in this region have centralized watering points. The individual brings their bucket to the watering point to collect the needed drinking water. A water supply of 14 to 20 gallons of water per person per day is considered to be minimum for adequate drinking, cooking, bathing and laundering. The only way to consistently provide this quantity of water is with a piped system. There are additional costs for the construction and operation of a wastewater collection and treatment system adequate to handle this volume.

Conclusion

All of these factors make the design, construction and operation of sanitary facilities in this region difficult and more costly than in urban areas. Until such time as necessary changes are made in water and wastewater treatment systems, this region will continue to bear the burden of their environment.

Responsibilities

Introduction

The responsibility for the reduction of disease and the prevention of the deterioration of the environment is shared among the individual, the community leaders, the plant operator and the regulatory agencies. The following is a brief overview of those responsibilities.

The Individual

Hygiene

Each individual in a community has the responsibility to practice good hygiene. This one act alone could drastically reduce disease for the individual, their family members and the community.

Honey Bucket

In communities that utilize honey buckets, there is an additional responsibility for the individual. Each individual is responsible for preventing spills. Should a spill occur, the individual is responsible to see that it is cleaned up and the area sanitized with chlorine or lime.

Disposal of Honey Buckets

The individual users of honey buckets are responsible to see that their waste is disposed of in a proper location and that this location is properly protected from children, dogs and birds. The individual is also responsible to see that the individual's disposal site is properly treated with lime.

Water Consumption

All water that is used must be disposed of in a safe manner. This disposal costs the individual and the community money. Therefore, each user of the system is responsible to manage their water consumption. Each person should use the water necessary for cooking and personal hygiene. Water that is allowed to run to prevent freezing is a wasteful practice.

Cost of Service

Those who use a service are responsible to pay for that service. This payment should be prompt. Only by prompt and reliable payment of services can the community afford to properly operate and maintain the wastewater system.

Community

The community is responsible for the management, operation and maintenance of the wastewater system.

Business

The wastewater utilities should be operated in a compassionate, honest and business-like fashion. That is, the utility income and expenses should be separated from the other services provided by the community. There should be clear, written rules, regulations and policies that the customers can understand and follow. Bills should be sent to each customer on a regular, predictable manner. As a business, the community is responsible to see that the bill for services is collected from the customer.

Training & Equipment

The community is responsible for providing proper and adequate equipment and adequate training for the system operator, the clerk responsible for the bookkeeping for the utility and the manager.

Safety

It is the responsibility of the community to provide the operator with proper safety equipment, a safety program and safe procedures for performing the work necessary to operate and maintain the utility.

Operator

Health of the Community

The operator of the wastewater system is the community's last link between health and disease. Therefore, the operator is responsible to see that the wastewater facilities are properly operated and maintained. In order to do the job correctly, the operator must be trained in many disciplines and skills. A typical operator needs skills as a:

- Chemist - in order to perform required tests properly
- Microbiologist - in order to understand how to properly make process control changes at a treatment plant
- Public relations expert - in order to effectively deal with customers
- Mechanic - in order to perform required preventive maintenance and make corrective repairs
- Troubleshooter - in order to solve problems that commonly occur in these systems

Regulatory Agencies

There are numerous agencies responsible for the various aspects of wastewater treatment and disposal. The following is a brief review of the basic functions of some of two typical agencies that impact wastewater treatment.

EPA

General Program

The Federal Environmental Protection Agency was charged by the U.S. Congress in 1972 to establish a program that:

- Improves the nation's water quality
- Eliminates pollution
- Establishes a permit system to regulate wastewater effluent.

State Agency

Permits

Most states have a single agency with the responsibility to issue permits for each wastewater system in the State. These permits describe the type of treatment and quality of the effluent that is required.

Certification Program

All wastewater systems that have more than a specific minimum number of service connections, or that are used or intended for use by minimum number of persons per day, must be operated and supervised by operator(s) certified under this program. A typical wastewater certification program covers two disciplines (collection and treatment) with five certification levels (OIT, 1, 2, 3, 4) for each discipline. The certification level required by an individual operator is based on the type of discipline of the system operated, the complexity of the system and the number of people served.

Intro to Wastewater Systems **Worksheet**

1. Wastewater is:

2. The three categories of wastewater are:
   a. ___________________________
   b. ___________________________
   c. ___________________________

3. The two main reasons for treating wastewater are:
   a. Prevent the spread of __________________________.
   b. Protect _____________________ ______________________ users.

4. In order to reduce the probability of the spread of disease in a community it is best to:

5. Microorganisms that cause disease are called ______________________ organisms.

6. Personal _________________ is one of the keys to reducing the probability of the spread of disease.

7. Describe how dogs, flies and birds contribute to the spread of disease.

8. Describe how untreated or partially treated wastewater impacts the aquatic environment?

9. The primary function of a wastewater collection system is to reduce _________________ with human waste and thus reduce the _________________ of disease.

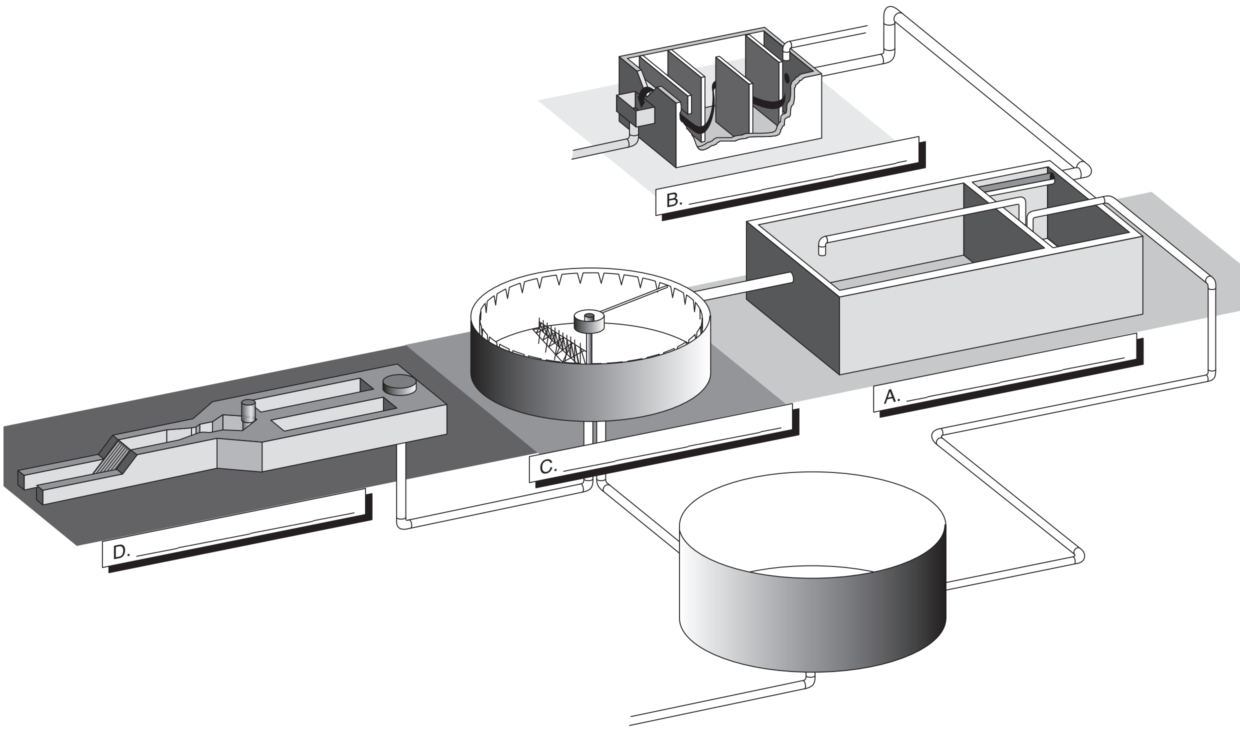
10. There are three natural processes of treating wastewater. They are:

    a. ___________________________

    b. ___________________________

    c. ___________________________

11. Using the treatment plant shown below identify the four basic treatment processes.



12. The two reasons for the use of a wastewater treatment facility are:

    a. Prevent the spread of _________________________

    b. Reduce the impact on _____________________ __________________ users

13. Describe one way an individual can prevent the spread of disease.

14. The Arctic and subarctic environments require special considerations associated with wastewater collection and treatment. In this lesson we discussed eight (8) special considerations. Identify four of these.
    a. ____________________________
    b. ____________________________
    c. ____________________________
    d. ____________________________

15. Describe two items that are the responsibility of the community in conjunction with their wastewater facilities.
    a. ____________________________
    b. ____________________________

16. List three of the five skill groups needed by a wastewater operator.
    a. ____________________________
    b. ____________________________
    c. ____________________________

17. What is the basic responsibility of the State in the management of the Statewide wastewater treatment program?

18. The required level of operator certification is based on the _________________ of the community and the ________________ of the wastewater system.

Characteristics of Wastewater

What is in this Lesson?

1. The composition and characteristics of wastewater
2. pH and the components of its scale
3. Description of settleable solids, suspended solids, dissolved solids and total solids
4. The difference between organic and inorganic material found in wastewater
5. The difference between aerobic, anaerobic and facultative organisms
6. The three temperature ranges for microorganisms and their names
7. The three shapes of bacteria
8. Typical waterborne diseases caused by bacteria and protozoa
9. The process that bacteria use to collect and process food
10. The impact that increased organics have on water quality of a receiving stream
11. The appearance and odor of septic and fresh sewage
12. The different flow characteristics of a wastewater system
13. The temperature DO relationship in water
14. The average flow per person in a wastewater system
15. The common gases found in septic wastewater
16. The population equivalent for BOD
17. The difference between aerobic and anaerobic decomposition
18. The importance DO has in wastewater treatment

Key Words

- Absorption
- Aerobic
- Anaerobic
- Bacteria
- BOD
- Combined Sewer
- Disinfection
- Facultative
- Gases
- Inert
- mg/L
- Organic
- Adsorption
- Alkalinity
- Aquatic
- Biodegradable
- Colloidal solids
- Constituent
- Dissolved solids
- Fecal Coliform Bacteria
- Hydraulic Loading
- Inorganic
- Microorganisms
- Peak Flow

- pH
- Photosynthesis
- Protozoa
- Sanitary Sewer
- Stabilization
- Suspended solids
- Total solids
- Turbidity
- Virus
- Waterborne disease
- Waterborne pathogens

Characteristics of Wastewater

What is Wastewater?

Water and Wastewater

Sewage or Wastewater?

In this lesson, and in fact this entire text, reference will be made to wastewater and sewage. These terms are interchangeable. However, the term wastewater is a broad, descriptive term. Generally, it includes liquids and water containing solids from homes, businesses and industry and is considered to be a more "modern" term.

From Water to Wastewater

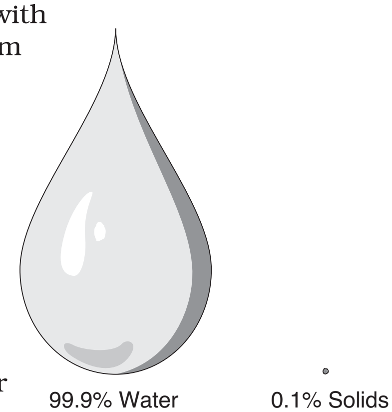
Wastewater is primarily water from the drinking water system and from leaks in the collection system. This water is used to carry waste from homes and businesses into collection systems and ultimately to wastewater treatment facilities or disposal.

Types of Wastewater

If a collection system (called a sewer) is attached to homes and businesses in the community, the sewer is classified as a **sanitary sewer**[1] and the treatment plant at the end of the pipe treats domestic sewage. If the sewer system also collects storm runoff, as well as domestic sewage, the sewage system is classified as a **combined sewer**[2] and the treatment plant receives domestic sewage along with storm water during storm events.

Mostly Water

On average, domestic wastewater contains 99.9% water and 0.1% **solids**[3]. These solids or impurities are sometimes called **constituents**[4]**.** These constituents and the components of the water are called the characteristics of the wastewater.



Drinking Water

The characteristics of the wastewater are influenced by the quality of the drinking water system, the quantity of leakage into the collection system and the material placed into the water by homes, businesses and industry.

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1 **Sanitary Sewer -** A sewer that carries water and water carried waste from residences, commercial buildings, industrial plants, and institutions, together with minor quantities of ground, storm, and surface water that are not admitted intentionally.

2 **Combined Sewer -** A sewer intended to receive both wastewater and storm or surface water.

3 **Solids -** As it pertains to wastewater - Suspended and dissolved material in wastewater.

4 **Constituent** - The parts of a whole. All of the components of wastewater other than H_2O.

Characteristics

Introduction

Three Categories

The characteristics of wastewater can be divided into three categories

- Physical
- Chemical and
- Biological

Physical

The physical characteristics of wastewater include, flow, color, odor, temperature, **turbidity**[5] and appearance.

Chemical

The chemical characteristics include the solids, **gases**[6] and chemical constituents found in the wastewater.

Biological

Each drop of wastewater contains millions of **bacteria**[7] as well as other **microorganisms**[8]. The biological characteristics of wastewater include these microorganisms, how they are impacted by the physical and chemical changes of the wastewater and how the microorganisms impact the wastewater.

Physical Characteristics

Introduction

Physical characteristics include flow, temperature, color, odor, turbidity and appearance.

Flow Considerations

Hydraulic Loading

The flow into a wastewater treatment plant is called the **hydraulic loading**[9]. Each process unit in a treatment plant is designed to provide the most efficient treatment when the hydraulic loading is within a specific range. This range is selected by the design engineer.

Factors Affecting Flow

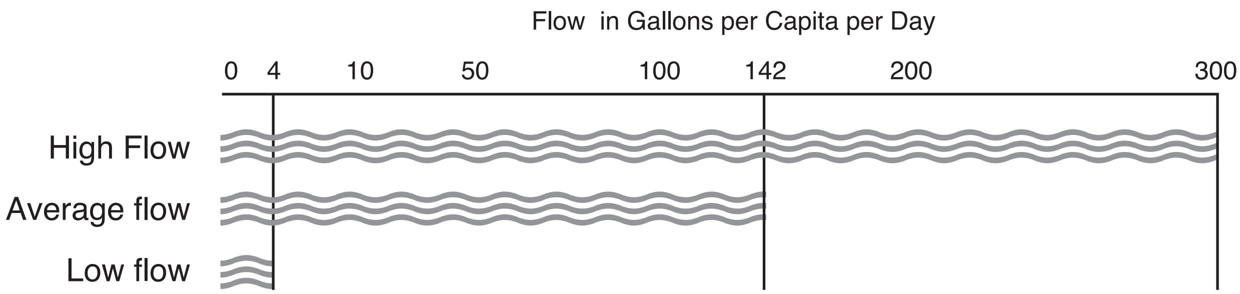
The flow into a wastewater plant is determined by a number of factors in the community. In Alaska the type of water and wastewater system in the community, the availability of potable water and the wasting of water to prevent freezing are probably the most significant factors.

Flow Ranges

Wastewater production in Alaska ranges from 4 gallons per person per day for individual haul systems to over 100 gallons per person per day for

[5] **Turbidity** - A condition in wastewater caused by the presence of suspended matter, resulting in the scattering and absorption of light rays.
[6] **Gases -** Of neither definite volume nor shape, they completely fill any container in which they are placed.
[7] **Bacteria -** Living organisms, microscopic in size, which consist of a single cell. Most bacteria utilize organic matter for their food and produce waste products as the result of their life processes.
[8] **Microorganisms -** Minute organisms, either plant or animal, invisible or barely visible to the naked eye.
[9] **Hydraulic loading -** Refers to the flows (MGD or cu m/day) to a treatment plant or treatment process. Detention times, surface loading and weir overflow rates are directly influenced by flows.

conventional potable water and collection systems. Communities with collection systems that allow ground water to enter may have flows exceeding 300 gpcpd. The average wastewater flow in the U.S. is considered to be 142 gpcpd.



Average Flow

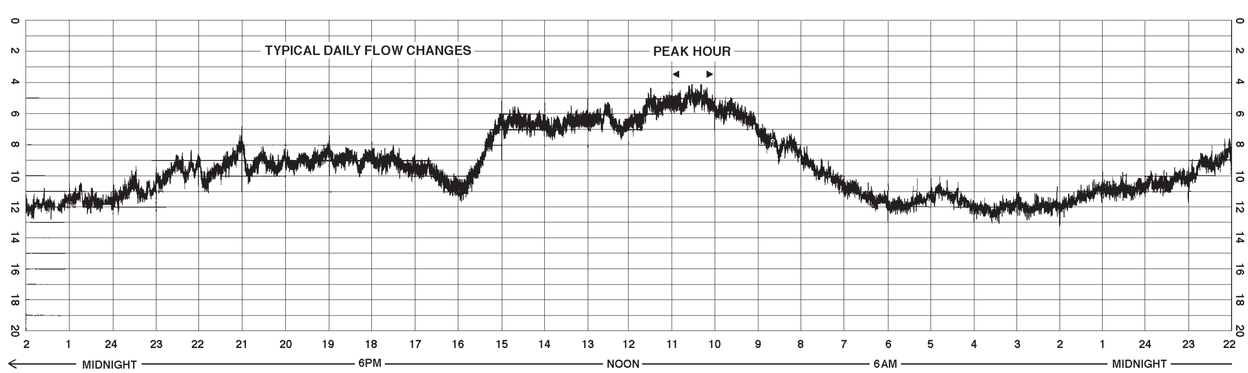
Wastewater treatment plants are designed to handle average flows. There is always some surface water and groundwater that enters the collection system through breaks in the lines and some water exits through these same breaks. If the rain or snow melt is heavy, flows to the plant will increase. If the ground is tremendously dry, some decrease in flow could result as sewage escapes from the collection system into the ground.

Dry Weather and Wet Weather Flow

Wastewater treatment plant discharge permits and plant design identify wet and dry flow requirements. The wet weather flow is called **peak flow**[10]. Flows above the peak flow could cause sewage to backup into the collection system and thus constitute a violation of the permit. This condition should be avoided.

Reporting Requirements

In addition to flows at the plant and lift stations being recorded and reported on monitoring reports, they are important information for the operator. Process control and system analysis require accurate flow readings. Flow meters must be calibrated and maintained to reflect accurate flow readings.



10 **Peak Flow** - The maximum design flow of a wastewater treatment plant.

Color and Odor

Fresh sewage

If domestic sewage is delivered to the wastewater plant in a timely manner, the sewage will be gray in color and have a musty but not offensive odor with observable particles of paper, food, and "other" solids. Sewage with this appearance and odor is called fresh sewage.

Septic Sewage

If wastewater is allowed to become old it will become **anaerobic**[11] or septic, and the color and the odor will change. Septic wastewater has a black color and a smell resembling rotten eggs. Septic sewage is very difficult for a biological treatment plant to treat.

Treating Septic Sewage

Continuous flow of septic sewage from the collection system is more difficult to treat than the septic material delivered by a septic tank truck. While the septic tank material is hard to treat, it is usually a small percentage of the flow and thus the **aerobic**[12] bacteria at the plant can usually buffer its impact. If the overall influent flow to the plant has become septic, tremendous electrical energy is needed to stimulate aerobic activity.

Temperature

Impact on Biological Activity

Temperature is very important to biological activity. The lower the temperature, the slower the biological activity. A rise in temperature increases biological activity. In conventional wastewater systems, sewage maintains an ambient temperature of about 55˚F due to biological activity. The temperature fluctuations that naturally occur in the influent should be documented daily. These changes can be used to make operational changes in the plant. For instance, as the temperature increases, biological activity increases and thus more oxygen may be needed. In an activated sludge plant, the increased demand for oxygen could require turning on more blowers.

Decrease in Temperature

As temperature decreases, biological activity also decreases. It is important to monitor temperature and take the bacterial activity into account when contemplating operational changes and troubleshooting systems. In freezing conditions, additional time is required for biological wastewater treatment to take place. Larger treatment plant biological basins and lagoons are required if freezing conditions are prevalent. The larger basins allow the bacteria more time to do their work given their slower metabolic rate.

[11] **Anaerobic -** A condition in which "free" or dissolved oxygen is not present in the aquatic environment.

[12] **Aerobic** - A condition in which "free" or dissolved oxygen is present in the aquatic environment.

Turbidity

Definition

Turbidity in wastewater is caused by **suspended solids**[13], usually particles of colloidal size. Turbidity is defined as that property of wastewater that causes light to be scattered or absorbed. High turbidity wastewater appears cloudy, whereas low turbidity wastewater often sparkles with clarity. Wastewater with low turbidity can still have **dissolved solids**[14] , because most dissolved solids do not cause light to be scattered or absorbed. The measurement of turbidity can be a quick method of evaluating the quality of the final effluent of a wastewater plant. Materials that cause turbidity can provide a place for microorganisms to hide and avoid **disinfection**[15].

Chemical Characteristics

Introduction

The chemical characteristics of wastewater include solids, gases and the chemical constituents of the wastewater.

Solids

Introduction

Even though the solids content of the wastewater is only a small percentage (0.1%) of the total volume, their objectionable characteristics are one of the principle reasons for wastewater treatment. One of the primary functions of a wastewater treatment plant is to reduce and/or remove as many of these solids as possible. Therefore, it is important that the operator understand the nature of these solids.

Divisions of Solids

All of the solids found in wastewater can be placed into one of two general groups. The solids are either **organic**[16] or non-organic. Non-organic solids are called **inorganic**[17] solids.

Organic Materials in Wastewater

Description

Organic solids come from plants and animals and contain oxygen and carbon. The principle organic compounds found in wastewater are proteins, carbohydrates and fats. Most organic solids are a food source for microorganisms and are therefore said to be **biodegradable**[18]. If not removed by treatment, they will decompose to produce objectionable odors and other undesirable conditions. Their removal and **stabilization**[19] is therefore one of the primary objectives of wastewater treatment.

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13 **Suspended solids** - The quantity of material deposited when a quantity of water, sewage or other liquid is filtered through a glass fiber filter.

14 **Dissolved Solids -** The material in wastewater that will pass through a glass fiber filter and remain in an evaporating dish after evaporation of the water.

15 **Disinfection -** The process used to control pathogenic organisms.

16 **Organic -** Chemical substances of animal or vegetable origin, made basically of carbon structure.

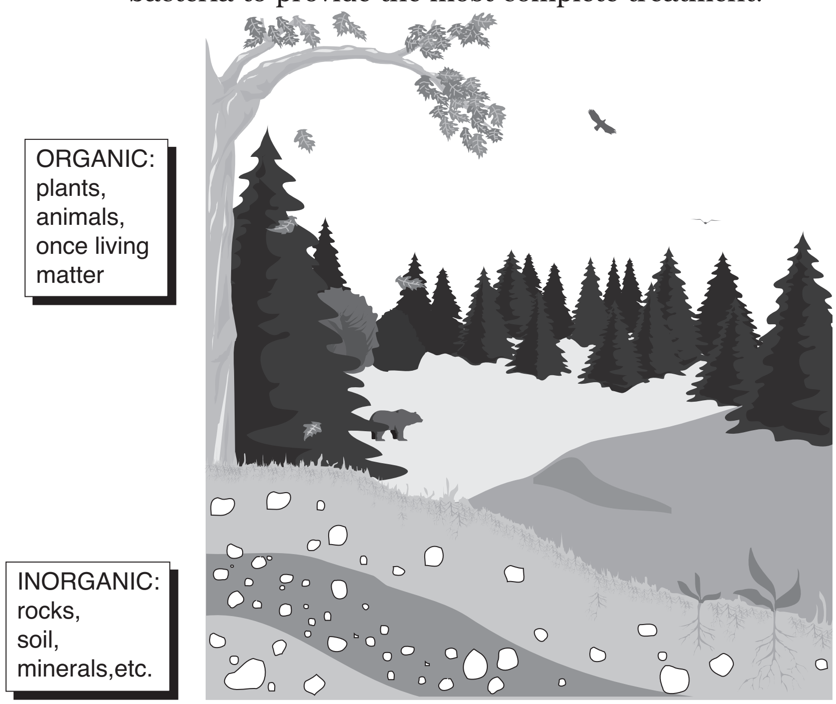
17 **Inorganic -** Chemical substances of mineral origin.

18 **Biodegradable** - (BUY-o-dee-GRAD-able) - Organic matter that can be easily broken down (decomposed) by bacteria to more stable forms which will not create a nuisance or give off foul odors.

19 **Stabilization -** The process of converting a material to a form that resists change. Organic material is stabilized by bacteria which converts the material to gases and other relatively inert substances. Stabilized organic material generally will not give off obnoxious odors.

Source of Organic Material

Organic material in wastewater includes any kitchen waste washed down drains or into garbage disposals, all sanitary connections including showers and toilets, and laundry facilities including clothes and dish washing. Basically, organic material includes any animal or vegetable material in sewage. Organic solids are a source of food for the bacteria in a wastewater treatment plant. The bacteria decompose the organic material in the wastewater so that the wastewater has a minimum impact on the environment. Because most wastewater treatment facilities are aerobic, it is important for this organic material to arrive fresh to the wastewater treatment plant. This allows the bacteria to provide the most complete treatment.



Inorganic materials in Wastewater

Description

Inorganic solids are frequently called mineral substances and include sand, gravel and silt, as well as the minerals or metals present from the water supply. Inorganic solids do not contain carbon and are not derived from living material and are therefore **inert**[20] and cannot be decomposed.

Source of Inorganic Material

The inorganic material in sewage includes plastic, rubber, sand, grit, egg shells, etc. Specific inorganic materials that cause wastewater plant problems include disposable diapers, plastic food containers, clothing, cans, bottles, soils, sand, plastic toys, plastic bags, and many others. These materials are not biodegradable, that is, they will not decay or burn.

[20] **Inert** - A material that will not react with any other material.

Impact on Treatment

Inorganic materials will not breakdown in aerobic or anaerobic wastewater treatment systems. Eventually these materials must be removed from the treatment system. Methods such as pre-screening and grinding can be used to reduce the impact inorganics have on a system. Either way, handling of these items become inevitable once they arrive at the plant.

Solids Groupings

Introduction

While all solids are either organic or inorganic, it is common practice to describe the solids found in wastewater in other categories based on test results. These results are used to determine the efficiency of the treatment process. The key point here is that the solids found in wastewater are defined, not by their size but by the test used to identify them. The following is a brief description of the seven types of solids found in wastewater. These seven are:

- Settleable solids
- Floatable solids
- Suspended solids
- Dissolved solids
- Colloidal solids
- Total solids
- Volatile solids

Settleable Solids

If the wastewater is allowed to sit quietly, as it does in a sedimentation basin or clarifier, most of the suspended solids will settle out and some solids will float. Solids that will settle in one hour in a funnel shaped glass, called an Imhoff cone, are called settleable solids. Therefore, we can say that settleable solids are those solids that are heavy enough to settle in a specified period of time. The quantity of settleable solids in wastewater is measured and reported as mL/L.

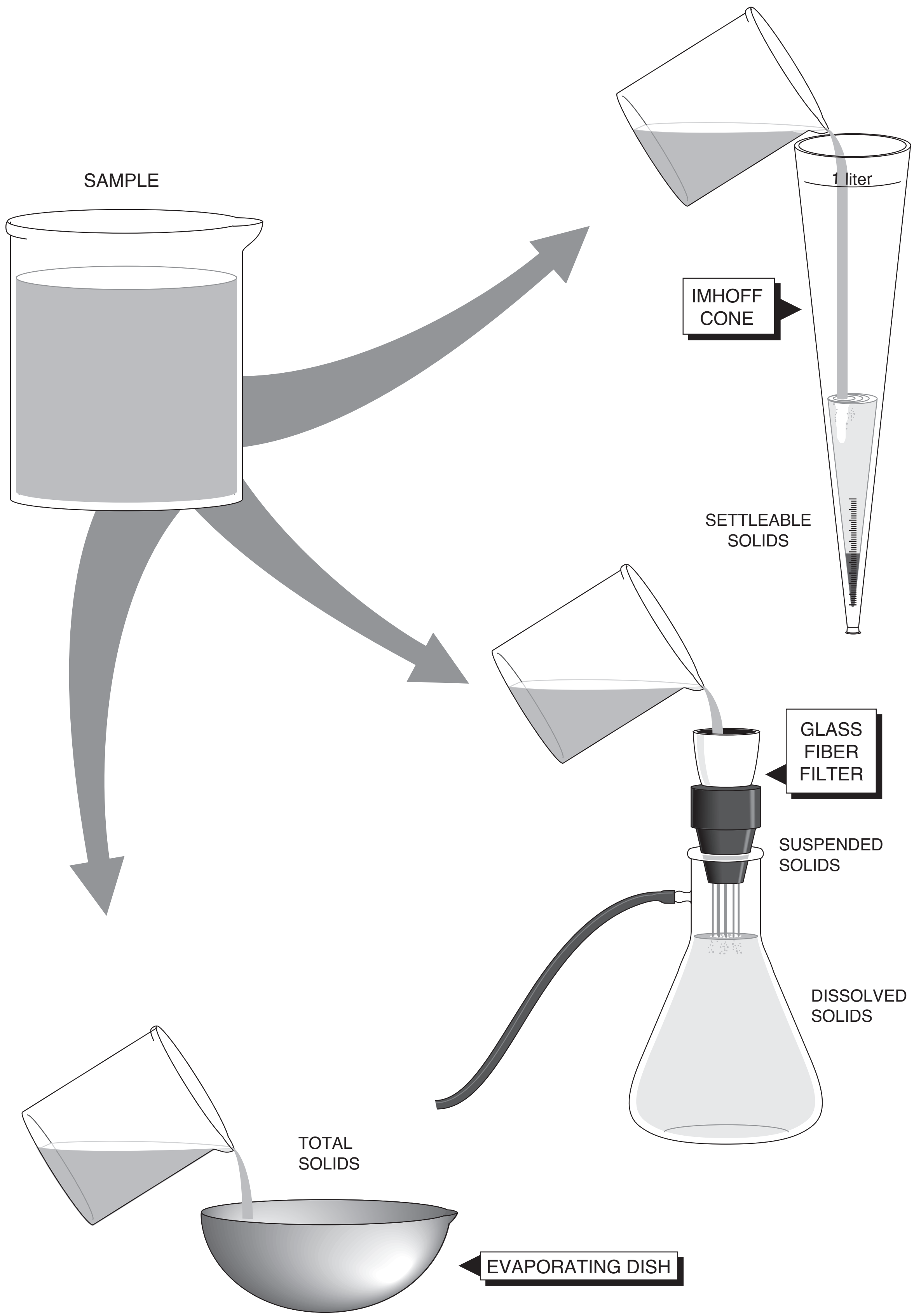
Floatable Solids

There is no test for floatable solids. However, materials such as oils, grease, plastic and rubber goods will float. Most floatable material is not easily biodegradable by aerobic or anaerobic bacteria and is commonly removed in the primary clarifier and sent to the digester.

Suspended Solids

If a sample of wastewater is thoroughly mixed and observed, it is typical to be able to see solids suspended in the liquid. When this sample is poured through a glass fiber filter, the material that is captured on the filter is called suspended solids (also called total suspended solids, TSS). Notice that if our sample were raw sewage, the suspended solids would include settleable and floatable solids. The quantity of suspended solids (TSS) in wastewater is measured and reported as **mg/L**[21].

[21] **mg/L -** Milligrams per liter. A unit of the concentration of a constituent in wastewater. It is 0.001g of the constituent in 1,000 mL of wastewater. mg/L has replaced the PPM (parts per million) in reporting results in wastewater.


SAMPLE
1 liter
IMHOFF CONE
SETTLEABLE SOLIDS
GLASS FIBER FILTER
SUSPENDED SOLIDS
DISSOLVED SOLIDS
TOTAL SOLIDS
EVAPORATING DISH

Suspended & Settleable

It is also important to note that the settleable solids contain some suspended solids. That is, settleable solids contain that portion of the suspended solids that will settle in a prescribed period of time.

Dissolved Solids

When our sample was poured through the glass fiber filter, a portion of the solids were caught on the filter (TSS) and a portion passed through the filter. The portion that passes through the filter is called dissolved solids. Approximately ninety percent (90%) of these solids are truly dissolved in the wastewater. The remaining ten percent (10%) are so small that they are held in solution. These solids are called **colloidal solids**[22]**.** The quantity of dissolved solids in wastewater is measured and reported in mg/L.

Colloidal Solids

Colloidal solids are suspended solids that are so small they will not settle even if allowed to sit quietly for days or weeks. They are not dissolved but even though they are extremely tiny, they often make the wastewater cloudy. In general, anything less than 1 micron (1/1000 of a millimeter) is considered a colloidal particle. Fine silt, tiny particles of vegetation, and small bacteria are examples of colloidal particles. This is the only solid that has been defined by size. In addition, there is no specific test for colloidal solids. They are part of the dissolved solids and are not tested independently.

Total Solids

If a portion of our original raw wastewater sample were poured into a ceramic evaporating dish and the water was allowed to evaporate, a residue would be left behind. This residue is called **total solids**[23]. Total solids contain the suspended (includes floatable and settleable solids) and dissolved portions of the solids. The quantity of total solids in wastewater is measured and reported as mg/L.

Volatile Solids

Volatile solids are determined by igniting the above samples at 550˚C and weighing the ashes. This test can determine inorganic components (inorganics do not burn at 550°C) and the test is used to determine microorganism densities.

Summary

Suspended solids are defined as those that can be filtered out in the suspended solids laboratory test. The material that passes through the filter is defined as dissolved solids. These definitions are not technically accurate from a chemical point of view because some finely suspended material can actually pass through the filter.

[22] **Colloidal -** Any substance in a certain state of fine division in which the particles are less than one micron in diameter.

[23] **Total Solids -** The solids in water, sewage, or other liquids. They include the suspended solids (largely removable by a filter) and filterable solids (those which pass through the filter).

Solids and Treatment

Influent and Effluent

One of the key measures of the efficiency of the treatment process is to measure the reduction in total suspended solids (TSS) through the plant. This is accomplished by comparing the TSS in the influent to the TSS in the effluent. The reduction in TSS is not accomplished by a single treatment process. Each process unit contributes to the overall reduction in the following ways.

Preliminary & Primary Treatment

Settleable solids and floatable material are removed by the preliminary and primary treatment processes. In the removal of these solids, the TSS is also reduced.

Secondary Treatment

After preliminary and primary treatment suspended and dissolved solids remain. The bacteria in the treatment process use the suspended and dissolved solids for food. They convert these solids to water, gases and settleable solids. While we measure the reduction of TSS as the efficiency of the treatment process, it is the dissolved solids that make up the major portion of the food supply for the bacteria in the secondary treatment process.

Nutrients

Impact on Biological Activity

The proper nutrient balance for proper biological activity is defined as the Carbon:Nitrogen:Phosphorus ratio. This ratio requirement for wastewater treatment is 100:5:1. For every 100 pounds of Carbon (**BOD**[24]) entering the treatment plant, 5 pounds of nitrogen (ammonia nitrogen + nitrate + nitrite) is required and 1 pound of phosphorus (as orthophosphate) is required to be available to the bacteria. If these minimum requirements are not met, the bacteria that will survive will not perform as expected. In other words, the nutrient deficient treatment plant will not make a clear effluent or produce a sludge that will settle or smell very good.

Dissolved Gases

What Gases?

Oxygen, carbon dioxide, hydrogen sulfide, methane and nitrogen are examples of gases that dissolve in wastewater. With the exception of oxygen, all of these gases are produced by the decomposition of organic material. Not all gases dissolve to the same extent. Some dissolve easily and others not as well. Oxygen and carbon dioxide are two dissolved gases that are important to wastewater operations.

24 **BOD** - Biochemical (BY-oh-KEM-ih-kul) Oxygen Demand - The quantity of oxygen required by microorganisms when stabilizing decomposable organic matter under aerobic conditions and other test conditions.

Dissolved Oxygen

The Impact of Dissolved Oxygen

Dissolved oxygen or D.O. is important to most **aquatic**[25] organisms and to secondary treatment plants. It is of particular importance in streams and lakes as an indicator of water quality. The amount of oxygen that can be dissolved in the wastewater depends upon the temperature. The higher the wastewater temperature, the lower the saturation level; the lower the water temperature, the higher the saturation level. Various wastewater treatment processes rely on the mechanical addition of oxygen into the wastewater to stabilize the organic matter before it is discharged into a stream or other water source.

Other Sewer Gases

Result of Biological Action

As mentioned above, there is a multitude of gases besides oxygen present in sewage. Most of these gases are by products of the biological decomposition of organics. While nothing can be done to stop the production of most of these gases, an understanding of their effect and possible hazards will help in the overall operation of the sewer system.

The Impact of Carbon Dioxide

The decomposition of organic material that contains carbon results in the production of carbon dioxide gas. Carbon dioxide is released into the wastewater by microorganisms. In a sewage lagoon, a portion of the carbon dioxide is consumed by algae and aquatic plants. Carbon dioxide is only slightly soluble in water. Most of the carbon dioxide reacts with the water to form carbonic acid.

$$\underset{\text{(carbon dioxide)}}{CO_2} + \underset{\text{(water)}}{H_2O} \leftrightarrow \underset{\text{(carbonic acid)}}{H_2CO_3}$$

Carbonic acid acts to lower the **pH**[26] of the wastewater.

Hydrogen Sulfide

The biological breakdown of organic material under anaerobic conditions will produce hydrogen sulfide (H_2S). Hydrogen sulfide has a characteristic “rotten egg” odor. Hydrogen sulfide is toxic to humans, very explosive and produces sulfuric acid which is corrosive to the collection system and treatment plant equipment basins and piping. Hydrogen sulfide combined with water, results in sulfuric acid which will corrode piping and other metal and concrete structures.

Methane

Another wastewater gas that is the by-product of anaerobic decomposition of organic material is Methane (CH_4). Methane, while dangerous is not classified as toxic, but it can suffocate a person. Methane is also explosive.

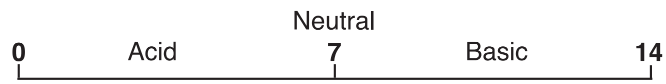
[25] **Aquatic** - Pertaining to water.

[26] **pH** - An expression of the intensity of the alkaline or acidic strength of a wastewater. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion concentration. pH may range from 0 to 14, where 0 is the most acid, 14 most alkaline, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5.

pH

Definition

The term used to describe how acidic or basic the wastewater is, is pH. More technically, pH is a measure of the hydrogen ion (H^+) concentration and is measured with a meter or colorimeter. The pH scale ranges from 0 to 14 with 7 being neutral.



pH Scale

pH Scale

Low pH values are considered acidic and high pH values are basic.

Impact on Biological Activity

The pH of wastewater must be maintained as near neutral (7) as possible because the bacteria that are most beneficial to wastewater treatment like a pH range of 6.8 - 7.2. Extreme pH variations in the influent can become an extreme hardship for wastewater plant operators. The bacteria in a wastewater treatment plant will not tolerate pH variations and other, less desirable microorganisms such as certain fungus and filamentous bacteria will take over the plant. These organisms have a negative impact on wastewater treatment and thrive at low pH.

Alkalinity

Definition

Alkalinity[27] is a measure of water's ability to neutralize an acid. Alkalinity can also be defined as a buffer; a chemical system that tends to stabilize and prevent fluctuations in pH. It is usually beneficial to have significant alkalinity in wastewater because it would tend to prevent quick changes in pH. Quick changes in pH interfere with the common secondary treatment processes. Maintaining sufficient alkalinity is a major key in the proper operation of an anaerobic digester.

What causes Alkalinity

Alkalinity is the result of carbonate (CO_3^{-2}), bicarbonate (HCO_3^{-1}) and hydroxide (OH^-) ions in the wastewater. Alkalinity should not be confused with pH. Even wastewater with an acid pH can contain alkalinity. Typical chemicals that can be used to increase alkalinity are quick lime (calcium oxide, CaO), hydrated lime (calcium hydroxide, $Ca(OH)_2$), and soda ash (sodium carbonate, Na_2CO_3).

[27] **Alkalinity -** The buffering capacity of wastewater to retard the change in pH by an acid. Alkalinity is composed of bicarbonates, carbonates and hydroxides.

Heavy Metals

The Impact of Metals

Wastewater often contains impurities such as lead, copper, mercury, arsenic, etc. called heavy metals. These metals generally come from the potable water source and distribution system. Metals can be toxic to some microorganisms and aquatic life. In excess quantities, metals such as copper, can upset a secondary treatment plant or harm fish and other aquatic life in the receiving stream. Wastewater treatment plants have a tendency to accumulate metals in the sludge that is produced by the treatment process. If the sludge is disposed of on land, these metals can adversely impact vegetation and may enter the groundwater supply. Some Alaska communities that have aggressive potable water find high concentrations of copper coming from the household plumbing. These high concentrations have placed the community in jeopardy of violating their discharge permit and make it difficult for them to dispose of their sludge.

BOD - Biochemical Oxygen Demand

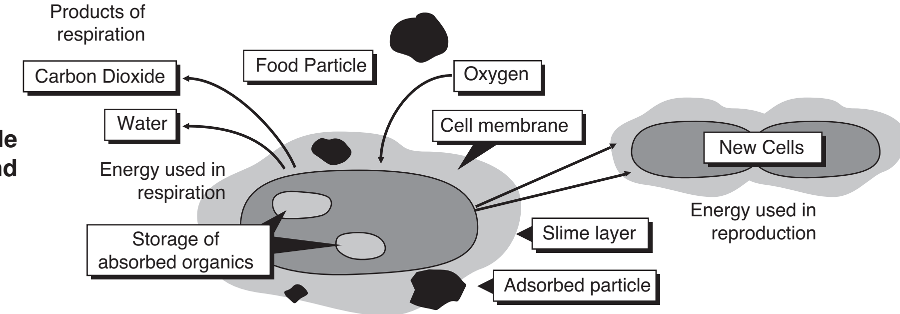
Definition

BOD or biochemical oxygen demand is a test used to measure the ability of microorganisms to oxidize organic material in the wastewater. The BOD of the wastewater is a direct reflection of its organic strength. The BOD test can be used to determine the size of a treatment facility as well as estimate the impact the effluent will have on the receiving stream. At a treatment plant, the BOD of the waste stream is referred to as the “food” for the microorganisms.

Uses of BOD Measurements

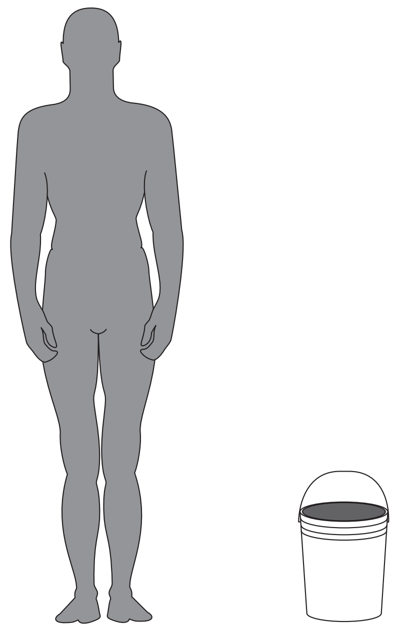
The BOD test doesn’t directly measure wastewater strength. The test measures the amount of oxygen that is consumed by microorganisms while stabilizing organic material. This oxygen consumption is considered a direct reflection of the organic strength of the wastewater. The amount of oxygen that can be consumed by microorganisms is based on a number of factors. Two of the most important are the amount of food and the length of time that the organisms are allowed to eat the food. Typical BOD measurements determine the amount of oxygen used over a five day period at 20°C.

Stabilization of biodegradable organic by bacteria. Food and oxygen intake and by-products produced.



Population Equivalent

It has been determined that the average person produces 0.2 pounds of BOD a day. The population equivalent is an alternate method of expressing the organic strength of the wastewater. Design engineers divide the actual BOD by 0.2 to obtain a population equivalent. This number is then used to determine the appropriate treatment process and size.



1 Person = 0.2 lbs. BOD/day

What is a pound of BOD?

It is common practice to refer to BOD as a specific mg/L concentration and as a certain number of pounds. For instance, a plant operator might say that the influent BOD averages 250 mg/L and a daily organic load on the plant is 500 pounds. What does this mean? A BOD of 250 mg/L indicates that in the process of stabilizing organic material the microorganisms will consume 250 milligrams of dissolved oxygen for each liter of wastewater. The 500 pounds indicates that while consuming organic material, the bacteria will consume 500 pounds of oxygen in a 24 hour period.

Plant Efficiency

The reduction of BOD throughout the treatment plant is one of the overall goals of wastewater treatment and pollution reduction. By measuring the influent BOD and measuring the effluent BOD and using the following calculation, the percent reduction through treatment can be determined.

$$\%\,\text{Efficiency} = \frac{BOD_{in} - BOD_{out}}{BOD_{in}}$$

Typical Removal

Most secondary treatment plants have specific percent removal requirements with 85% being the average for the country. It takes a properly operating treatment plant to make these reduction requirements.

Biological Characteristics

Impact of Microorganisms

All wastewater as it leaves a residence or commercial establishment is teaming with bacteria, **virus**[28], **protozoa**[29] and other microscopic organisms. These organisms, primarily the bacteria, begin immediately to consume the organic solids in the sewage. In addition, these organisms could carry communicable waterborne disease from the population that is served by the sewer collection system. The wastewater also carries large numbers of viruses that can cause waterborne disease.

Waterborne Diseases

Wastewater system operators must also be concerned about how to control microorganisms. They are a major health concern because many of them cause the spread of **waterborne diseases**[30]. Organisms that cause disease by transmission through contaminated water are called **waterborne pathogens**[31].

Importance of Bacteria

Biological wastewater treatment processes utilize microorganisms, mostly bacteria, to consume the organics and reduce the waste in the wastewater to water, carbon dioxide and biological solids. Efficient treatment depends on understanding the requirements for optimal growth as well as recognizing unfavorable biological conditions.

Groups of Microorganisms

While all types of microorganisms have some effect on wastewater or are affected by wastewater, bacteria, protozoa and algae are the most significant to the operator. The following discussion will provide an overview of these organisms.

Bacteria

Most Common Microorganism

Bacteria are among the most common microorganisms in wastewater. Bacteria are primitive, single celled organisms with a variety of shapes and nutritional needs.

Size Range

Bacteria range in size from 0.5 - 2 microns in diameter and about 1 - 10 microns long. A micron is a metric unit of measurement equal to 1 millionth of a meter or 1 thousandth of a millimeter. Another way to visualize the size of bacteria is to consider that it would take about 1000 bacteria laying side-by-side to reach across the head of a straight pin.

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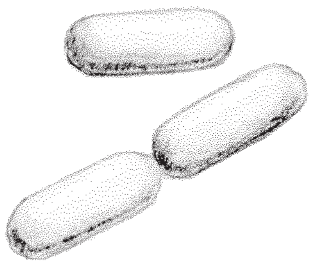
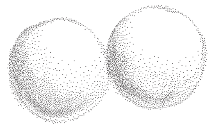
28 **Virus -** A submicroscopic organism which passes through filters which will strain out bacteria.
29 **Protozoa** - A small one-celled animal including, but not limited to, amoebae, ciliates, and flagellates.
30 **Waterborne disease -** A disease caused by organisms or toxic substances which are carried by wastewater. The most common waterborne diseases are typhoid fever, Asiatic Cholera, Dysentery, and other intestinal disturbances.
31 **Waterborne Pathogens** - Bacteria, virus and protozoa which cause disease and are carried by wastewater.

Three Shapes

There are three general groups of bacteria based on their physical shapes. Rod shaped bacteria are called bacilli. Spherical shaped bacteria are called cocci. Spiral shaped bacteria make up the third group.



bacilli - rods



cocci - spheres

Spiral

Oxygen Requirements

Introduction

Many bacteria are aerobic. They require free or dissolved oxygen. The bacteria responsible for most of the biological treatment of wastewater are aerobic. A few bacteria are anaerobic. They can only exist and multiply in an environment that lacks dissolved oxygen. Anaerobic bacteria are responsible for most of the treatment that takes place in a septic tank. Some bacteria which are normally aerobic can exist under anaerobic conditions. These adaptable bacteria are said to be **facultative**[32]. Facultative bacteria are responsible for most of the treatment that takes place in a sewage lagoon.

Aerobic Bacteria

If dissolved oxygen (DO) is available, the type of bacteria that will predominate will be the aerobic variety. These bacteria utilize free oxygen for metabolism and perform their duties in the most efficient manner. As opposed to the other types of bacteria listed in this section, an aerobic bacteria will consume and reduce the greatest volume of organics, thus reducing pollution faster with little odor.

Anaerobic bacteria

If no free oxygen is available to the bacteria and food is present, a type of bacteria known as anaerobic will prevail. These bacteria, while still utilizing oxygen for metabolizing the organics, get their oxygen by breaking the chemical bonds that attach the oxygen to other compounds. This chemically-bound oxygen is harder to get to and it takes longer for the bacteria to get air to do their work. As a result of this chemical process, gases are given off as the oxygen molecule is lifted from the compounds. In large volumes these gases have terrific odors.

[32] **Facultative -** In reference to microorganisms - those that can switch from an aerobic to anaerobic or from an anaerobic to an aerobic environment.

Anaerobic Digestion

Anaerobic bacteria are desirable and if managed properly, result in sludge digestion which reduces volume and odors. Anaerobic organisms should be left to their anaerobic environment. These environments include sealed tank digesters, septic tanks and the bottom of a lagoon.

Anaerobic Bacteria & Septic Tanks

Anaerobic organisms are prevalent in septic tanks. If septic material is allowed to be in open contact with the air, terrific odors result. If septic material is delivered to a wastewater treatment plant for disposal, operators should plan on disposing one pound of solids for each pound of septic waste brought into the plant. No further digestion of the septic tank waste will take place and no further reduction of volume will take place in the plant. If wastewater in a collection system is allowed to become septic on its way to the treatment plant, the wastewater plant will expend tremendous amounts of electricity to convert the anaerobic environment into an aerobic environment. This conversion must be done in order for treatment to be effective.

Anaerobic Bacteria and Lagoons

The sludge layer at the bottom of a lagoon system is maintained as an anaerobic sludge digestion process. The sludge in a properly operated lagoon system should be removed at least every 15-20 years to allow enough room for ongoing sludge accumulation. The surface of a lagoon system will often have bubbles rising to the surface indicating the ongoing anaerobic decomposition process.

Food Requirements

Most bacteria require organic food to survive and multiply. This food comes from plant and animal material that gets in the wastewater. The bacteria convert the food to energy and use the energy to move around and make new cells. Some bacteria can use inorganics (such as iron) as an energy source. These bacteria can exist and multiply even where organic food is not present.

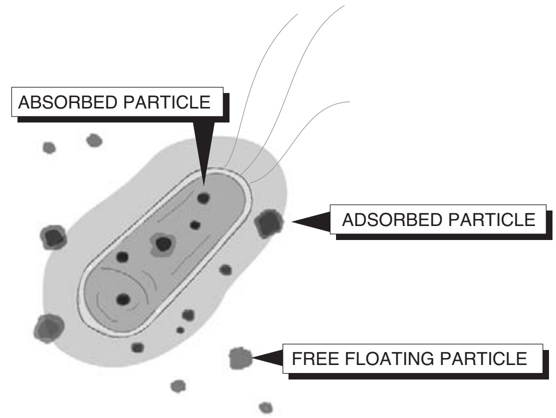
Intake of Food

Bacteria collect food as suspended organic material in a slime layer that surrounds the bacteria. This process is called **adsorption**[33]. The bacteria then excretes an enzyme into the slime layer. The enzyme breaks down the food and allows it to pass through the semipermeable membrane wall of the bacteria using a process called **absorption**[34].

[33] **Adsorption** - (add-SORP-shun) - The gathering of a gas, liquid, or dissolved substance on the surface or interface zone of another substance.

[34] **Absorption** - (Ab-SORP-shun) - Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

Bacteria Metabolism Process



Temperature Requirements

Temperature affects the rate at which bacteria grow. The warmer the environment, the faster the rate of growth. Generally, for each increase of 10°C, the growth rate doubles.

Temperature Ranges

In order to function at maximum efficiency, bacteria require a favorable temperature. They are very susceptible to changes in temperature which affects their growth and the amount of work they can do. Bacteria that are helpful in a wastewater treatment plant are placed into one of three temperature ranges. These ranges coincide with the temperature that is best for the growth and reproduction of the bacteria. The ranges are:

Name	Temperature Range
Psychrophilic	below 68°F
Mesophilic	68°F to 113 °F
Thermophilic	above 113 °F

pH Requirements

pH affects bacteria growth. Most bacteria grow best at a neutral pH. Extreme acidic or basic conditions will inhibit growth. Other materials, such as metal ions (copper, lead, silver, etc.) and some organics such as pesticides and herbicides are more toxic at a specific pH.

Pathogenic Bacteria

Bacteria are responsible for a number of the most infamous epidemic diseases. If the water is not properly treated and disinfected, the bacterial pathogens responsible for these diseases enter potential drinking water supplies through fecal contamination and are ingested by humans. The table below list a number of bacterial waterborne diseases.

Bacteria	Disease
Salmonella typhi	Typhoid Fever
Shigella spp.	Gastroenteritis
Vibrio cholerae	Cholera
Campylobacter spp.	Gastroenteritis
Enteropathogenic E. coli	Gastroenteritis
Leptospira spp.	Leptospirosis

Coliform Bacteria

One particular group of bacteria is used by water quality experts and wastewater plant operators to determine the effectiveness of disinfection in a wastewater system. This bacterial group is the **fecal coliform bacteria**[35]. This is one of the subgroups of coliform bacteria. These are chosen as an indicator organism because they are less susceptible to destruction by chlorine than most of the pathogens. If the number of fecal coliforms are low, then it is assumed that there are few pathogenic bacteria present.

Protozoa

Definition & Size

Protozoa are one celled animal-like organisms with a fairly complex cellular structure. The protozoa are the giants of the microbial world. They are many times larger than bacteria. They range in size from 4 microns to 500 microns. The larger ones can almost be seen with the naked eye.

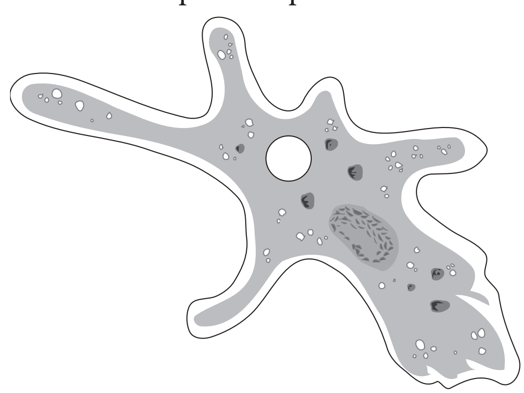
Significance

Protozoa are predators that feed on bacteria. The numbers of certain protozoa found in specific treatment processes is a good indication of the quality of the treatment. In addition, certain protozoa are pathogenic.

Groups of Protozoa - Amoeba

Protozoa are placed into groups based on their method of locomotion. The amoeba move about by a streaming or gliding action. The shape of amoeba change as they sort of ooze from place to place.

Amoeba

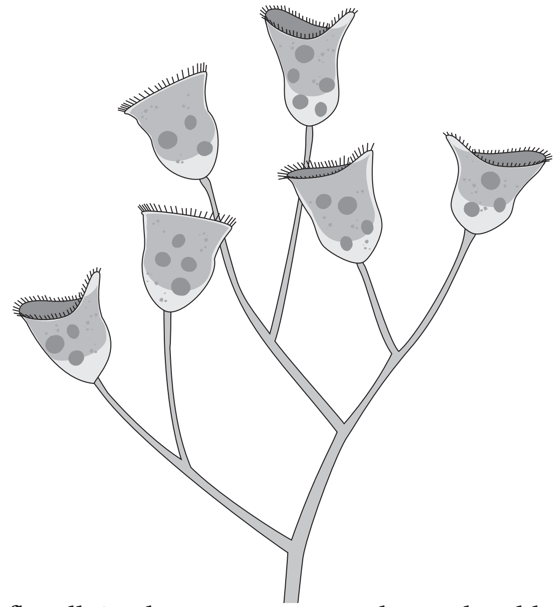


Ciliates

The ciliates are covered with short hair-like projections called cilia that beat rapidly and propel the ciliate through the wastewater. Most ciliates are free-swimming although some are attached to floating material or basin walls. Ciliates are the most important protozoa in stream pollution reduction and in wastewater treatment. Their presence in an activated sludge plant in high numbers is usually an indicator of good treatment.

[35] **Fecal Coliform Bacteria -** The Fecal coliform group of bacteria is a bacterial indicator of contamination. This group has as one of its primary habitats the intestinal tract of human beings. Coliforms also may be found in the intestinal tract of other warm-blooded animals. Also called E. Coli or Escherichia Coli

Stalked Ciliates



Flagellates

The flagellates have one or more long whip-like projections called flagella that propel the free-swimming organisms. (Giardia lamblia is a flagellated protozoa).

Food Requirements

Protozoa use organics for food. In fact, bacteria are one of their favorite prey. Protozoa are mostly aerobic or facultative. pH, toxic materials, and temperature affect their rate of growth in the same way as bacteria.

Food Chain Position

The protozoa is higher up the food chain than bacteria. While the bacteria are the main contributors to waste treatment, they become food for the protozoa.

Waterborne Disease

Three protozoan waterborne diseases are listed in the table below:

Protozoa	**Disease**
Entamoeba histolytica	Amoebic dysentery
Giardia lamblia (5 to 21μ in size)	Giardiasis
Cryptosporidia (4 to 6μ in size)	Cryptosporidosis

Algae

Description

Algae is a form of aquatic plant. Although in mass growths, algae mats are easily seen by the naked eye. They exist as microscopic, single celled forms and also as huge, multicellular forms, such as marine kelp. They occur in fresh and polluted water, as well as in salt water. Since they are plants, they are capable of using energy from the sun in the process called **photosynthesis**[36]. In fact, they only grow when there is light (the daytime) and they grow better when there is bright sunlight, as opposed to cloudy weather. They

[36] **Photosynthesis** - (foto-SIN-the-sis) - A process in which organisms with the aid of chlorophyll (green plant enzyme) convert carbon dioxide and inorganic substances to oxygen and additional plant material, utilizing sunlight for energy.

usually grow near the surface of the water because light cannot penetrate very far through the water.

Classification System

Algae are classified by their color (green, brown, blue-green). The green algae contain green chlorophyll and are found mostly in fresh water. This form is the green road-side ditch algae, and are found on clarifier and basin walls. Diatoms are golden-brown, single-celled forms that have a hard silica shell. Another organism, formally called blue-green algae, are bluish-green in color and undergo photosynthesis. They are now classified as a type of bacteria called *Cyanobacterium.* The most serious algae problems in receiving water are associated with the growth of blue-green algae (bacteria).

Algae and Waste Treatment

Algae is one of the major treatment microorganisms in a wastewater lagoon. They consume carbon dioxide produced by bacteria and provide oxygen that is needed by bacteria to stabilize the wastewater. Without oxygen, anaerobic conditions would exist and treatment would be severely limited.

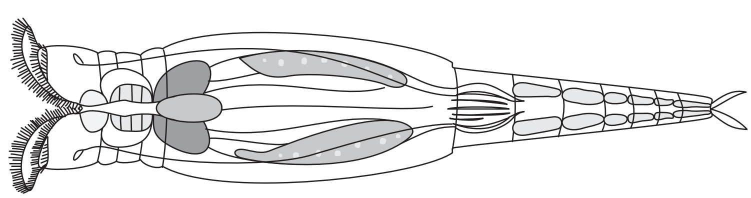
Higher Forms

The Food Chain

As we progress up the food chain from bacteria through protozoa we reach a group of organisms that the microbiologists call higher forms. These include simple multi-celled animals, crustaceans, worms and larvae.

Rotifers

The rotifer is the simplest of the multicellular animals. Its name comes from the apparent rotating motion of two sets of cilia on its head. This motion draws in food and moves the animal through the water. A well operated activated sludge plant will contain a few rotifers in each drop of fluid. Rotifers are strict aerobes that feed on bacteria.



The Effluent

Water Quality Requirements

The overall intent of wastewater treatment is to minimize the pollution impact on any receiving streams, oceans, or groundwater sources and protect downstream users from waterborne disease. The BOD test is used to measure the impact the plant effluent will have on receiving streams. This is accomplished by measuring the potential of the effluent to deplete oxygen in the receiving water. Discharge permits allow certain amounts of BOD and Suspended Solids to be discharged to receiving streams. The assimilation capacity or ability of the stream to accept the effluent without damaging the water quality has been determined. As a result, the organic load that can be placed on the stream is distributed among dischargers using the stream for disposal. It is important to safeguard the health of any receiving body of water by staying within permit limits at all times and planning for future needs in a responsible manner.

Objective of Wastewater Treatment

The objective of wastewater treatment is to reduce pollution and protect public health by containing and stabilizing raw sewage. Pollution prevention and public health concerns are a worthy objective.

Characteristics of Wastewater **Worksheet**

1. Typical domestic wastewater is _______ % water and _______ % solids.

2. The impurities in wastewater are called ________ or __________________.

3. Peak flow will normally occur during (a) dry weather or (b) wet weather.

4. In Alaska, wastewater flows will range from ___________ to ________ gpcpd.

5. The size of a treatment plant is based on _____________ flow.

6. The average hydraulic load contributed by each person in a community in the U.S. is __________ gpcpd.

7. Fresh sewage is _____________ in color and has a _____________ odor.

8. Septic sewage is ____________ in color and has a ____________ odor.

9. Turbidity is the property of wastewater that causes light to be ______________ or _______________.

10. Solids that can be captured on a filter are called _________________ solids and solids that pass through a filter are called ______________ solids.

11. A solid that is less than 1μ in size is called a _____________.

12. Compounds that are derived from material that was once alive are called ____________ compounds.

13. Compounds that are derived from minerals are called __________ compounds.

14. When a gas is mixed in wastewater it is called a _______________ gas.

15. A gas with a rotten egg odor is ________________ ________________.

16. The pH range is from _______ to _______. The acid portion of the range is from ________ to _____.

17. What is alkalinity?

18. The problem with most metals that are found in wastewater is.....

19. BOD is a measure of the amount of _________ consumed by microorganisms.

20. The population equivalent is ______ pounds of BOD per person.

21. The process of food attaching to a bacteria is called _______________, and the process of this food passing through the wall of the bacteria is called ________________.

22. A high organic load on a receiving stream can cause a drop in its ___________ ____________.

23. Waterborne pathogens cause ________________ _____________.

24. The three common shapes of bacteria are:
    a. _______________________
    b. _______________________
    c. _______________________

25. Bacteria that utilize dissolved oxygen are called _________________ bacteria.

26. Bacteria that can live with or without dissolved oxygen are called ___________________.

27. Three waterborne diseases caused by bacteria are:
    a. _______________________
    b. _______________________
    c. _______________________

28. The bacteria used in wastewater as an indicator of disinfection efficiency is the ____________ ____________ bacteria.

29. Rank the following bacteria by temperature range. Give a one (1) to the bacteria that prefers the highest temperature.

______	Mesophilic
______	Psychrophilic
______	Thermophilic

30. Algae are forms of _______________ plants.

31. The three major groups of microorganisms found in wastewater that cause disease are:

    a. ________________________
    b. ________________________
    c. ________________________

Collection Systems

What is in this Lesson?

1. The basic function of a wastewater collection system
2. The cause of odors in sanitary sewers
3. The characteristics of a gravity flow sewer
4. The difference between a sanitary sewer manhole cover and a storm sewer manhole cover
5. Those items that impact the flow capacity of a sewer line
6. The minimum design velocity in a sewer and why this velocity is important
7. The components of an above ground utilidor system used for a piped sewer
8. The difference between combined sewers, sanitary sewers and storm sewers
9. The normal location of manholes
10. The process and components of a pressure sewer line
11. The various types of sewer lines
12. The components of an individual honey bucket system
13. The components of a manhole
14. The components of a pipe
15. The components of a storm sewer
16. The components of a typical haul system
17. The major components of a gravity piped collection system
18. The various types of manholes and their components
19. The impact of freezing on various types of piping material
20. Which portion of the collection system is the responsibility of the property owner
21. The major components of a vacuum collection system
22. Conditions that would be detected using smoke testing
23. How to identify and control exfiltration
24. How to identify and control infiltration
25. The method used to identify the connection to a sanitary sewer
26. The problems associated with cracks in the lid ring of a manhole
27. The process and function of CCTV inspection
28. The process and use of dye tests
29. The process of lamping a pipeline
30. The process of smoke testing
31. The purpose of performing a manhole inspection
32. The reasons for inspecting a collection system

33. What conditions can be identified by lamping a pipeline
34. Common sources of inflow
35. The basic equipment used to inspect the interior of the collection system piping
36. The frequency of manhole inspection
37. Three things that the dye test can be used to identify
38. Types of typical lift stations
39. The deciding factors used to determine the frequency that water should be pumped from a wet well
40. The components of a lift station
41. How mechanical cleaning methods differ from hydraulic cleaning methods
42. Common collection system cleaning methods
43. The conditions that would allow roots to enter a collection system
44. The material that may be removed in cleaning a sewer line
45. The principle of hydraulic cleaning
46. The problems associated with using hydraulic sewer cleaning equipment
47. The process of cleaning a sewer line with a ball
48. The reasons for controlling hydrogen sulfide in a sewer
49. Chemicals which can be used to control hydrogen sulfide
50. Common methods used to prevent the spread of disease when a bucket or haul system is used
51. The function of the various components of a vacuum collection system
52. The health concerns associated with an individual bucket system
53. The most common health concerns associated with haul systems
54. The most common operational problems with haul systems
55. The problems associated with operating a collection system in an Arctic environment

Key Words

- AC
- Blockage
- Building sewer
- Cesspool
- Circumventional
- Combined sewer
- Confined space
- DCIP
- Dry well lift station
- Exfiltration
- Force main
- HVC
- Inflow
- Lift Station
- Main Sewer
- Package lift stations
- Pit toilets
- Privies
- Sanitary sewer
- Staff Gauge
- Storm sewer
- Suction Lift
- Vector
- Weirs
- Arctic pipe
- Branch sewer
- CCTV
- Check valve
- Cleanout
- Concentric manhole cone
- Cross-connection
- Debris
- Eccentric manhole cone
- Flume
- HDPE
- Infiltration
- Lateral Sewer
- Longitudinal
- Manhole
- Permafrost
- Plug valve
- PVC
- Seal Water
- Stoppage
- Suction Head
- Surcharge
- Vitrified Clay Pipe
- Wet well lift station

Collection Systems

Functions of a Collection System

What is a Collection System?

A collection system is composed of a means of collecting and transporting human waste, storm water and industrial waste from its source to a treatment facility, receiving body of water or a disposal site.

Why Have a Collection System?

When we eliminate or reduce contact with human waste we reduce the frequency of disease. By transporting the waste away from its source, we also improve the appearance of the neighborhood and community. Therefore, we build and operate wastewater collection systems for two reasons:

- Prevent disease and
- Improve the appearance of the community (aesthetics)

Brief History of Collection Systems

Oldest

Collection systems are the oldest component of the various wastewater facilities. The early collection systems were underground piped systems that operated by gravity. The oldest wastewater collection system was built in India around 3750 B.C. The oldest collection system still in use is the arched sewer built in Rome around the first century. This arched sewer was used to carry waste from the Roman Forum to the Tiber River.

16th - 19th Centuries

The earliest drainage systems built in modern times were constructed in the 16th and 17th centuries to carry storm runoff to prevent local flooding. At the time of their construction, most of the human waste was disposed of in individual **privies**[1] and **cesspools**[2]**.** Household waste (graywater) was thrown onto the street and collected in the drainage system. This process created deplorable conditions and was a major contributor to widespread disease in Europe, England and the eastern U.S. Even so, cities such as London and Philadelphia prohibited the discharge of household waste into the drainage system as late as 1850.

Pump & Piping

With the development of piping materials and the steam engine for pumping came the development of the indoor toilet. These developments led to the installation of piped collection systems and the banning of **pit toilets**[3] and cesspools in large cities.

[1] **Privies** - Another name for a pit toilet.
[2] **Cesspool** - A lined or partially lined excavation or pit for dumping raw household wastewater for natural decomposition and percolation into the soil.
[3] **Pit Toilet** - A toilet constructed by digging a pit in the ground and placing a small building over the pit. Also called an out house.

Understanding of Disease

Once the relationship between disease and waste disposal was understood, changes were needed. One of these changes was to connect the house sewer to the storm drainage system. While this reduced the spread of disease in the local community, it polluted the receiving water and increased the spread of disease among downstream users.

Current Thinking

Once it was determined that one of the major causes of the destruction of receiving streams was domestic waste, the construction of sewage treatment plants was started. With this, came the separation of domestic waste from the drainage system.

Types of Collection Systems

Basis of Classification

The standard method of classifying the various types of collection systems is based on an assumption that all collection systems use buried pipes. While this assumption fits most of the U.S. and Canada, it does not fit the conditions found in the Arctic and subarctic of Alaska and Canada. A separate classification system for these areas will be discussed later in this lesson.

Three Types

There are three basic types of collection systems;

- **Sanitary sewers**[4]
- **Storm sewers**[5]
- **Combined sewers**[6]

Sanitary Sewers

A sanitary sewer is a collection system designed to transport domestic wastewater, commercial wastewater and industrial wastewater. Domestic wastewater is the flow from homes. Commercial wastewater is the flow from businesses, hospitals, hotels, clinics and similar facilities in a community. Industrial wastewater is the flow from facilities that manufacture or process products or food.

Storm Sewer

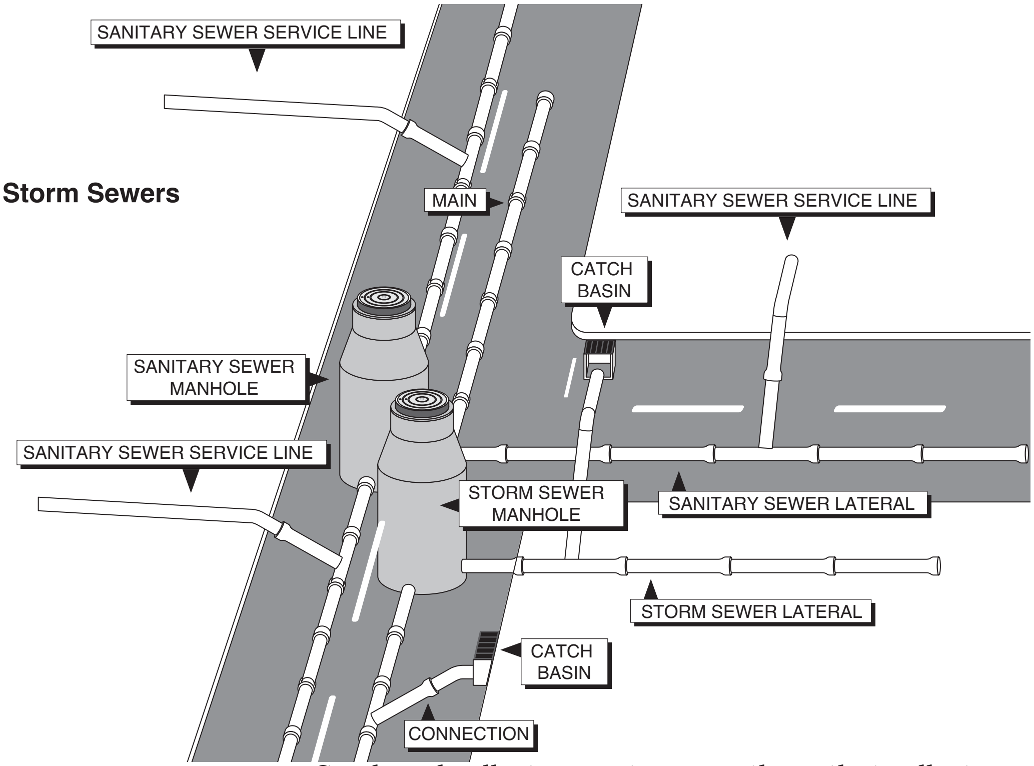
Storm sewers (also called storm drains) collect water from house roof drains, street runoff and surface runoff. All of these sources may be referred to as surface runoff. The storm sewer collection system includes ditches, culverts, catch basins, manholes, and lines. The storm drain system gathers surface water from the community and transports it to a receiving stream.

[4] **Sanitary Sewer** - A sewer that carries water and water carried waste from residences, commercial buildings, industrial plants, and institutions, together with minor quantities of ground, storm, and surface water that are not admitted intentionally.

[5] **Storm Sewer -** A sewer that carries storm water and surface water, street wash and other wash waters, or drainage, but excludes domestic wastewater and industrial wastes.

[6] **Combined sewer** - A sewer intended to receive both wastewater and storm or surface water.

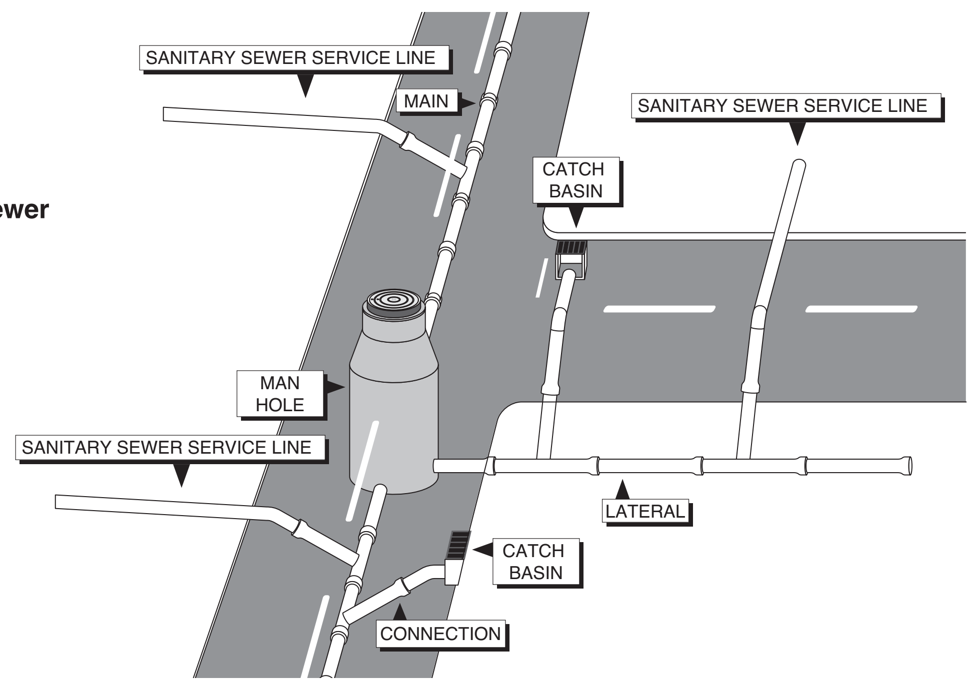
Sanitary and Storm Sewers



Combined Sewers

Combined collection systems are those that collect and transport domestic waste as well as surface runoff in the same pipe system. While combined sewers are not built today, they are common in many older cities. Because these collection systems can be a major source of pollution, as well as hydraulically overload the treatment plant, communities are spending large sums of money to separate the domestic wastewater from the surface runoff.

Combined Sewer



Classification of Systems in Alaska

VSW and PHS

The Village Safe Water (VSW) and US Public Health Service (PHS) have developed a system of classification for collection and treatment systems in Alaska. These systems are identified by the letters A through E. The systems are classified by level of complication and potential for contact with human waste.

Level A- Honey Bucket System

Description

Level A systems are those with pit toilets, privies or honey buckets. Disposal is in a pit bunker, on frozen rivers, in the ocean, on the tidal plane, in tundra ponds or lagoons. Disposal is provided by the individual home owner.

Disadvantages

This system presents the highest potential for contact with human waste and therefore the highest probability for the spread of disease.

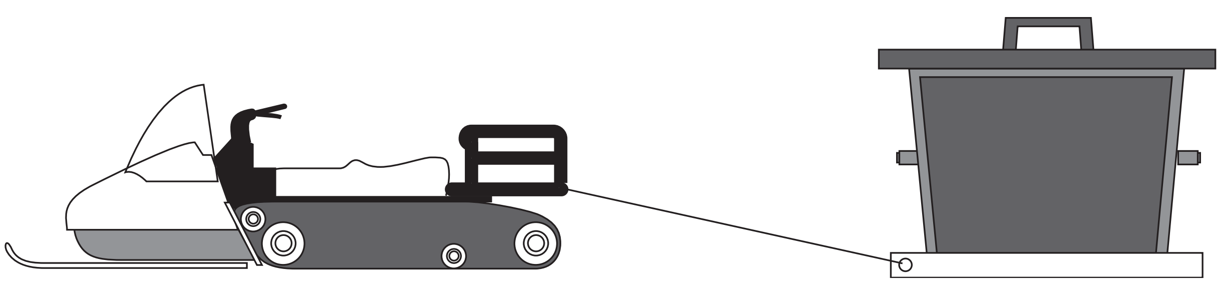
Advantages

There is no community organization needed with level A systems and as such they are the least expensive to operate.

Level B- Honey Bucket - Centralized Collection

Description

Level B systems are those who utilize honey buckets which are dumped in central containers which are then hauled to a dump site by the community. Central metal bins or tanks are placed at strategic locations throughout the community. Individuals dump their honey buckets into the bins. The bins are hauled by ATV, truck or snow machine to a central dump site such as a lagoon or tundra pond.



Disadvantages

Like the Level A systems, this system provides a high potential for contact with human waste and thus a high probability of illness. The major disadvantage is the increased cost for the operation of the haul system.

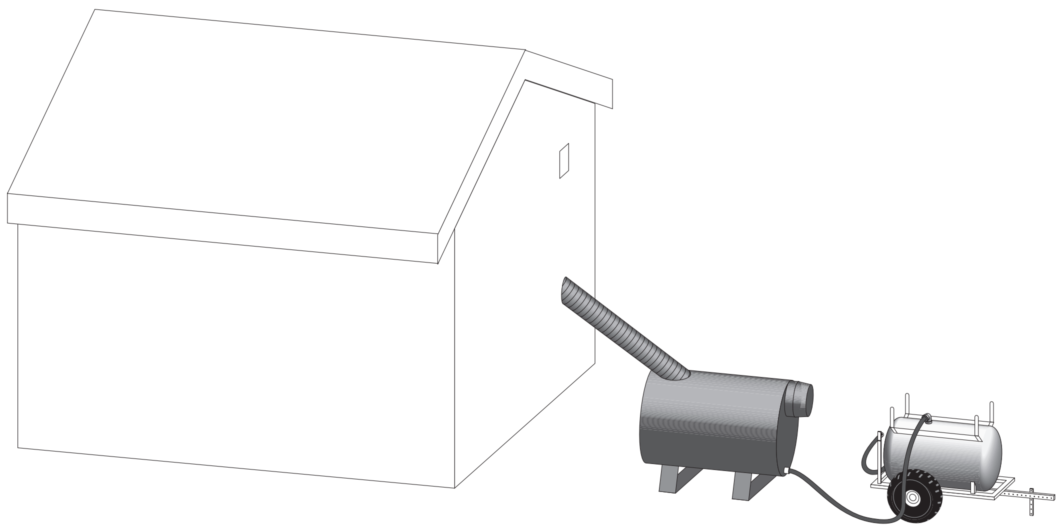
Advantages

The community advantage to the Level B system is that the waste is commonly hauled out of the central area of the village, reducing the contact with humans.

Level C - Haul System

Description

Level C systems use flush toilets and individual wastewater holding tanks. These tanks hold several hundred gallons and can be located inside or outside of the home. The contents of the tank are collected using a vacuum or pressure system on a truck. The contents are then disposed of at a sewage lagoon or tundra pond.



Disadvantage

The major disadvantages are the increase in individual water consumption to operate the flush toilet and the increased cost for the operator and haul truck.

Advantage

The major advantage of this system is the contact with human waste is nearly eliminated. Only the operator of the haul truck contacts the waste.

Level D - Septic Tanks

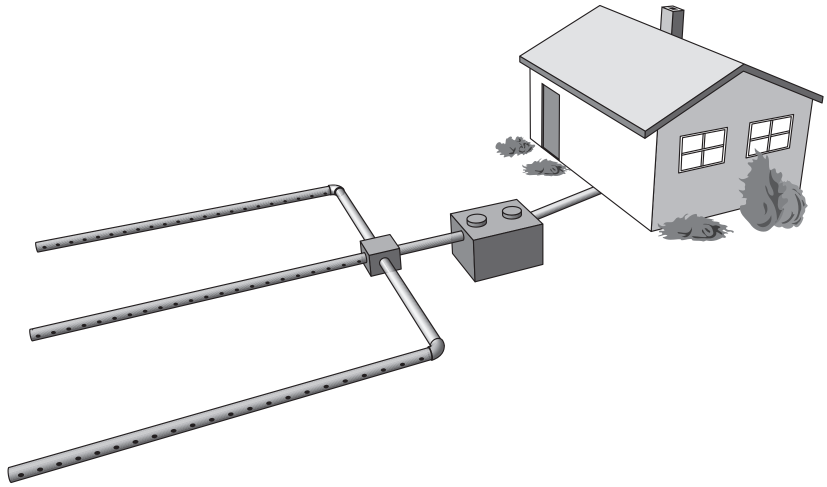
Description

Level D systems are those with flush toilets and individual septic tanks and leach fields. Unfortunately these have limited application in Alaska due to poor soil conditions and **permafrost**[7].

Disadvantages

The disadvantages include increased water consumption to operate the flush toilet and increased cost for pumping and maintaining the septic tank.

[7] **Permafrost -** (PER-ma-fra-st) - Soil, bedrock or other material that has remained below 0°C for two or more years.



Advantages

The major advantage to this system is the near elimination of contact with human waste and thus a reduction in the potential for disease. When soils are suitable, this system is less expensive than Level C systems.

Level E - Piped system

Description

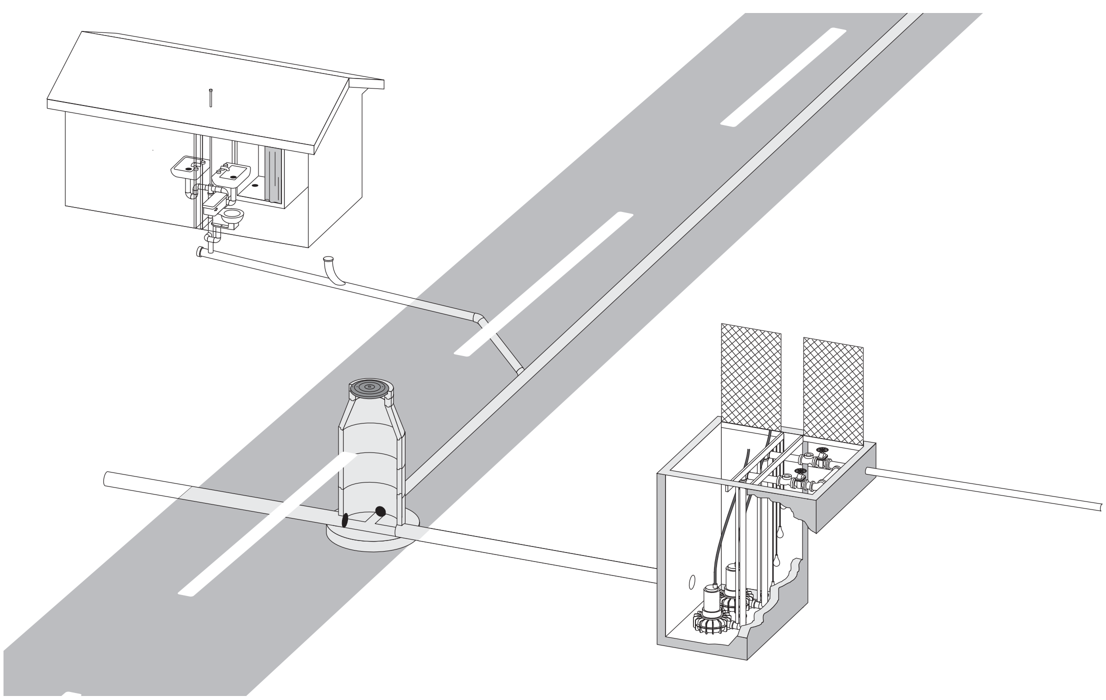
Level E systems are the most complicated and include flush toilets and piped collection systems.

Disadvantages

The major disadvantages include high water consumption to operate the flush toilets, high capital cost for construction, and high cost of operation and maintenance.

Advantages

The major advantage of these systems is the near elimination of contact with human waste.



Summary

Common Systems

While level C, D and E systems are the most desirable in terms of reducing contact with human waste and a reduction in the potential for disease, they are the most costly to operate and maintain. Due to limitations in geology, climate and economics, less than one-half of the village systems in Alaska use level C, D or E systems.

Arctic & sub-Arctic Considerations

In the introduction lesson of this text we discussed eight considerations that impact the cost and feasibility of constructing, operating and maintaining waste-water systems in Arctic and subArctic conditions. Those considerations are:

- Vastness of the area
- Sparse population
- Transportation cost
- Lack of an economic base
- Climate
- Geology
- Lack of previous planning
- Increase in water consumption

For more details see Lesson 1 of this text.

Collection Components - Levels A - D

Introduction

The following discussion is a brief overview of the components that are found in Level A through D wastewater systems. While this lesson focuses on collection systems, we will discuss collection and disposal associated with levels A through D systems. This is provided because of the close connection between collection and disposal in these systems.

Level A Systems

Components

The level A system is composed of individual honey buckets and disposal site. The honey bucket is commonly a five gallon plastic bucket with a plastic bag liner, a toilet seat and a lid.

Disposal

Disposal is done by the individual at a common dump site or individual bunkers. Most bunkers are made by digging a hole in the ground and then lining it with plywood. A lid with access holes are provided at the top. When the pit is full, the plywood is removed and the bunker filled in with soil from a second bunker.

Operation

While it is difficult to do in cold climates, the honey bucket should be disinfected with a chlorine solution or lime after each use.

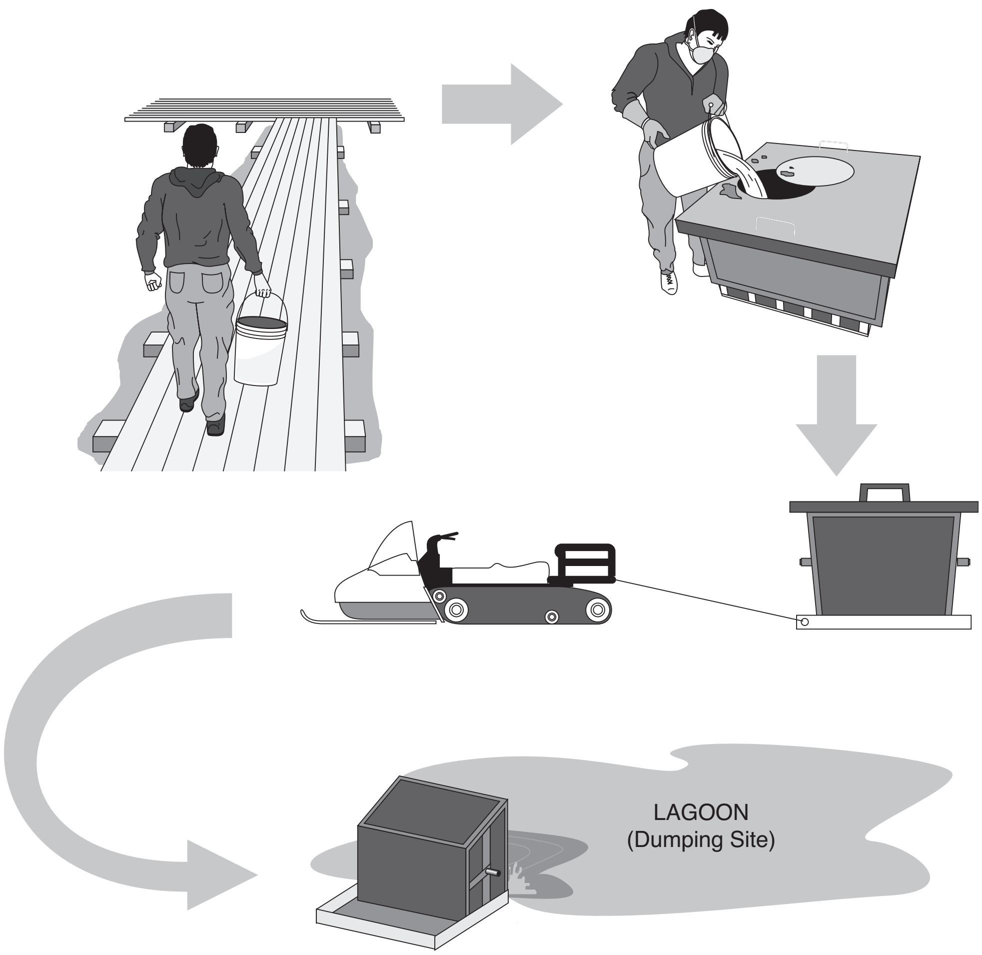
Level B Systems

Components

This system utilizes the same honey bucket system described above. The major difference is the distribution of centralized steel containers with lids placed throughout the community to collect individual homeowner's honey buckets. These containers are placed on a wooden platform.

Transportation

When the container is full, a community employee uses one of several methods to haul the container to a dump site. One of the methods is to use a portable set of wheels designed for the container and a truck or ATV to haul the container to the dump site. In the winter the container may be placed on a sled and hauled with an ATV or snow machine.



Operation

The containers must be cleaned and disinfected with a chlorine solution or lime in the spring and again in the fall just before freeze up. Any spills must be treated with lime. A discussion on the use of lime for disinfection is found in the lesson on disinfection. Any damage to the container must be repaired as soon as possible. The wheel bearings on the trailer wheels should be replaced at least once each year.

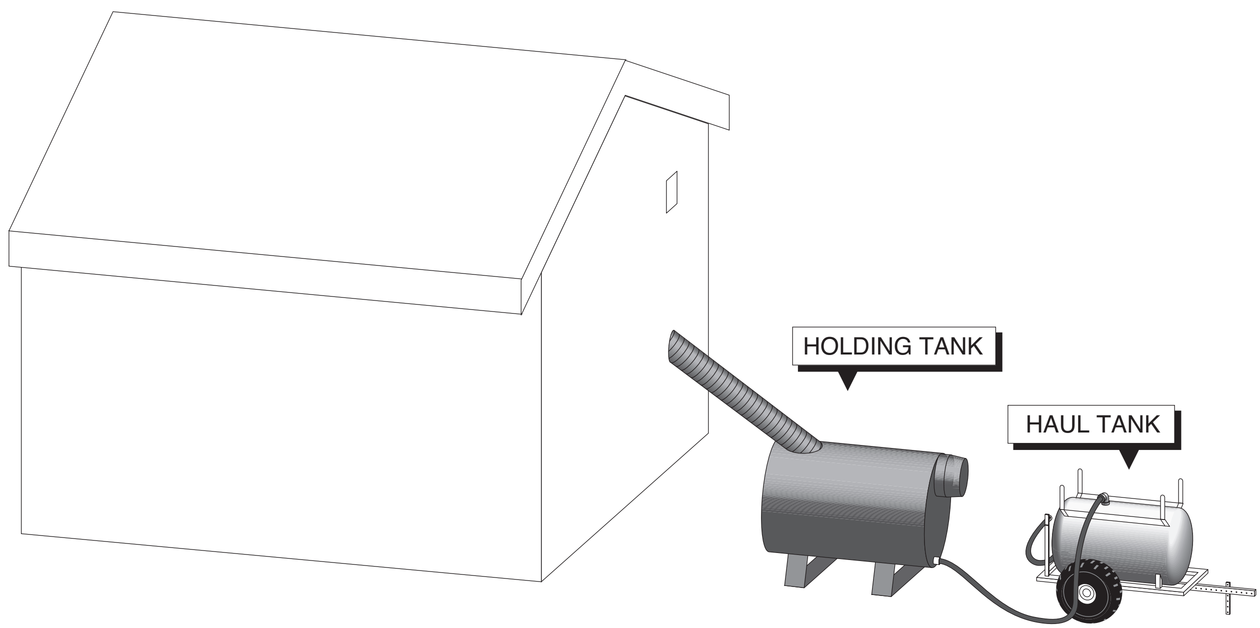
Level C Systems

Internal Components

Level C systems utilize standard household plumbing including standard "P" traps and vents. The fixtures are low water use devices. The toilets may be the newer low water use type or pump toilets.

Tank

A holding tank of several hundred gallons is placed inside or outside of the home. This tank must be insulated to prevent freezing. In some cases, the tank may need to be heated.



Haul System

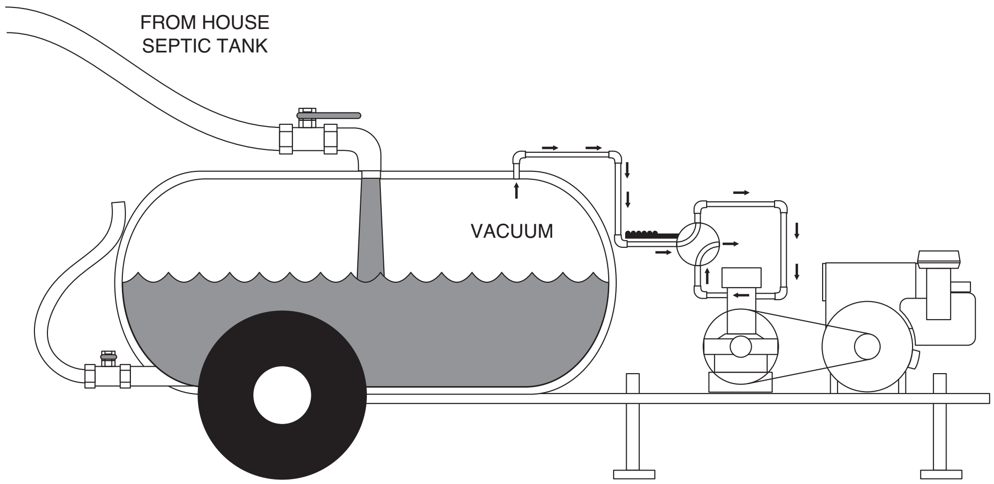
The most common haul system includes a truck or trailer mounted tank and an air pumping system. The pumping system is designed to use a vacuum when filling the haul tank and pressure when emptying. The pumping system is operated by a small internal combustion engine.

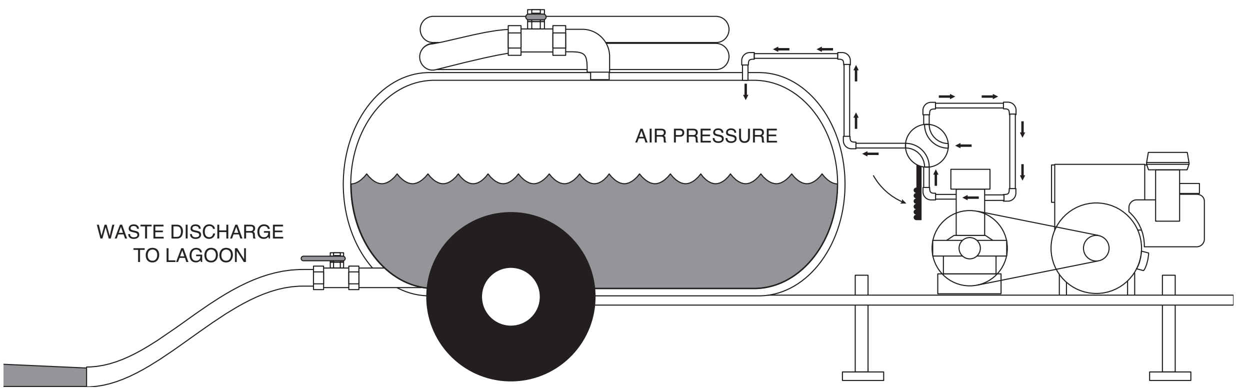
Operation - Filling the Tank

In order to fill the haul tank, a hose is connected between the haul tank and the house tank. The air pump is started and set to provide a low vacuum. The inlet valve on the haul tank and outlet valve on the house tank are opened. Atmospheric pressure flows down the house vent into the house tank where it forces the fluid in the haul tank. Once the house tank is empty, the valves are closed, the pump is shut down and the hose disconnected.

Operation - Emptying the Tank

To empty the tank, a hose is connected from the haul tank to the disposal site. The engine is started and the 4-way valve is rotated to provide pressure on the tank. When sufficient pressure is obtained, the discharge valve is opened and the tank is dumped.





Maintenance

If weather permits, the tank should be flushed with clean water after each use in order to clean the valves and prevent deterioration of the haul tank. The tank and valves should be inspected once a year and disinfected with a chlorine solution or lime. The air pump should be rebuilt once every three years along with the 4-way valve.

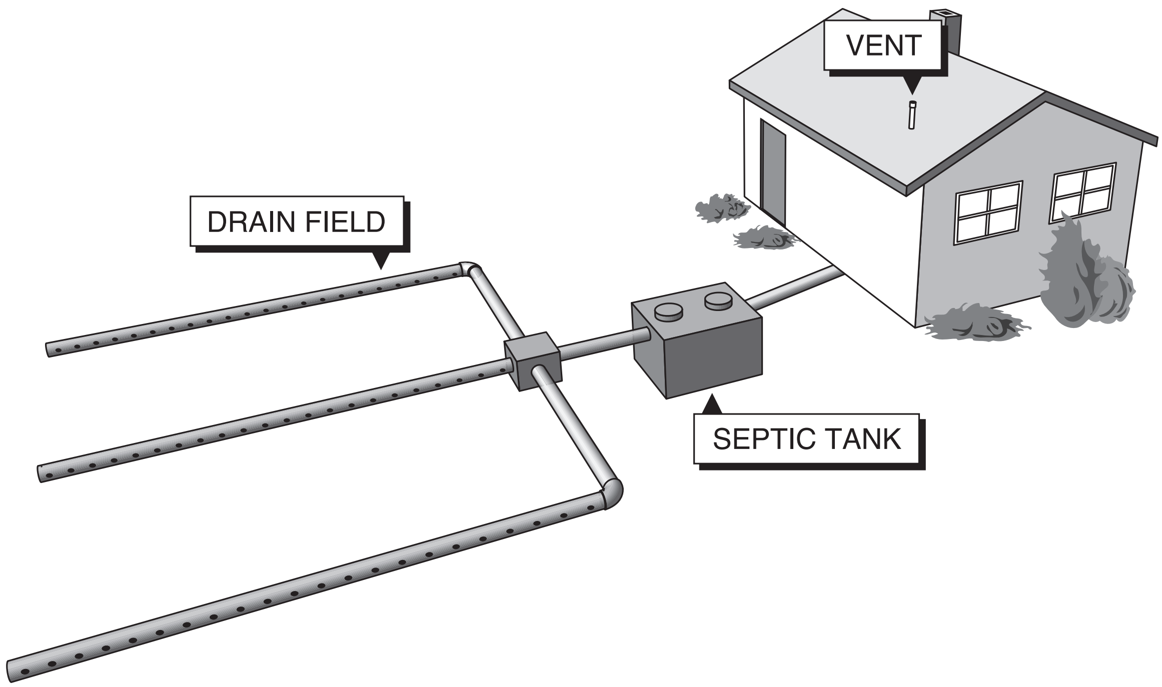
LEVEL D SYSTEMS

Components - House

Standard household plumbing fixtures are used in level D systems, including piping and a vent system. It is best if all fixtures use low water use nozzles. The toilets can be standard low water devices or pump toilets.

Septic Tanks

The operation and maintenance of septic tanks is discussed in the lesson on treatment.



Collection System Components - Level E

Types of Systems

Level E systems include three types of piped collection systems. They are:

- Gravity systems
- Pressure systems
- Vacuum systems

Each of these systems will be discussed individually.

Gravity System

Piping

Building Sewer

Description

The gravity system starts at the individual building with the **building sewer**[8]. This system is composed of the standard household piping system and extends to 2 to 10 feet from the building. Four inch plastic or cast iron pipe is commonly used for the building sewer.

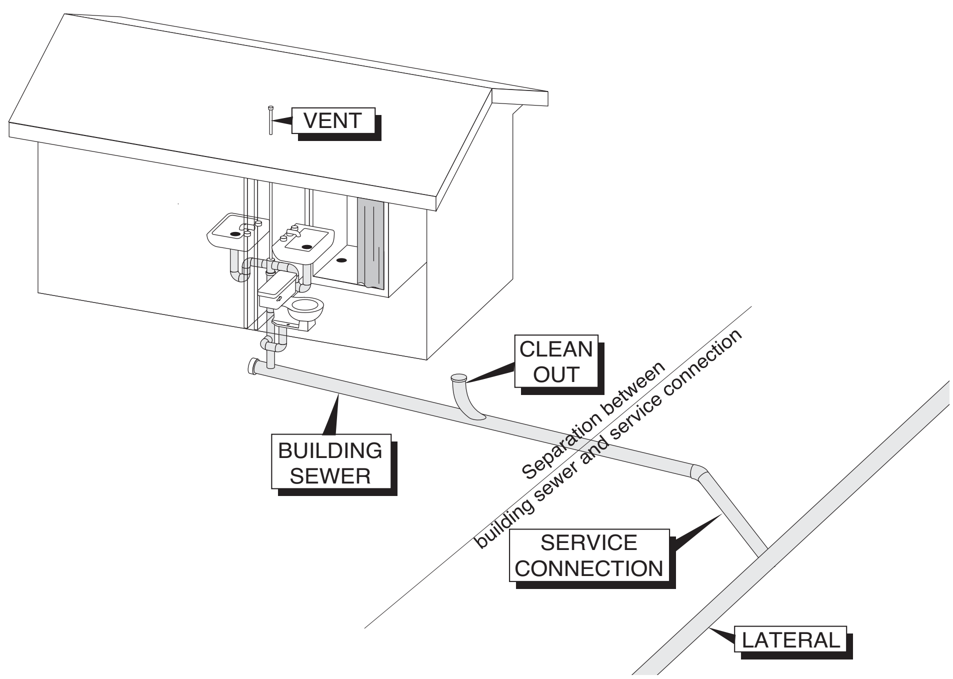
Vent

The building vent provides two functions:

- Allows gases that are formed in the collection system to exit into the atmosphere and not into the house.
- Allows air to enter the collection system thus helping to maintain constant flow.

Maintenance

The maintenance of the building sewer is the responsibility of the home owner.



[8] **Building sewer** - A gravity, pressure or vacuum flow pipeline connecting a building wastewater collection system to a lateral or branch sewer. The building sewer may begin at the outside of the building's foundation wall or some distance (such as 2 to 10 feet) from the wall, depending on local sewer ordinances.

Clean-Out

A properly installed building sewer has a clean-out placed just outside of the building. This allows access to remove a **blockage**[9] in the line between the building and the street, should one occur.

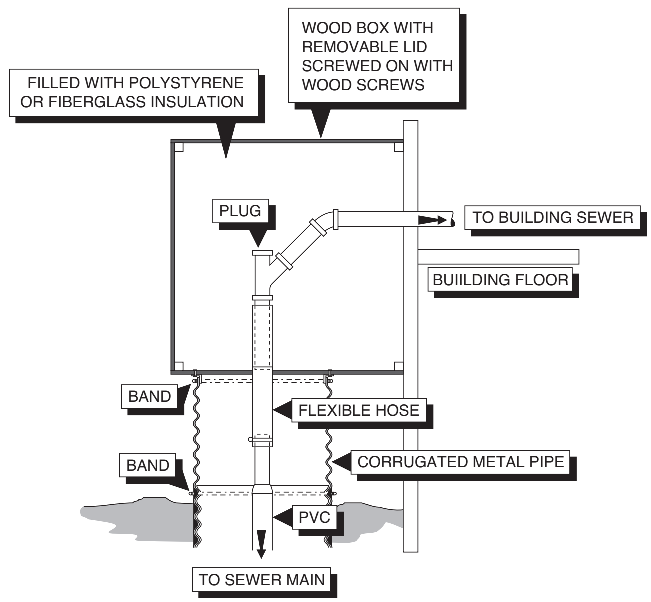
Service Connection

Description

A service connection is the connection between the building sewer and the lateral (the line in the street). Service connections are typically made of four or six inch plastic, **AC**[10] or **vitrified clay pipe**[11].

Arctic Connections

In Arctic conditions, the collection system lines are not always buried underground. Therefore, special household connections are used. These connections provide easy access for maintenance. They are designed to prevent freezing and to flex in order to prevent breakage during frost heave.



Connections

Services are connected to lateral, branch or main sewers with tees, wyes or a saddle. Tees and wyes are fittings that can be installed when the branch sewer is being constructed. A saddle is a means of connecting to the sewer after the line has been installed.

9 **Blockage** - When a collection system becomes plugged and the flow backs up, it is said to have a blockage.
10 **AC - Asbestos Cement** - A piping material made from Portland cement, long fiber asbestos and silica sand. The pipe is formed on a spinning anvil and cured in an autoclave. Also referred to as AC pipe and Transite™.
11 **Vitrified Clay Pipe** - A piping material made from clay and shale. The mixture is extruded through a die to form a pipe section. Each section is allowed to dry and then fired in a kiln.

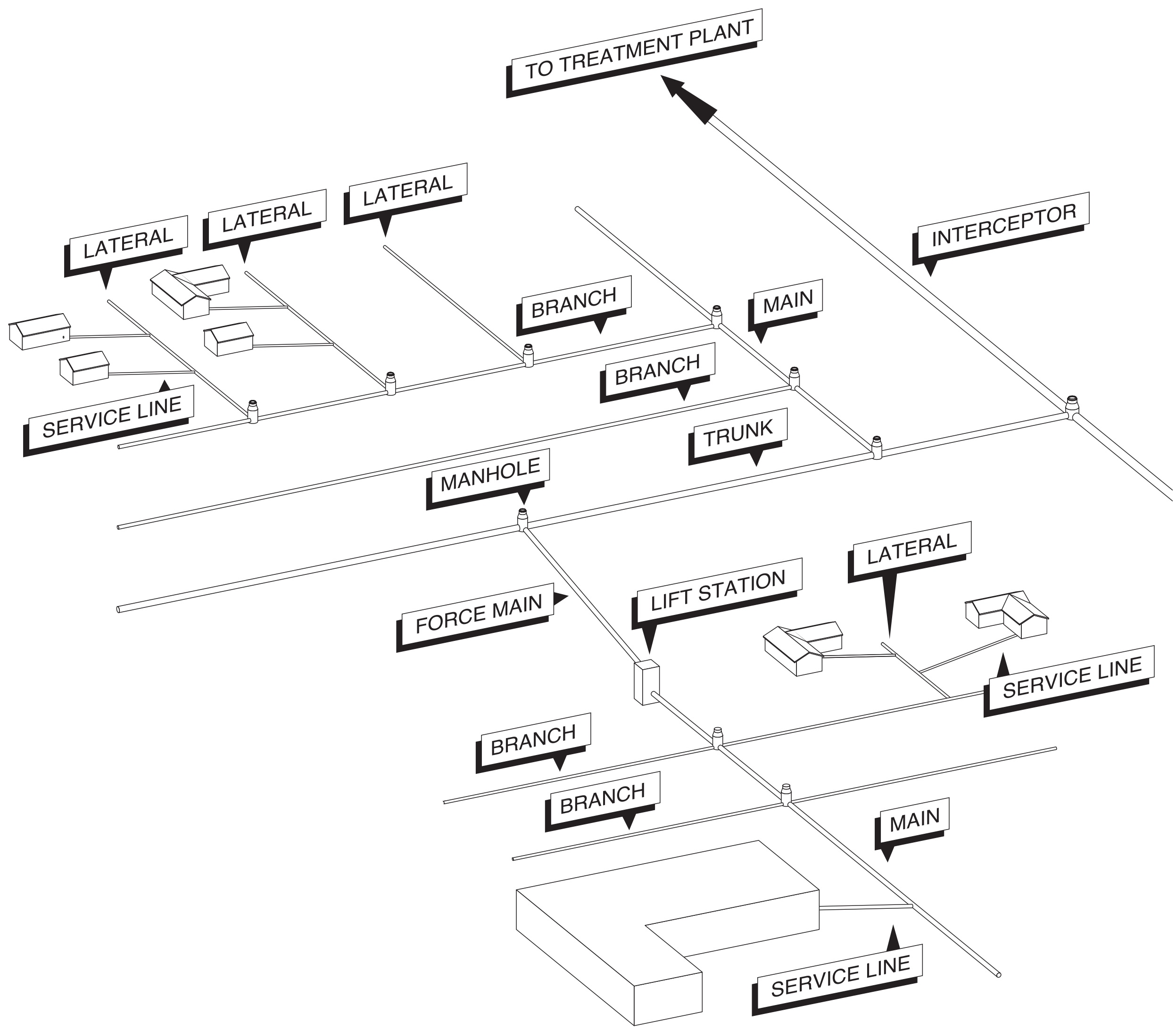
Laterals

Description

Lateral sewers[12] collect sewage from one or more individual buildings and connect to a **branch sewer**[13]. Lateral sewers are located in the street or in easements. A lateral is also called a side sewer. Lateral sewers are typically made of six inch or larger piping. In order to allow easy access for connections, the lateral sewer is typically laid down the center of the street. In Arctic conditions, where above ground utilidors are used, the branch sewer may run along the back of the houses.

Connections

Lateral sewers connect to branch sewers. The connection between the two is at a **manhole**[14].



12 **Lateral Sewer** - A sewer that discharges into a branch or other sewer and has no other common sewer tributary to it. Sometimes called a side sewer.
13 **Branch Sewer -** A sewer that receives wastewater from a relatively small area and discharges into a main sewer serving more than one branch sewer area.
14 **Manhole** - An opening in a sewer provided for the purpose of permitting workers or equipment to enter or leave a sewer.

Branch Sewers

Description

Branch sewers are located in the street. They are usually constructed of a six inch or larger pipe and connect two or more lateral sewers. In order to allow easy access for connections, the branch sewer is typically laid down the center of the street. In Arctic conditions, where above ground utilidors are used, the branch sewer may run along the back of the houses.

Connection

Branch sewers flow into **main sewers**[15]. The connection between the two is at a manhole.

Main Sewer

Description

A main sewer carries wastewater from two or more branch sewers. Main sewers connect into trunk sewers. Main sewers are commonly six inches and larger.

Trunk Sewers

Description

Trunk sewers connect two or more main sewers to the wastewater treatment plant or disposal site.

Interceptor Sewer

Description

An interceptor sewer is one that has been installed in a system to connect (intercept) one or more lines that use to flow directly into the ocean or a stream. The interceptor sewer flows to the treatment plant.

Force Main

Description

Most of the flow in a standard collection system is the result of gravity. However, the line leading away from a **lift station**[16] is under pressure and is called a **force main**[17]. Force mains connect to manholes and are made of 4 inch or larger DCIP, HDPE or PVC pipe.

Piping Material

Six Materials

The piping used for laterals, branch sewers, main sewers and interceptor sewers is made of one of six materials. These materials are:

- Vitrified clay (VCP)
- Concrete (CP)
- Ductile Cast Iron (**DCIP**[18])
- Asbestos Cement (AC)
- Polyvinyl Chloride (**PVC**[19])
- High Density Polyethylene (**HDPE**[20])

15 **Main Sewer** - A sewer line that receives wastewater from many tributary branches and sewer lines and serves as an outlet for a large territory.

16 **Lift Station** - A wastewater pumping station that lifts the wastewater to a higher elevation. Also called a pump station.

17 **Force main** - A pipe that conveys wastewater under pressure from the discharge side of a pump to a point of gravity flow downstream (usually a manhole).

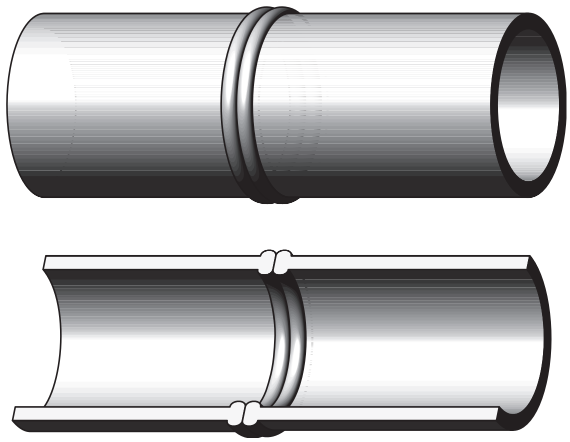
18 **DCIP - Ductile Cast Iron Pipe** - Ductile pipe is made by injecting magnesium into the cast iron during the molding process. The magnesium alters the shape of the carbon structure of the cast iron. This gives the pipe superior beam strength. It will resist high impacts and is more corrosion resistant than gray cast iron.

19 **PVC** - Polyvinyl Chloride - A piping material used to make plastic pipe. The manufacturing process uses an extruding mold to form a continuous pipe that is cut into the desired lengths.

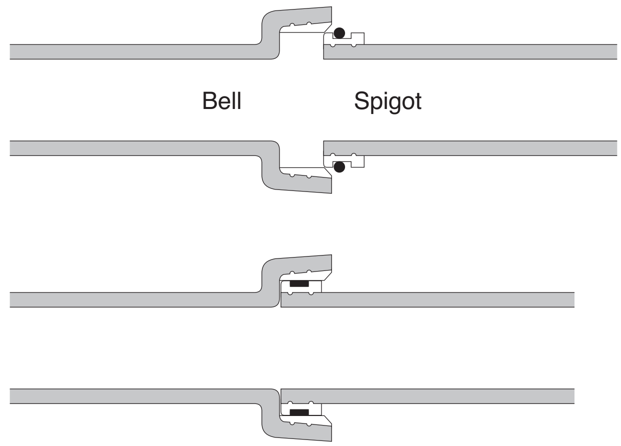
20 **HDPE** - High Density Polyethylene pipe - HDPE is manufactured using a heat extrusion process and polyethylene resins.

Joints

While several types of joints have been developed over the years, the most common joint used is the bell and spigot joint with a rubber ring. The rubber ring forms the seal between the bell and spigot. Special solvent weld fittings may be used with PVC. The HDPE pipe is typically connected using a heat fuse weld process.



HDPE - Heat Fused Joint



Vitrified Clay - Bell & Spigot Joint

The following is a chart of the common piping materials and their features.

Type of Pipe	Identification on Construction Drawings	Common lengths	Common Size range	Joints	Advantage	Disadvantage
Vitrified Clay	VC or VCP	2' & 5'	3" - 40"	Bell & Spigot	Resistant to corrosion	Easily broken
Concrete	CP	3'	4" - 100"	Bell & Spigot	Cost, resistant abrasion	Subject to corrosion
Ductile Cast Iron	DI or DCIP	18' & 20'	3" - 54"	Bell & Spigot	Not easily broken	Weight
Asbestos Cement	AC or ACP	13'	3" - 36"	Rubber ring coupling	Cost	Easily broken
Polyvinyl Chloride	PVC	20'	4" - 24"	Bell & Spigot solvent weld	Light weight Resistant to corrosion	Easily crushed
High Density Polyethylene	HDPE	20' & 40'	3/4" - 16"	Heat fuse	Won't break when frozen Resistant to corrosion	Cost - special equipment & training to make connections

Flow Considerations

The design engineer considers line size, slope and material type so that the velocity in the line is maintained at 2 feet per second or greater. When the velocity falls below this point, solids are deposited along the bottom of the pipe. This leads to the development of hydrogen sulfide which will then be converted to sulfuric acid and destroy the top of the pipe, manhole steps and pumps.

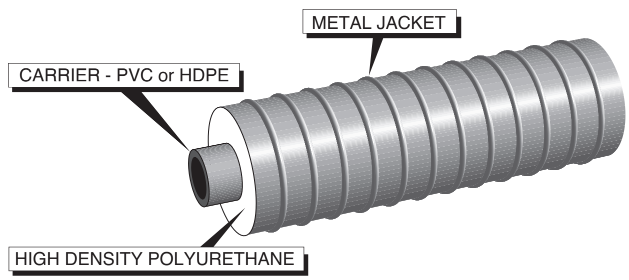
Arctic Pipe

Description

Arctic pipe[21] is a general name given to piping material that is made of three components; an inside pipe called a carrier, several inches of high density polyurethane or polystyrene insulation that protects the carrier and an outside protective layer. The most common carriers are made of PVC or HDPE. The outside cover can be made from a variety of materials. The two most common are polyvinyl chloride butyl rubber and 16 gauge corrugated steel or aluminum.

The polyvinyl chloride butyl rubber coating is commonly used in underground installations and the corrugated steel is the most commonly used in above ground installations.

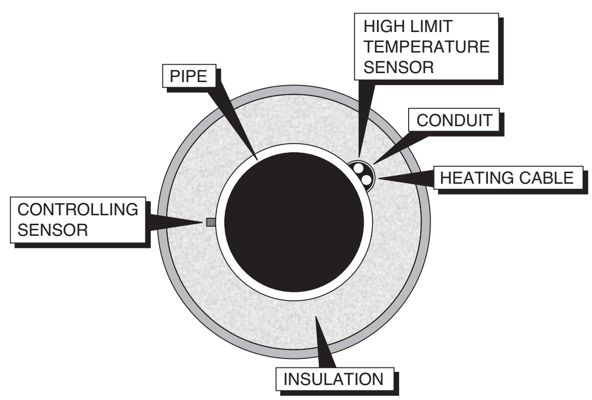
Arctic Pipe



Heat Trace

Arctic pipe can be purchased with a built in heat trace tape designed to prevent freezing in extreme conditions. This tape can be installed in the field or at the factory. The tape is placed against the carrier and electrical connections need to be made at each joint.

Arctic Pipe With Heat Trace



[21] **Arctic Pipe** - PVC or HDPE pipe, called the carrier, coated with several inches of high density polyurethane or polystyrene insulation. The outside of the insulation is covered with polyvinyl chloride butyl rubber or 16 gauge corrugated steel or aluminum.

Size

The Arctic pipe industry makes insulated pipe from all of the popular piping materials and in the normal size ranges. In Alaska's rural communities, the most common carriers are 160 psi, 2 inch through 6 inch HDPE. Insulation thickness varies from 1 to 3 inches depending on the expected temperature around the pipe. The exterior material varies from a 20 mil laminated polyvinyl chloride butyl rubber coating to 16 gauge steel or aluminum.

Joints

The joints for the HDPE carrier are made of HDPE and are connected with a heat fused weld. The joints for the polybutyl cover are made by installing insulation over the carrier, wrapping the insulation with the tape and covering the tape with an epoxy. Joints for the corrugated cover are made by using a two piece cover that is placed around the joint and bolted together.

Fittings and Special Devices

Introduction

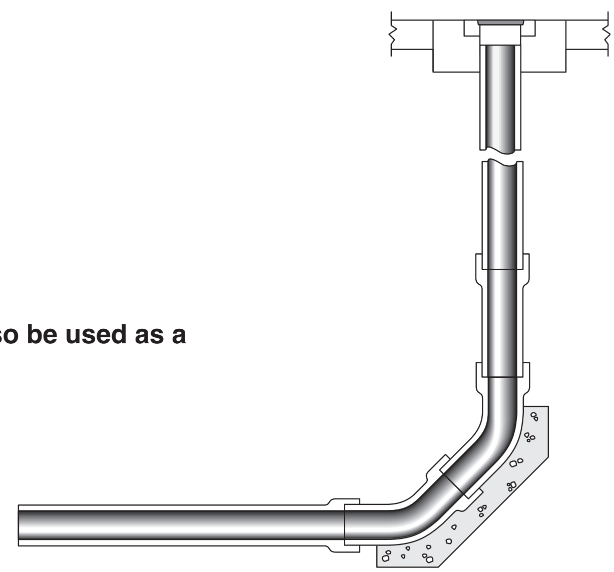
Along with the piping, the collection system is composed of various special fittings and manholes. Each of these devices has some specific function.

Cleanouts

Cleanouts[22] are installed at buildings and on dead end lines in place of manholes. They allow access for inspection and line cleaning.

Flush Branch

Flush branch connections are found in older sewers. They were used as access points to flush the line.

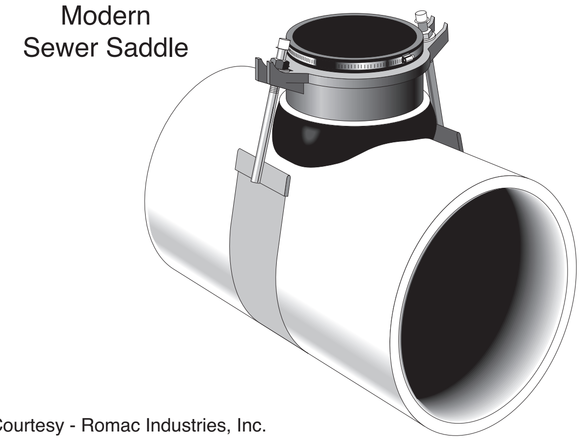


Flush Branch may also be used as a cleanout.

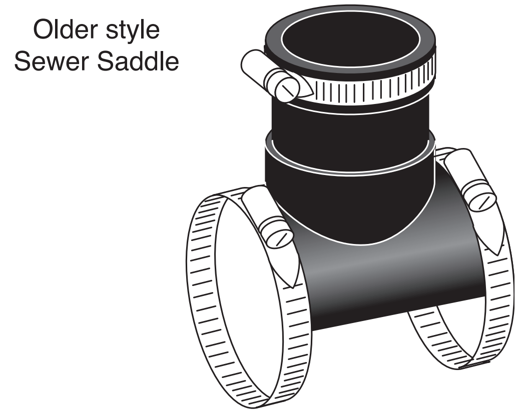
22 **Cleanout -** A point of access to a wastewater collection system for insertion of tools, rods or snakes to effect pipeline cleaning.

Tap

A sewer tap is a means of connecting to an existing sewer line. A hole saw is used to make a hole in the sewer line. The saddle is a pliable device that is placed over the hole and held in place by clamps making a watertight joint.

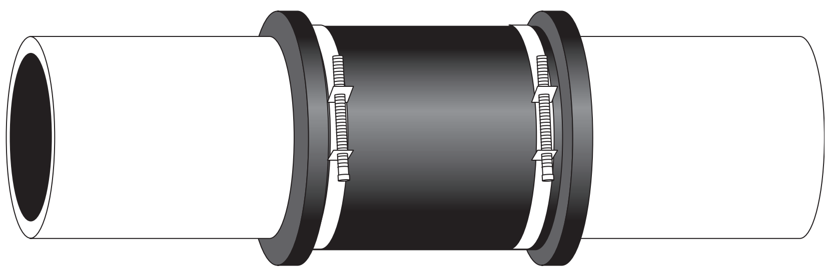


Courtesy - Romac Industries, Inc.



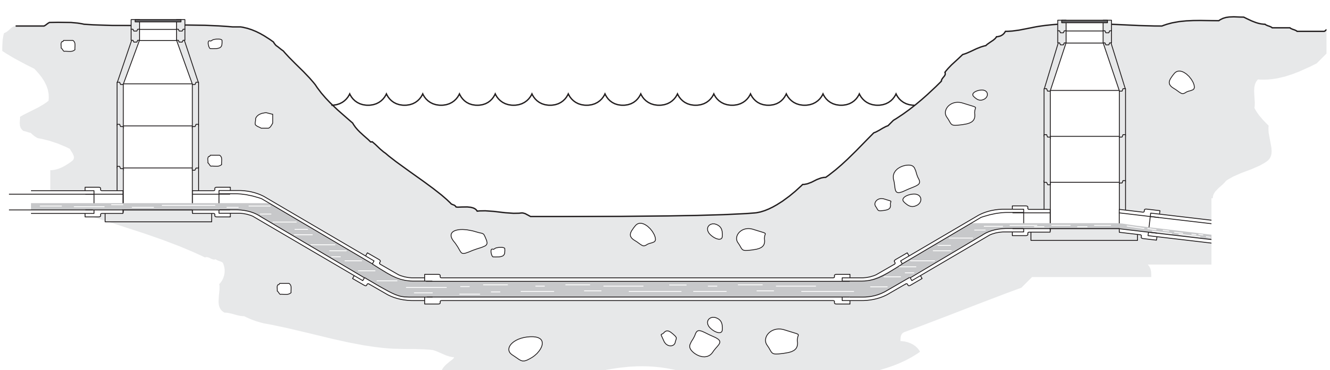
Calder Coupling

Calder couplings are flexible couplings that use a rubber like liner and two clamps to connect two pipes together. They are commonly used in repair of broken pipes or connecting two pipes of different sizes.



Inverted Siphon

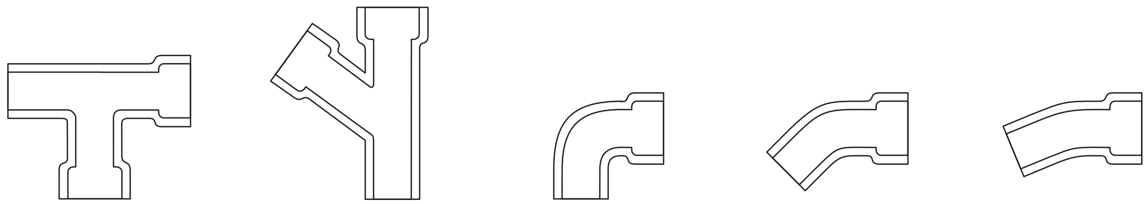
An inverted siphon is a section of sewer line that is used to carry wastewater under a depression, such as a stream, storm sewer or large water line.



Fittings

Fittings are rarely used on any sewer lines other than service connections and building sewers. There are five common fittings used. They are:

- Tee's
- Wye's
- 90° bend, also called a 1/4 bend
- 45° bend also called a 1/8 bend
- 22 1/2° bend also called a 1/16 bend.

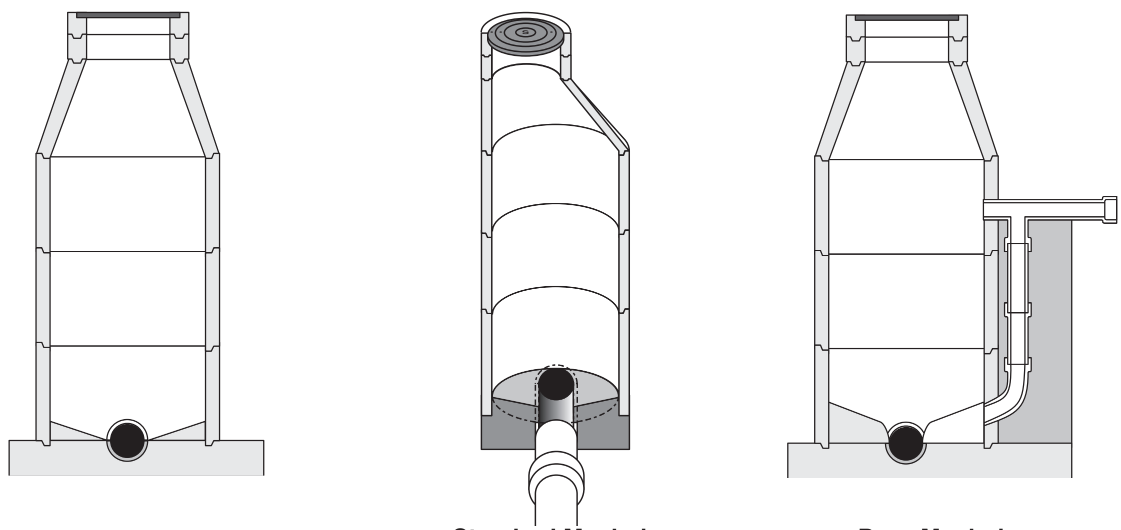


Tee Wye 90° 45° 22 1/2°

Manholes

Types

There are three types of manholes used in Alaska: the standard manhole, drop manholes and special Arctic manholes.



Standard Manhole Concentric cone **Standard Manhole Eccentric cone** **Drop Manhole Concentric cone**

Drop Manholes

Drop manholes allow the connection of a lateral that is at a much higher elevation than the main. The drop can be placed outside or inside the manhole. When plugged the outside drops are more difficult to clean.

Function

Manholes are installed in a collection system in order to provide access for line maintenance and inspection.

Location

Manholes are located at each change in direction of the sewer line, major changes in grade (slope of the line) and at connections between laterals and branch sewers, branch and main sewers and main and trunk sewers. Manholes are also located every 400 feet on lines less than 15” in diameter and every 500 feet on lines 18” and larger.

Standard and Drop Manhole Components

Base

Standard and drop manholes are commonly made of concrete. A concrete bottom or base is poured in the bottom of an excavation.

Flow Channel

Formed in the base is a “U” shaped channel called the flow channel. The flow channel is also called the invert. This channel improves the hydraulics through the system and prevents the buildup of solids in the manhole.

Barrel Sections

Placed on top of the base are precast concrete barrel (also called risers) sections. These sections are commonly three feet tall. The joints between each section are sealed with grout to prevent groundwater from entering the manhole.

Top Section

Placed on top of the barrels is a top section also called a cone. This top section is made of concrete and is either an **eccentric**[23] or **concentric**[24] cone. In order to prevent groundwater from entering the manhole, the top section is grouted to the riser section.

Lid Ring

At the top of the manhole is a lid ring made of cast iron. This ring is used to hold the manhole cover. The ring is grouted to the cone with a flexible material called mastic.

Lid

Standard manhole lids or covers are made of cast iron and are either 22 or 24 inches in diameter. Lids may or may not have vent holes.

Rings

When the level of a street is raised, it is necessary to raise the manhole cover. This is accomplished by removing the lid ring and installing a concrete riser ring and then reinstalling the lid ring. These riser rings are manufactured in 2”, 3” and 4” heights.

Steps

Many manholes are installed with steps built into the sides of the cone and riser sections. These steps may be made of steel, galvanized steel or stainless steel. While these steps provide easy access into the manhole, they are also a safety hazard. The presence of hydrogen sulfide in the sewer can rapidly deteriorate the steps. They most often rust close to the concrete and thus the damage is not easily seen until it is too late. With older collection systems, it is a common practice to remove these steps and use a portable ladder for safe easy entry.

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[23] **Eccentric Manhole Cone** - A cone that tapers non-uniformly from the barrel to the manhole ring. One side is usually vertical.

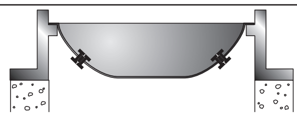
[24] **Concentric Manhole Cone** - A cone that tapers uniformly from the barrel to the manhole cover ring.

Bench

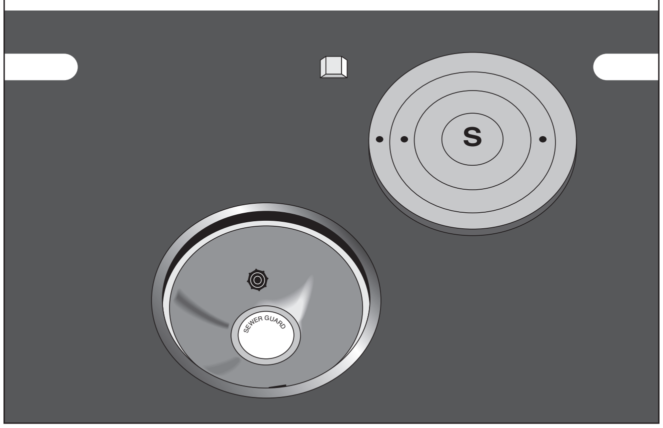
In order to have a location to install flow measuring equipment, a concrete bench is often installed in large manholes.(The bench is not shown on any of the drawings in this text.)

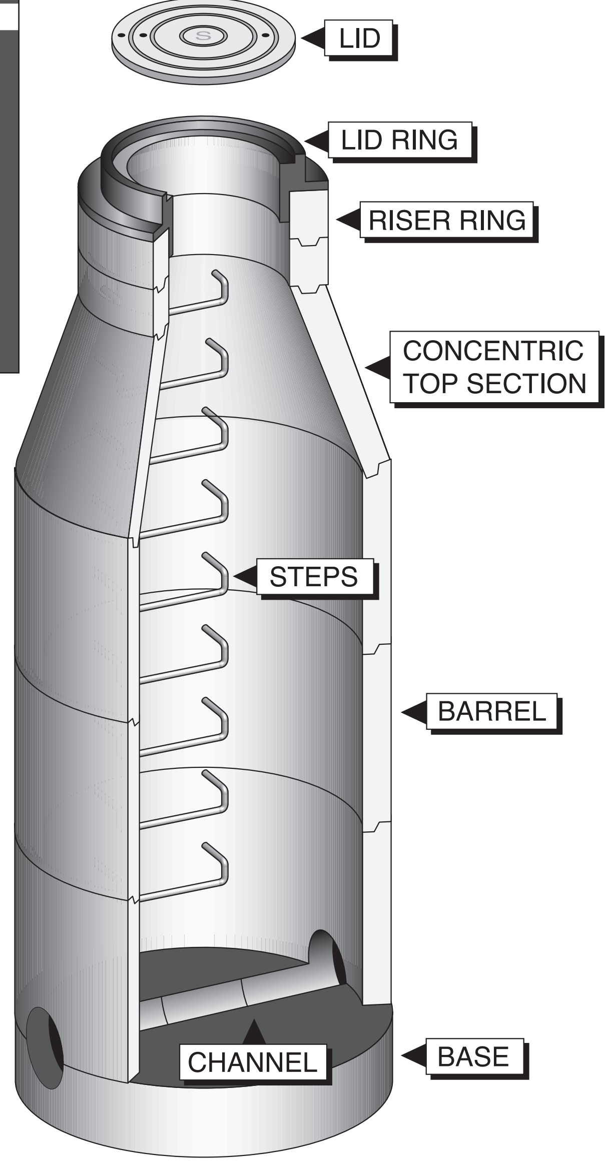
Inserts

In areas such as southeast Alaska that receive high quantities of rain a plastic device called an insert can be placed in the manhole lid ring. This device reduces the amount of water that flows into the manhole through the lid while allowing gases to escape through valves in the sides or bottom of the insert.



Cross-section of manhole insert.





Arctic Manhole Components

Why?

Precast concrete manholes that were described above are very expensive to ship to remote locations because of their weight. Built on-site manholes using corrugated steel culvert have proven adequate and less expensive.

Base

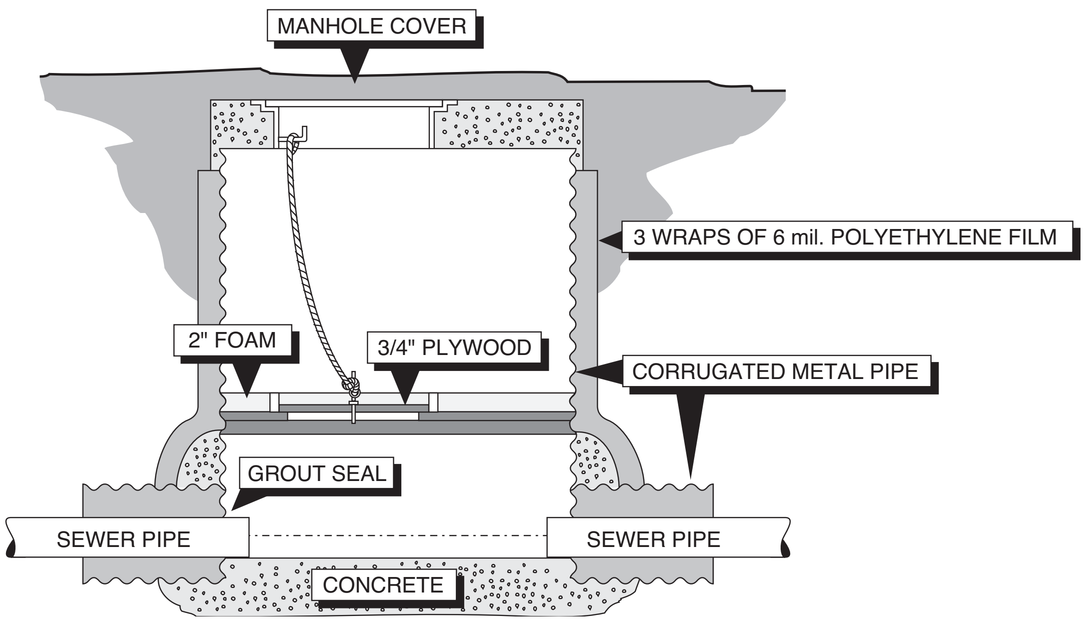
The base of the manhole is poured concrete with a flow channel as described above. The concrete may be placed on piling or on a bed of gravel covered by insulation. The insulation reduces heat loss down through the concrete. Arctic pipe is cast into the base and forms the inlet and outlet of the flow channel.

Riser - Exterior

The riser section is made of corrugated steel 3.5 to 4 feet in diameter. The length can be cut on the job site. The exterior of the manhole is covered with three inches of Styrofoam or urethane insulation and triple wrapped with polyethylene. The polyethylene wrap reduces damage as a result of frost heaving.

Riser - Interior

A galvanized steel angle iron ring is bolted near the bottom of the riser to hold the frost lid. A frost lid made of 3/4” plywood covered with 2 inches of insulation is placed on this ring. This lid helps hold the heat in the water and reduces freezing.



Top - Traffic Conditions

When the manhole is placed in a street, the top is made of precast concrete with the manhole lid ring cast in place. The top is then placed at least six inches under the street level.

Lid - Traffic

In traffic conditions, the manhole lid is a standard 22 inch or 24 inch cast iron lid.

Top & Lid- Nontraffic

In nontraffic conditions, the top and lid may be one or two pieces made of galvanized sheet metal with two to three inches of insulation placed on the inside.

Utilidors

Functions

Utilidors are used in some Arctic locations to house and protect water distribution and sewer collection systems. The utilidor also provides access for maintenance to piping, valves and fire hydrants.

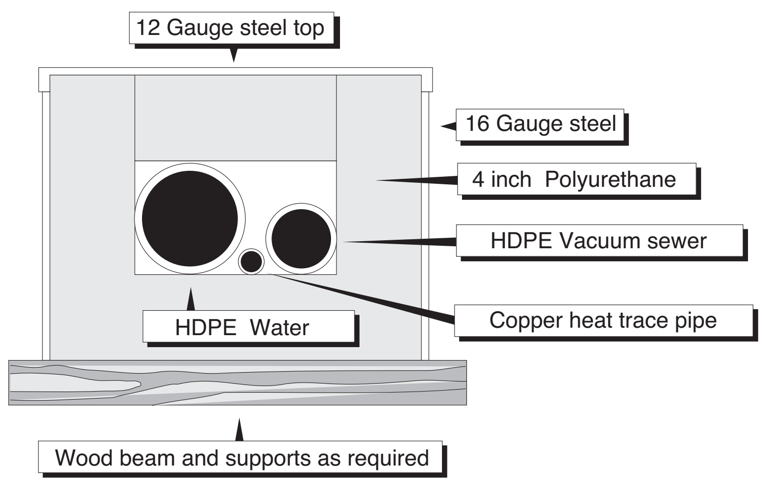
Materials

There are three types of utilidors: those made with concrete, those made with wood and those made with Arctic pipe. The concrete utilidors are usually installed underground, such as in Fairbanks. Concrete utilidors are not very common because of their cost. They usually serve a large variety of utilities such as water, sewer, electricity, phone, TV cable and commercial heat.

Wood Utilidors

Wood utilidors are more popular than concrete but still not very common. The cost of construction is their major disadvantage. There are two types of wooden utilidors; those constructed of plywood and insulated on the inside with high density polyurethane or polystyrene and those made of laminated planks and insulated on the outside (such as in Barrow). Wood utilidors can be installed above or below ground. One of the major problems with below ground utilidors is flooding from a water or sewer line failure or leakage from the outside during spring and summer months.

Above Ground Plywood Utilidor



Arctic Pipe Utilidors

One of the most common utilidor systems is that made with Arctic pipe. Standard Arctic pipe made with PVC or HDPE carrier, and 16 gauge corrugated steel coating is used. The sewer line is laid inside of the carrier. The carrier may also contain, water lines and heating lines or heat trace tape. Arctic pipe utilidors may be installed above or below ground.

Heating Utilidors

Utilidors are commonly heated with a hot water or a heated propylene glycol loop from a low pressure boiler and heat exchanger, from a forced air heating system, or from self regulating heat trace tapes.

Service Connections

Service connections from the utilidor to the customer are made using Arctic pipe containing all of the services. The Arctic pipe is sealed to the utilidor.

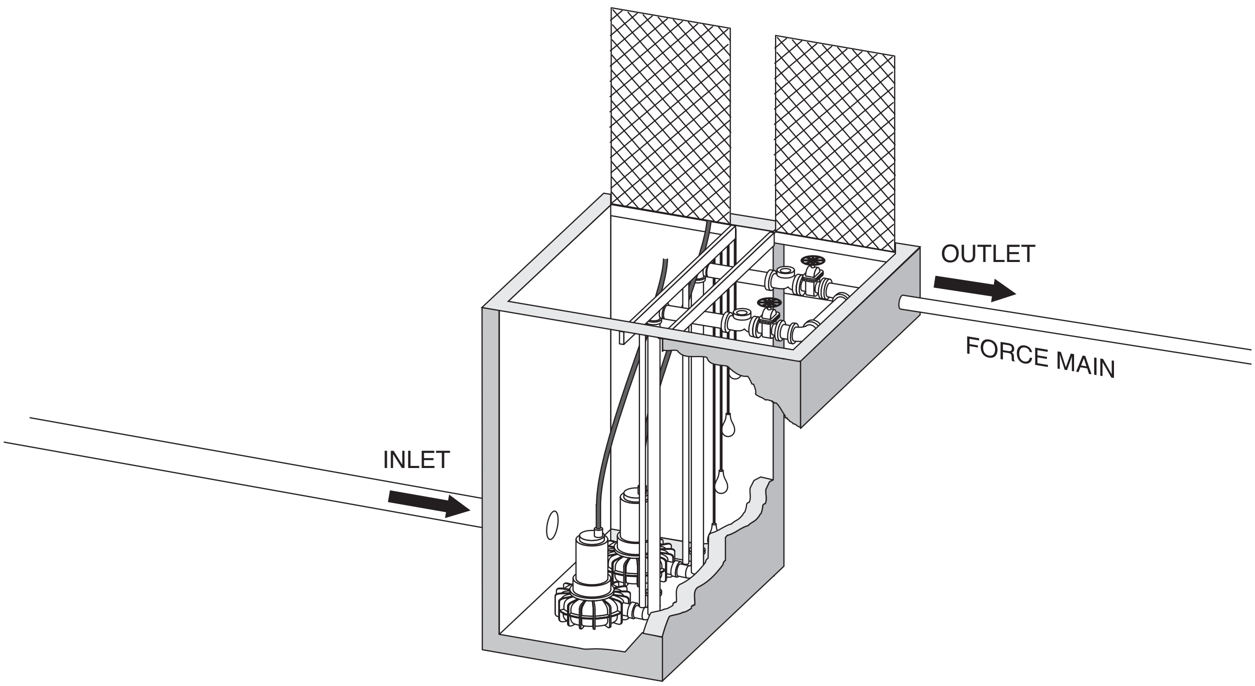
Lift Stations

Introduction

In this portion of the lesson we provide only a brief overview of lift stations. A discussion of the various types and their components is found later in this lesson.

Function

A lift station contains a tank, pumps and electrical controls. The pump is used to move wastewater from its present location to a higher elevation so that gravity can be used to move it further along its way.



Why Installed?

Lift stations are installed when:

- The topography of the land does not allow gravity flow from the individual connections to the treatment plant.
- In order to maintain a gravity flow to the plant, the line must be buried excessively deep.

Flow Description

With a lift station, wastewater flows into a tank where it is pumped out. The wastewater exits the lift station through the force main where it is pumped to a manhole. From the manhole it flows by gravity to the treatment facility or to another lift station.

Pressure System

Types

There are several types of pressure systems. Our discussion here will include two types:

- Individual home pumping systems and
- Central pumping systems

Individual Home Pumping

Basic Components

The individual home pumping system starts with a tank and pump at each home. The pump is a grinder type that shreds any solid material before it enters the pump.

Controls

The system is equipped with some type of control system, usually a float switch, that turns the pump on and off and sends an alarm should the water level in the tank exceed a predetermined safety level.

Piping

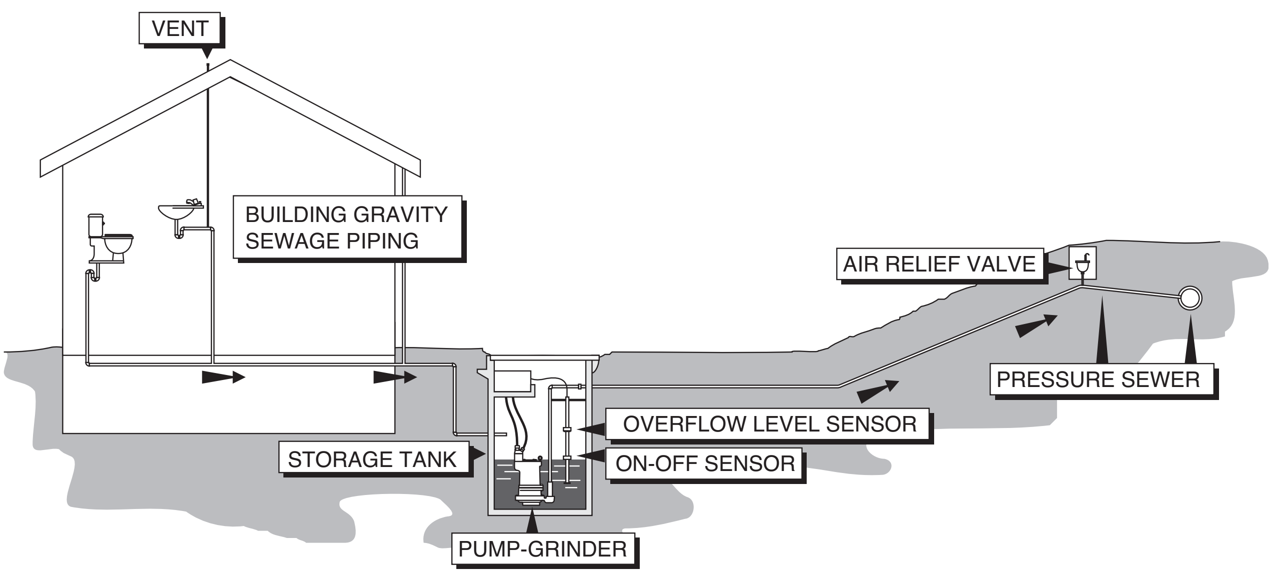
A **check valve**[25] is installed on the inlet to the tank to prevent wastewater from backing up into the house. A check valve is installed on the discharge of the pump to prevent sewage from the collection system from flowing into the tank.

Pumping Process

The individual house pump, pumps the wastewater into a pressure main which flows to the treatment plant or to a secondary lift station. With this type of system nearly all of the collection system piping is under pressure.

Air Relief Valves

To prevent an accumulation of air in the lines, which can stop flow, special air relief valves are installed at high points in the pressure line.



[25] **Check Valve** - A special valve with a disc, flap or ball designed in a way so that it opens in the direction of normal flow and is forced shut when flows attempt to go in the reverse or opposite direction of normal flows.

Advantages

A pressure system offers the following advantages:

- The main lines are smaller (2 inch is normal) thus reducing capital construction cost.
- Overall construction costs are less than gravity and vacuum systems.
- The major O & M costs are shifted from the community to the homeowner.
- The water use can be reduced if low water use toilets are used. Because the homeowner is paying all pumping costs, it is fairly easy to convince them to reduce water consumption.

Disadvantages

The pressure system provides the following disadvantages.

- The electrical cost for pumping is passed on to the customer increasing their overall electrical bill.
- The repair and maintenance of the pumping system is the responsibility of the homeowner. The homeowner may choose not to provide the proper maintenance thereby creating a health hazard.
- When an in-ground tank is used, it is subject to damage by frost heaving.

Central Pumping

With this system, wastewater flows from the individual homes to a small lift station by gravity. One lift station only handles a few homes. Wastewater is pumped from the lift stations directly to the treatment plant.

Vacuum System

When Used?

Vacuum systems are used when soil conditions or topography do not allow the use of gravity systems. Two communities using vacuum systems in Alaska are Noorvik and Emmonak.

Basic Components

Vacuum Pump System

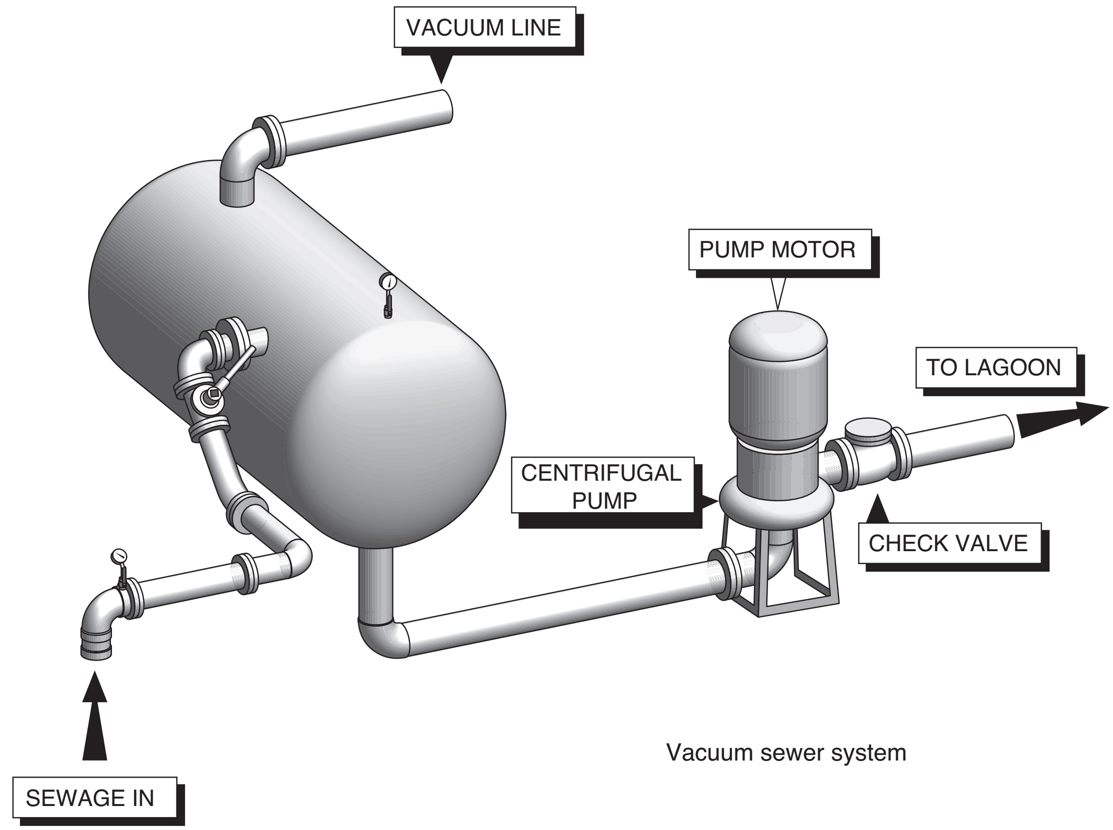
The heart of the vacuum system is a vacuum pump and vacuum storage tank. These are located at or near the treatment facility. The tank is used to hold solids and maintain the vacuum. A second tank may be installed to provide extra vacuum storage capacity.

Discharge Pump

The wastewater is pumped from the storage tank to the treatment facility by a special end-suction centrifugal pump. This pump must be designed to operate with a high vacuum on its suction side.

Lines

Each individual home is connected directly to the system by small lines, usually 2.5". These individual lines connect into larger branch and main lines. A ball valve is placed every 200 feet in the branch, main and trunk lines to allow for maintenance.



Vacuum sewer system

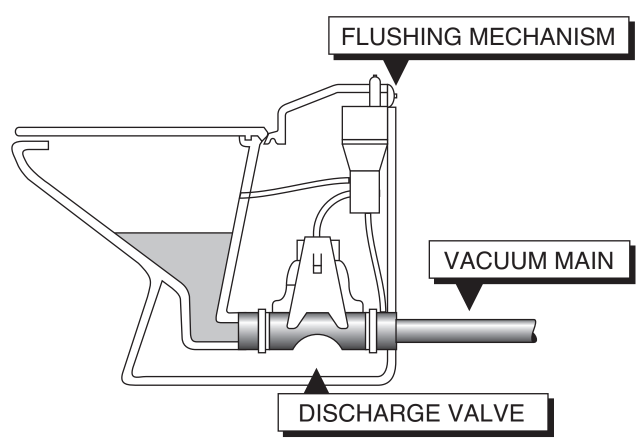
Fixtures

Special vacuum toilets are required by this system. While other fixtures can be standard, they must be equipped with a special graywater valve.

How the Toilet Works

Control Valve

The flow of water out of the vacuum toilet is controlled by a small pinch valve. When the toilet is flushed, the valve is opened by vacuum. This allows the wastewater to flow into the system. While this is happening, 1 to 2 quarts of water flow into the toilet as a rinse. The water continues to flow after the valve is closed in order to maintain a small amount in the toilet to provide a seal, preventing sewer gases from entering the house.



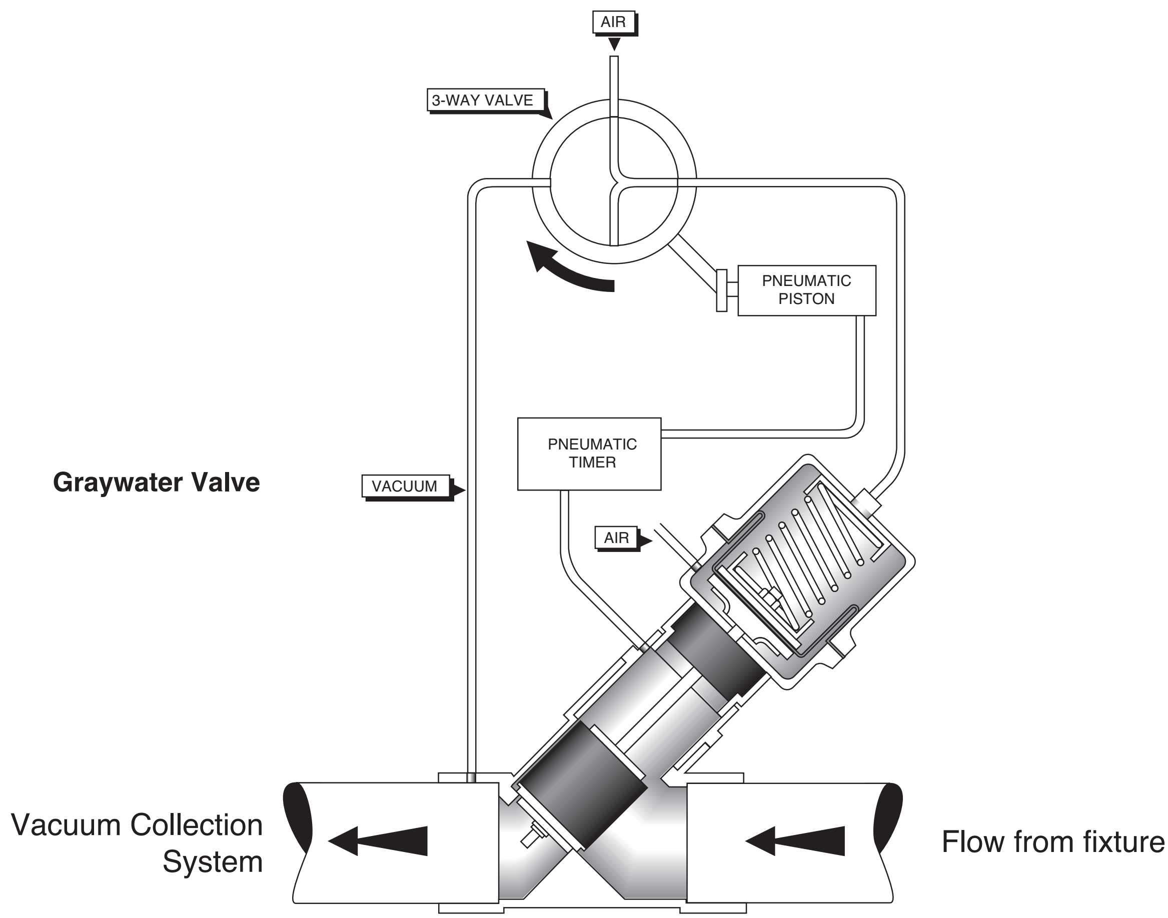
How the Graywater Valve Works

Components

The graywater valve is much more complicated than the toilet valve. This valve is composed of a vacuum operated piston, a three-way valve, check valve and pneumatic timer.

Upstream Pressure

When a fixture is used, water flows up against the back of the valve and begins to fill the drain line below the fixture. As this water level rises it is sensed by a pneumatic timer valve. When adequate pressure is reached, the pneumatic timer trips sending a signal to the pneumatic piston that moves the three-way valve.



Apply Vacuum

When the three-way valve rotates, it allows vacuum to be piped from the downstream side of the graywater valve, through the three-way valve to the top of the graywater valve. This causes the graywater valve to lift its piston allowing water to flow into the vacuum source.

Timer

The pneumatic timer holds the graywater valve open for a set period of time then it is closed. If upon closing adequate pressure is still available on the upstream side of the graywater valve, the process is repeated.

Advantages & Disadvantages

Advantages

The basic advantage to this system is the low water use. Noorvik uses approximately 17 gpcpd. The normal water consumption is 142 gpcpd in the U.S.

Disadvantages

The cost of maintenance of this system increases as it ages. The basic toilet and graywater valves were originally designed for occasional use on boats and trains. The frequent use that they receive in a home causes them to deteriorate more rapidly than normal. Because maintenance of the valve is costly and the responsibility of the individual homeowner, it is often neglected. This causes high vacuum leaks which increase electrical cost and reduce the effectiveness of the system.

Storm Sewers

Function

Storm sewers are constructed in communities to prevent localized flooding and damage to roadways.

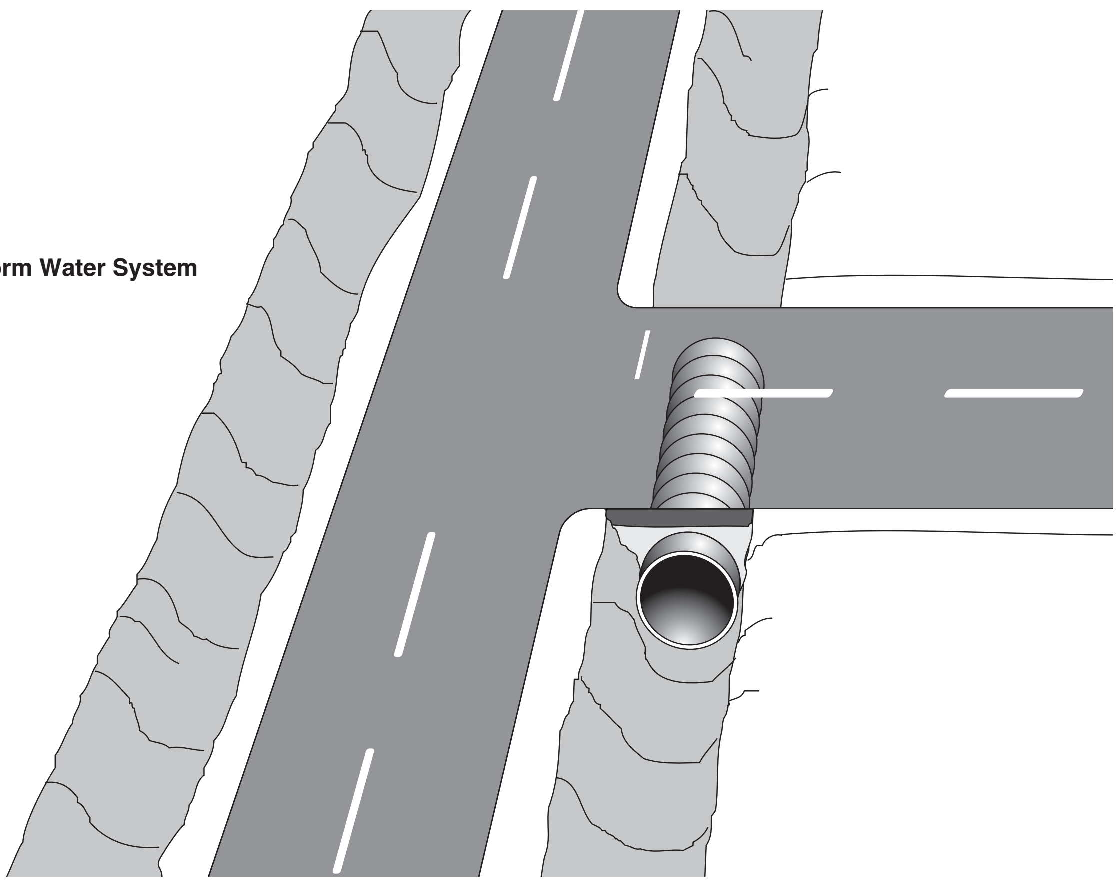
Components

A storm sewer system may consist of ditches, culverts, catch basins, manholes and piping.

Components - Rural Communities

In rural areas, the storm sewer mainly consists of ditches and culverts under roadways. The main task of the operator is to prevent plugging of the culverts and keep the ditches clean.

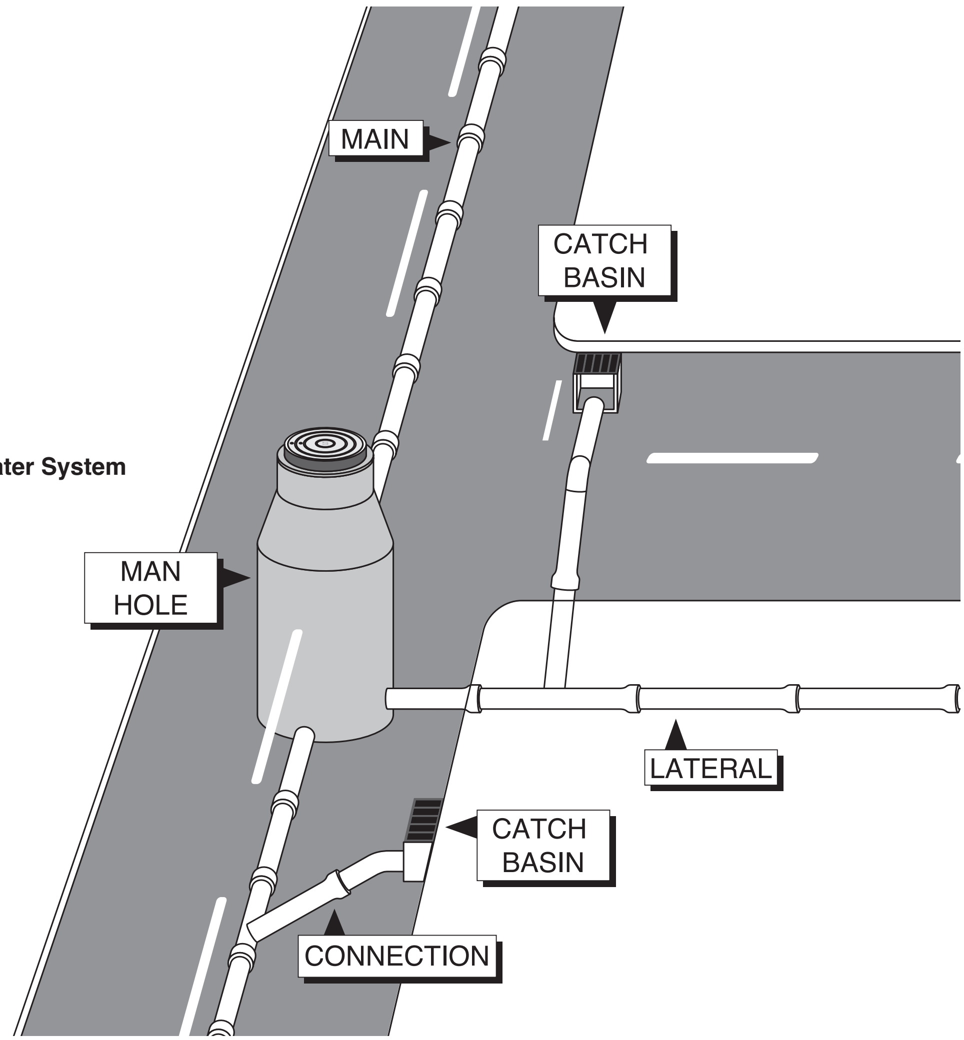
Rural Storm Water System

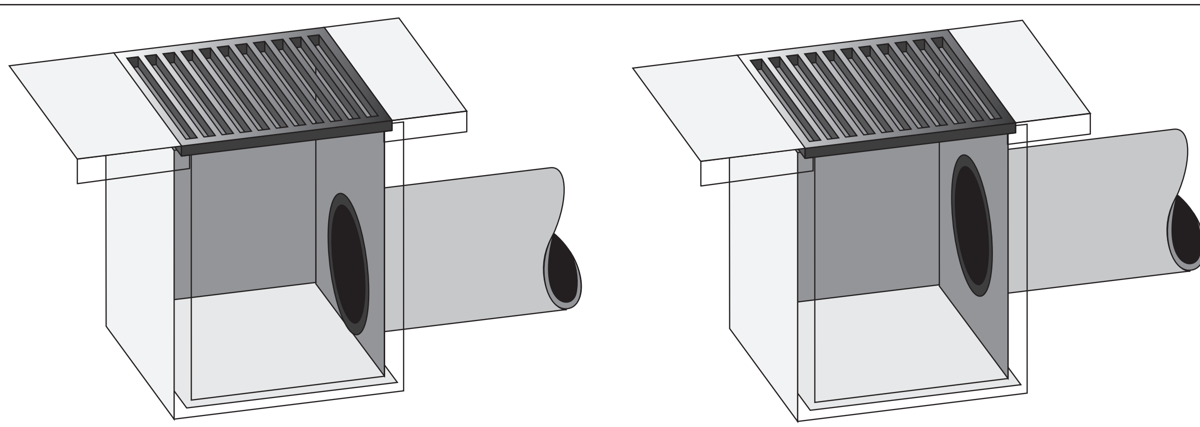


Components - Urban

In small and large communities with paved roads the storm sewer system will include catch basins and curb inlets as well as piping. The difference between a catch basin and a curb inlet is the space in the catch basin to collect gravel and grit. These catch basins and curb inlets need to be cleaned once each year.

Urban Storm Water System





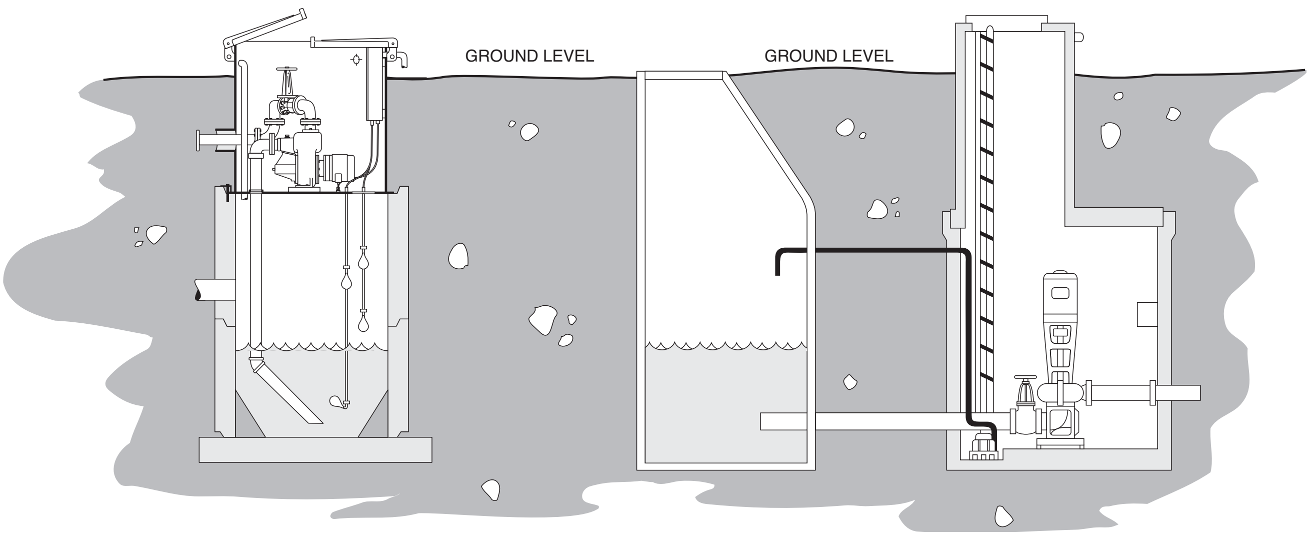
Curb Inlet

Catch Basin

Lift Stations

Types

While there are a number of different styles of lift stations they all can be divided into two types; **wet well**[26] and **dry well stations**[27]. The primary difference between the two is the number of tanks. The wet well station has one tank and the dry well station has two tanks. Besides identifying a lift station as wet well or dry well, we often describe it in terms of suction conditions and/or pump type. The following provides a description of various types of lift stations in these various categories.



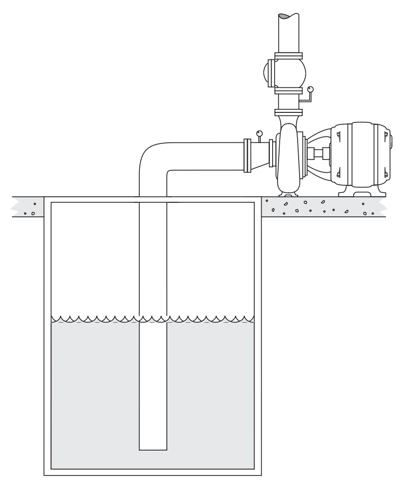
Wet Well Lift Station

Dry Well Lift Station

Suction Conditions

Suction Lift

The most common lift station is the **suction lift**[28] station. A suction lift condition exists anytime the eye of the pump impeller is above the water it is pumping from. This condition occurs in the wet well lift station shown above.



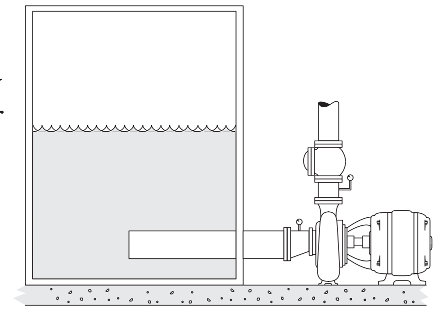
[26] **Wet Well Lift Station** - A lift station in which there is a single tank. Pumps can be installed in a wet well lift station in either a suction lift or suction head condition.

[27] **Dry Well Lift Station** - A lift station composed of two tanks. One tank contains the wastewater and the second tank contains the pumps. Dry well lift stations are used so that the pumps may be dry and in a suction head condition.

[28] **Suction Lift** - A pumping condition where the eye of the impeller of the pump is above the surface of the water from which the pump is pumping.

Suction Head - Submersible

A **suction head**[29] condition occurs anytime the eye of the impeller is below the level of the water it is pumping from. This condition occurs when a submersible pump is used in a wet well lift station and in dry well lift stations. This suction condition is also called flooded suction.



Suction Head - Dry Well

The primary reason for building dry well stations is so the pumps can be installed in a suction head condition. This assures that the pump will maintain prime.

Components

Tanks

The tank that holds the wastewater is called the wet well. If the lift station is a dry well station, the tank that holds the wastewater is called the wet well and the tank that holds the pumps is called the dry well. These tanks are commonly made of concrete. With **package lift stations**[30] the dry well is commonly made of steel.

Screens

While not always present, screens and screen boxes are sometimes installed on the inlet of the station. These screens are used to collect large solid material that may flow into the station. By collecting this material the pumps are protected from damage. However, the screen boxes can become stuck in position if not cleaned regularly (weekly). In addition, the material that is collected from the screen must be properly disposed of in a landfill or incinerator.

Piping System

Piping

In most cases, all of the piping in a lift station is standard schedule 40 steel. To provide the best hydraulic conditions, a suction bell should be installed on the inlet of the suction piping. Piping in a lift station is commonly connected with flanged, screwed or welded fittings.

Valves

The three common isolation valves used in a lift station are the gate valve, knife gate and the **plug valve**[30].

29 **Suction Head** - A pumping condition where the eye of the impeller of the pump is below the surface of the water from which the pump is pumping.

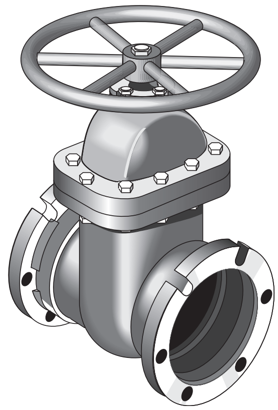
30 **Package Lift Station** - A lift station built by a supplier and delivered as a single item to the site. Installation requires digging a hole and connecting the piping and wiring.

31 **Plug Valve** - A valve consisting of a body and tapered movable closure which is held in place by force from the bonnet. The closure contains an oblong opening that when open provides full flow with little or no restriction. Opening or closing the valve requires 1/4 turn.

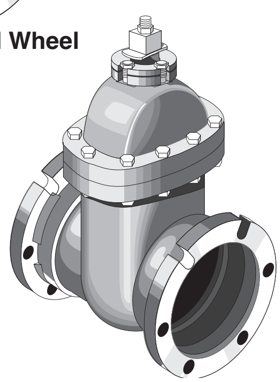
Gate Valves

Major Components

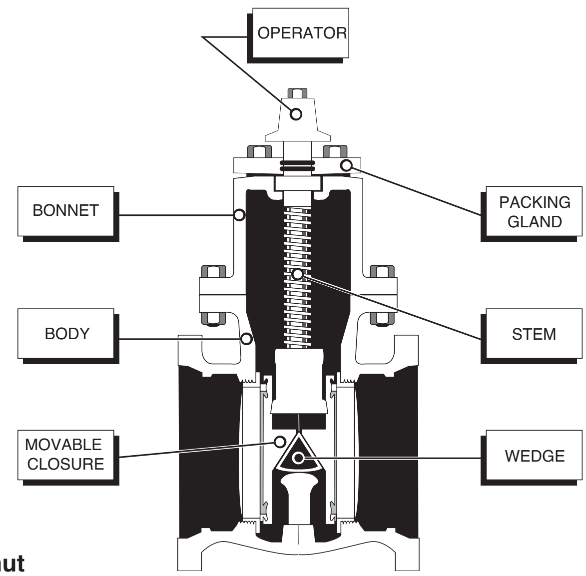
The lower portion of the gate valve, called the body, houses the connections and the seat that the movable closure comes against. The closure is moved up and down by an operating stem. The closure, when in an open position is stored in the bonnet of the valve. The bonnet also holds the stuffing box. The stuffing box contains the packing or “O” ring which controls the leakage around the stem.



Gate Valve - with Hand Wheel



Gate Valve - 2" Operating nut



Movable Closure Types

The common movable closures are single disc, double disc and resilient seat.

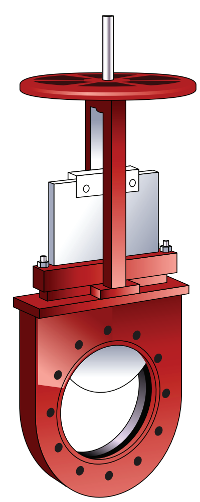
Valve Operator

The device used to turn the stem is called a valve operator. Common operators are two-inch square nuts and hand wheels.

Knife Gate

Major Components

The lower portion of the gate valve, called the body, houses the connection and the seat that the movable closure comes up against. The closure is moved up and down by raising and lowering the operating stem. The closure, when open is stored in the bonnet and outside of the valve. A rubber like seal is placed next to the closure to prevent leakage. The closure is moved by rotating a handle on top of the yoke. This style of gate valve is called an OS&Y (outside stem & yoke) valve.



Closure

The closure is a single sheet of metal, usually stainless steel. When closed, the valve is not completely watertight.

Plug Valve

Components

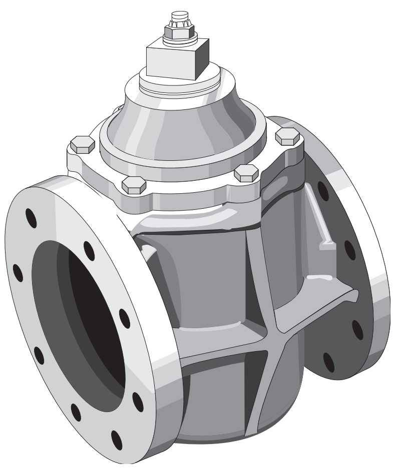
The plug valve used in lift stations utilizes a cast iron body and cast iron closure.

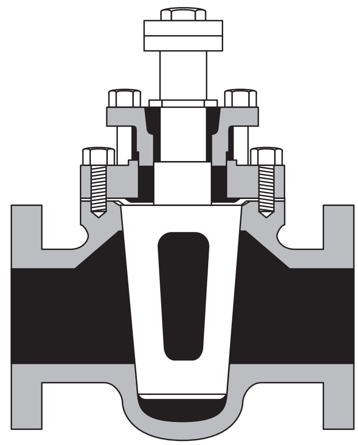
Operation

The movable closure of the plug valve has a rectangular hole through which water will pass. A 1/4 turn moves the valve from open to closed.

Seals

Older plug valves control leakage between the movable closure and the valve body by the close tolerance between the two components. These close tolerances make it difficult to open and close the valve. Frequent lubrication is required to prevent the valve from freezing in one position. Newer valves use Teflon™ or O-ring seals. These valves are much easier to operate.

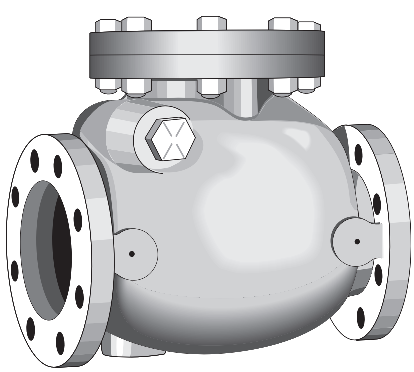


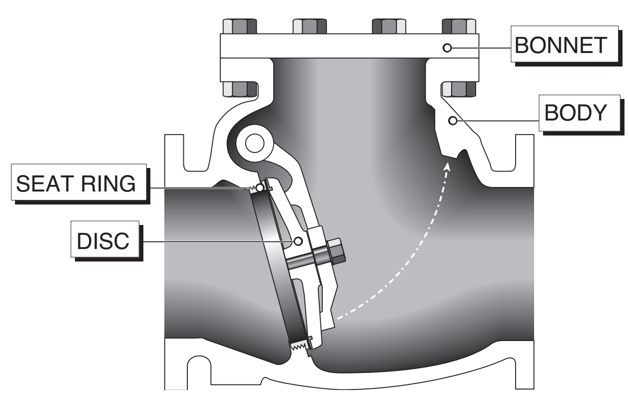


Swing Check

Components & Operation

To prevent the sewage from flowing back from the force main into the lift station a check valve is placed on the discharge side of the pump. The most common check valve used is the swing check. The swing check has a simple design with a cast iron body and bonnet, a brass seat ring and a movable disc. Flow forces the valve open and when the flow is reversed, the flow closes the valve. Swing checks are prone to plugging by rags and are a constant source of maintenance.

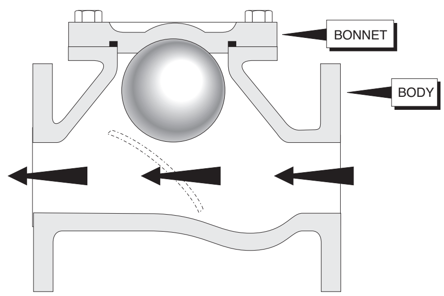




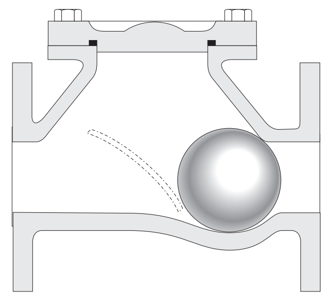
Ball Check

Components & Operation

Another type of check valve used in sewage lift stations is the ball check. The ball check has a simple design with a cast iron body and bonnet, a guide and a movable resilient ball. Flow pushes the ball up out of the flow path and thus opens the valve. When the flow is reversed, the ball drops down into the valve body and is forced against a seat that is machined into the body, thus preventing a reversal of flow.



Ball Check - Open



Ball Check - Closed

Pump Types

Details in Pump Lesson

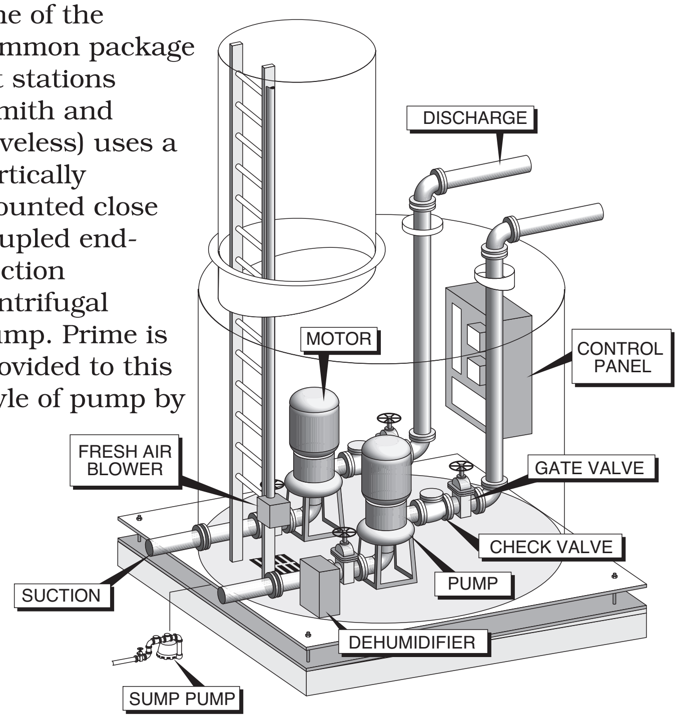
The details of the various types of pumps used in wastewater lift stations can be found in the lesson on pumping systems. A preview of the basic pump types is provided below.

Most Common

Close coupled and frame mounted end-suction centrifugal pumps are the most common pumps used in lift stations. In their most popular form they are usually found in dry well lift stations.

Close Coupled

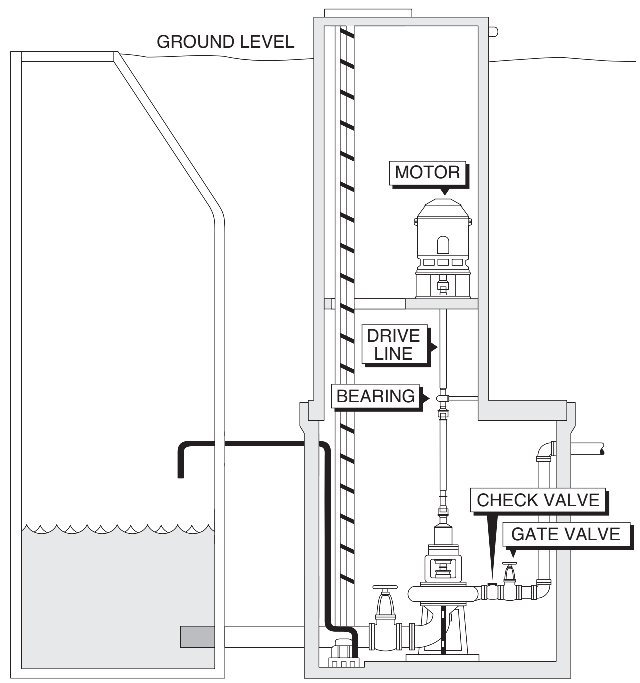
One of the common package lift stations (Smith and Loveless) uses a vertically mounted close coupled end-suction centrifugal pump. Prime is provided to this style of pump by



an electric vacuum pump. This type of lift station places the pump and motor within easy reach of the operator. However, the vacuum pump used for prime and the suction lift conditions require considerable maintenance.

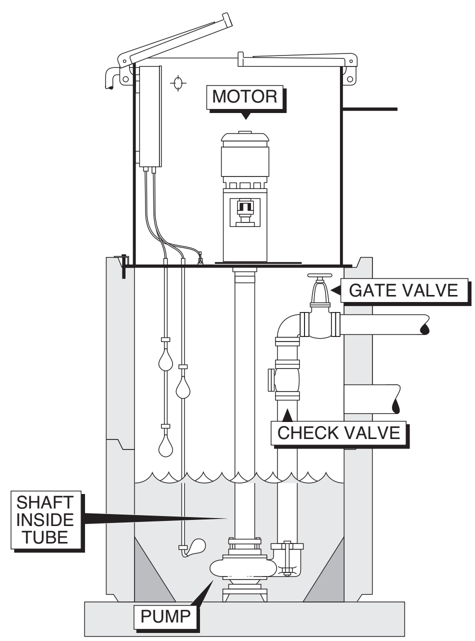
Frame Mounted - Drive Line

One special style of the frame mounted pump is one where the motor is placed one or more floors above the pump and connected to the pump with a drive line. If the station floods, the motor and electrical control panel is protected.



Vertical Shaft

Another special type of frame mounted pump is the vertical shaft pump. This pump has a long shaft in the frame (4 to 10 feet) that allows the motor to be mounted above the wet well. This provides easy access as well as prevents the motor from flooding. Several of these pumps are installed in the lift stations of the ARCO facility at Prudhoe.

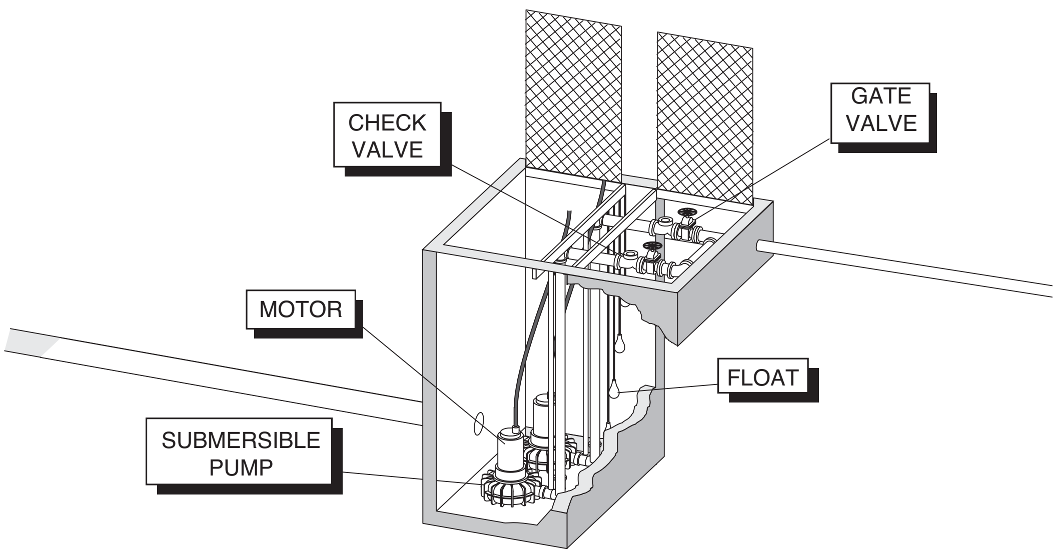


Self Priming

One of the most common end-suction centrifugal pumps used in a suction lift condition is the self priming pump. While causing considerable maintenance problems, the pump and motor are placed in an easy access position. An example of this type of station is the wet well station shown at the start of this lesson.

Submersible

A style of lift station that is gaining popularity is the wet well station with a submersible, close coupled, end-suction centrifugal pump. This type of station usually gives the least number of maintenance problems. However, removal of the pump and motor requires a chain hoist or similar device. Entrance into the wet well for repairs is not necessary. The pump is maintained in proper position by sliding up and down guide rails.



Number of Pumps

Most lift stations have at least two pumps. One is in a lead position and one in a lag position. When the water level rises in the wet well the first pump (lead) comes on. If the level continues to rise as a result of high flow or a failure of the first pump the second (lag) pump comes on.

Level Controls

Introduction

The details of the electrical controls are found in the lesson on pumping systems. There are four common control systems used in lift stations. They are the float system, bubbler tube, pressure transducer and the electrode system.

Function

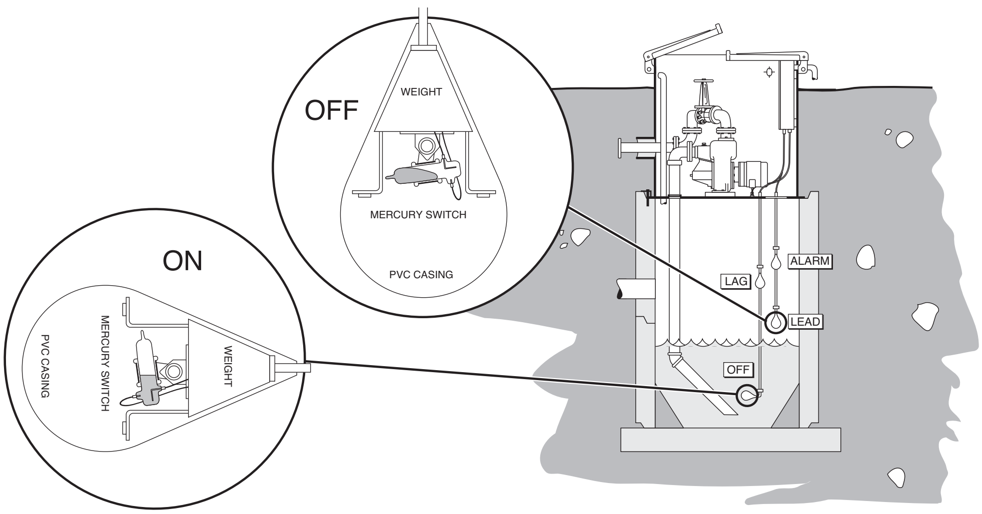
The control system is used to turn the lead and lag pumps on as well as send an alarm should the station overfill with water. This overfill condition is called a high water alarm.

Pumping Frequency

The water level between the off and lead pump level controls, along with system flow, determines the frequency that the station operates. The station must pump frequently enough to prevent the raw sewage from going septic in the wet well. In most cases this is at least 2 to 3 times in a 24-hour period.

Floats

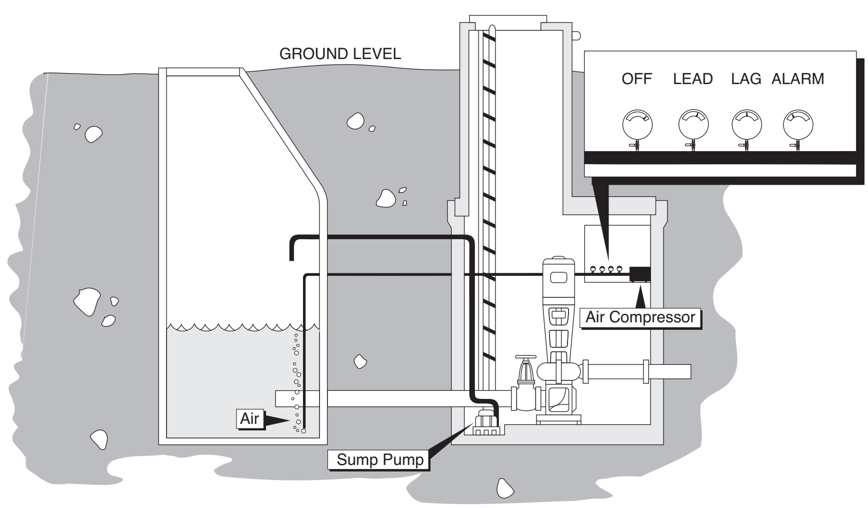
The most common float system is composed of four floats. One float each for the lead pump, lag pump, pump off and high water alarm. Each float contains a glass vial of mercury with a pair of electrodes. When the float is laid sideways due to the rising liquid level, the mercury runs across the electrodes making an electrical connection and sending a signal to the controls.



Bubbler

The bubbler system works similar to the float system. In this system there is a small air compressor and four pressure-sensitive switches each with a vial of mercury similar to the float switches. Air is pumped through a header and a plastic or metal tube in the wet well. As the water level in the wet well rises, the pressure in the header is increased. The pressure switches are set to turn the pumps on, off and send a high water alarm based on water level in the wet well and the resulting pressure in the header. (The relationship between water level and pressure is

Bubbler System

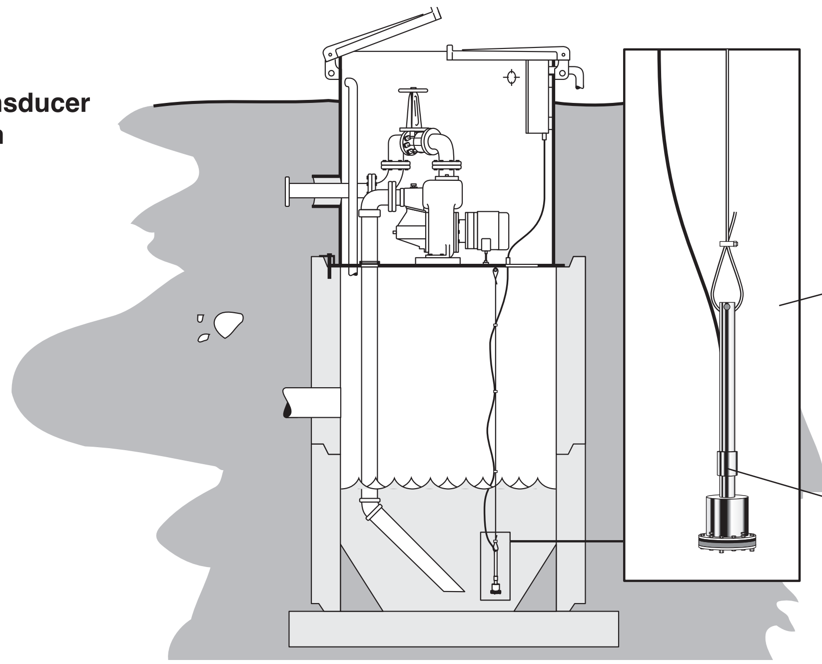


discussed in the math sections and in the hydraulics section of the pumping system lesson.)

Pressure Transducer

A pressure transducer is a device that will provide a varying electrical output based on pressure. This device is placed in a water tight housing. A flexible diaphragm is fastened to the bottom of the housing. The transducer is secured to the flexible diaphragm. As the water level in the wet well rises the signal from the transducer changes. This signal is sent to an electrical control panel and used to turn pumps on and off. The major advantage to this type of control system is that the electrical components are kept dry and the level used to turn pumps on and off can be varied easily from the control panel.

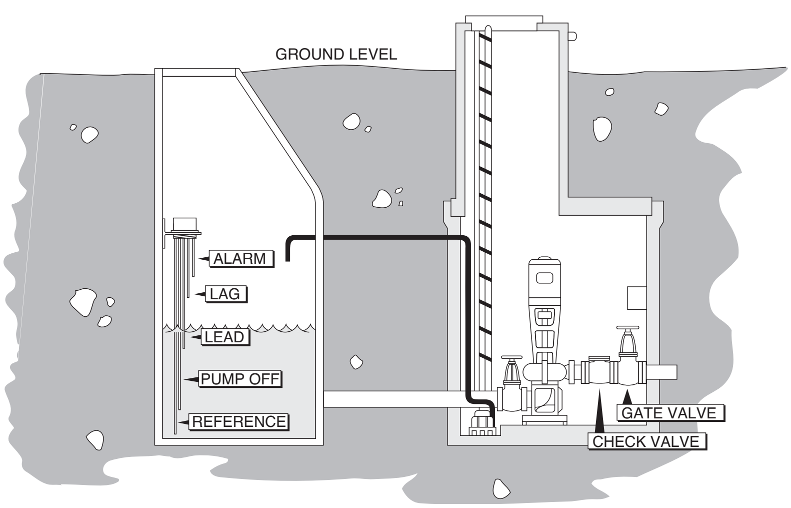
Pressure Transducer System



Electrodes

With the electrode system there are five electrodes: a reference, pumps off, lead pump on, lag pump on and

Electrode System



high water alarm electrode. As the water level rises, an electrical connection is made between the reference electrode and each of the level electrodes.

H-O-A Switch

Most control panels have one H-O-A (Hand, Off, Auto) switch for each pump. Placing this switch in the hand position allows you to run the pumps any time. When placed in the auto position the pumps are controlled by the wet well level.

Hour Meter

An hour meter is installed on most control panels and provides information on the number of hours the pump has operated. This information can be used in a maintenance management system to determine when it is time to perform specific maintenance.

Status Lights

It is common to provide on-off and alarm lights on the control panel. These are used by the operator to determine pump status.

Amperage & Voltage

In recent years it has been a common practice to install analog or digital amperage and voltage meters in the control panel. This allows the operator to make these readings without opening the control panel. Thus reducing a major safety hazard. These readings are used to help evaluate the operating condition of the pumps and motors.

Auxiliary Equipment

Introduction

Auxiliary equipment are the items that help the operator in the performance of normal operation and maintenance tasks but do not directly impact the pump performance.

Air Blower

With dry well stations, a mechanical blower is installed and wired so that it comes on each time the hatch is opened. This is a safety feature, it draws fresh air into the dry well, which is a **confined space**[32].

Ladder

Dry well stations require a ladder so that the operator can check station operation and provide maintenance to the pumps and motors.

Dehumidifier

Dry well stations are commonly equipped with dehumidifiers. These reduce the moisture content in the dry well and thus reduce corrosion of the equipment, including the electrical controls.

Heater

Most control panels are equipped with a strip heater. This is used to reduce the moisture content in the panel and prevent deterioration of the electrical controls.

[32] **Confined Space** - A space that is large enough and so configured that an employee can bodily enter and perform assigned work, has limited or restricted means for entry and exit, and is NOT designed for continuous employee occupancy.

Sump Pump

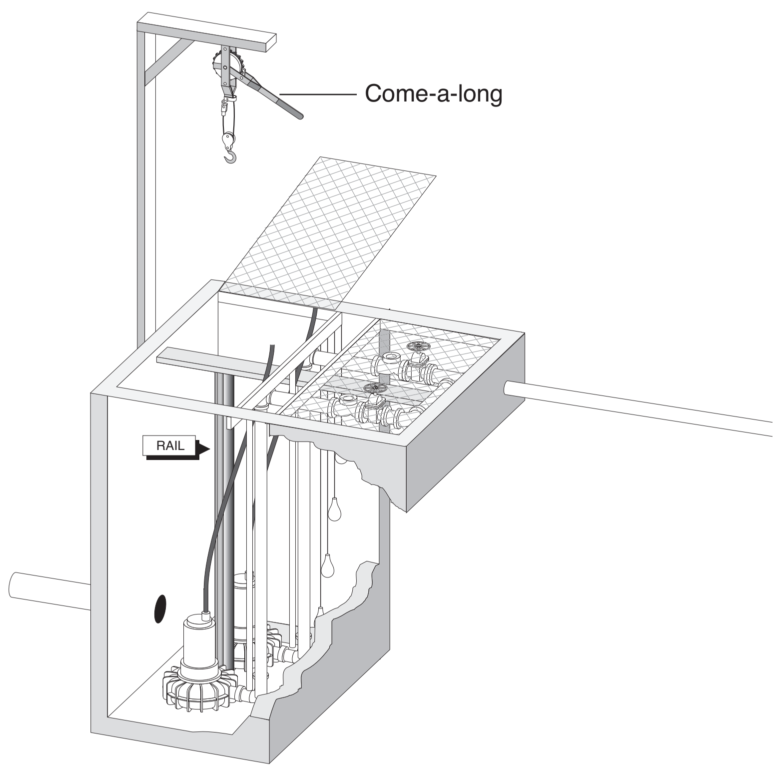
A sump pump is another common feature of a dry well lift station. This pump is used to remove water from condensation, small leaks and the **seal water**[33] used to flush and lubricate the pump packing or mechanical seals.

Vacuum Pumps

Some suction lift wet well stations are equipped with an electric vacuum primer to prime the pump. The system is composed of the vacuum pump, a flexible hose that is connected to a glass or plastic dome and an electrode. The dome and electrode are connected to the volute case. When there is a demand for the pump to come on, the vacuum pump will start. As a vacuum is developed, water will be pushed up the suction pipe by atmospheric pressure. When the volute case is filled, the electrode will make contact with the water, turning on the pump and shutting off the vacuum pump.

Rails & Come-a-long

With wet well lift stations using submersible pumps, a way must be made to remove and install the pumps without entering the wet well. (This is a permit required confined space). To facilitate this process, rails made of galvanized pipe and a come-a-long are installed. The rails are used to guide the pump into proper position.



[33] **Seal Water** - Water applied to the stuffing box in order to lubricate and flush the packing.

Operation and Maintenance

Introduction

Routine Activities

In order to assure the proper operation of a collection system and pervent the plugging of lines the system must be routinely inspected and cleaned. This process includes inspecting and cleaning lift stations, manholes and lines.

Safety

Manholes and lift station dry wells and wet wells are confined spaces. Special entry procedures must be followed when entering a confined space. A discussion of the proper procedure is found in the lesson on Safety.

Typical Problems

I & I

The major and most common collection system problem is **inflow**[34] and **infiltration**[35] (I & I). I & I results in increased flow through the lines, increasing pumping cost and reduces the effectiveness of treatment. If the I & I is greater than the flow capacity of the lines, water may back up in the lines and exit through manhole vents, flood basements or flood lift stations. When raw wastewater exits onto the ground, it represents a health hazard. When flow backs up in a line, the line is said to be **surcharged**[36]**.**

Inflow Defined

Inflow is defined as surface water entering the collection system. This can occur from roof drains or floor drains connected to the collection system. These connections are considered to be illegal connections. Surface water can also enter the collection system through the vent holes in manhole lids.

Manhole Lid Vents

Water can be prevented from entering manhole vents by plugging the vents, using manhole covers with no vents or installing a manhole cover seal that prevents water from entering the manhole. Sealing the vents or using manholes with no vents or special manhole covers with vents prevents the escape of gases. This increases the atmospheric hazard in the collection system and increases the possibility of an explosion in the collection system.

Infiltration Defined

Infiltration is the result of groundwater entering the collection system through broken pipes, bad joints or failed seals on manhole risers or rings.

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[34] **Inflow** - The water discharged into a sewer system and service connections from such sources as, but not limited to, roof drains, cellar drains, yard and area drains, foundation drains, cooling water discharges, drains from springs, and swamps, and around manhole covers or through holes in the covers, cross-connections from storm and combined sewer systems, catch basins, storm waters, surface runoff, street wash waters or drainage.

[35] **Infiltration** - (In-fil-TRAY-shun) - The water entering a sewer system, including service connections, from the ground, through such means as, but not limited to, defective pipes, pipe joints, connections or manhole walls.

[36] **Surcharge** - Sewers are surcharged when the surface of the wastewater in manholes is above the top of the sewer pipe. The sewer is then placed under pressure rather than being at atmospheric pressure. This condition contributes to exfiltration and the backup of sewage into individual homes.

Exfiltration

The movement of water from a collection system pipe or manhole into the ground is called **exfiltration**[37]. The major concern with exfiltration is the potential to contaminate the groundwater or surface water supply.

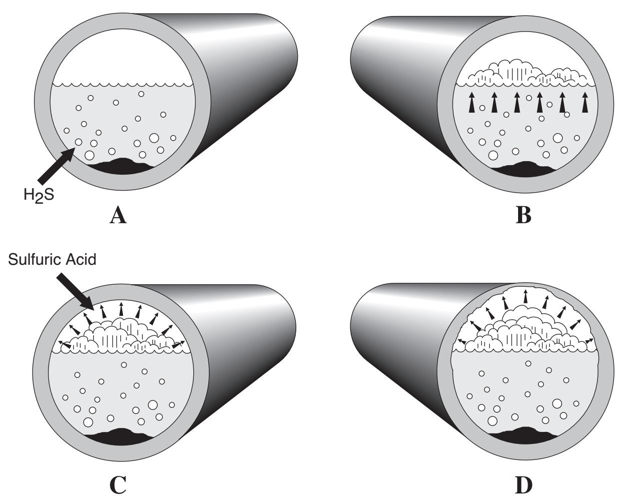
Deposits

When the flow in a line is below two foot per second (2 fps) solids can be deposited on the bottom of the pipe. These solids include organic material that becomes food for the microorganisms that are in the wastewater. The result is a drop in DO and the material in the bottom of the pipe becomes septic. This represents two problems. One is septic material is more difficult for the treatment plant to treat then aerobic material. The second problem is the production of hydrogen sulfide.

Hydrogen Sulfide and Pipe

Hydrogen sulfide gas (H_2S) causes two problems. One is the creation of unfavorable atmospheric conditions in the collection system. A level of hydrogen sulfide above 10 ppm is considered toxic. The second problem with hydrogen sulfide is corrosion. Hydrogen sulfide combines with water to form sulfuric acid. This acid deteriorates concrete, AC and cast iron pipe as well as manhole steps, pumps and pump station piping.

Stages of corrosion from hydrogen sulfide



Roots

In areas with long growing seasons the roots of trees and other plants enter the pipe at bad joints and through cracks in the pipe. Once the roots find a water source, they begin to multiply and grow. This growth can become so great that it plugs the line.

Service Connections

Improperly installed service connections fall into two categories. Those that damage the pipe or are not watertight and those where the service line protrudes into the branch sewer line. This latter problem is called a protruding service. Cracks or poor seals allow infiltration and exfiltration. The protruding tap contributes to the plugging of the line and makes

[37] **Exfiltration** - (EX-fill-TRAY-shun) - Liquid waste and liquid carried waste which unintentionally leaks out of a sewer pipe system and into the environment.

using a TV camera for inspection difficult or in some cases impossible.

Grease

Grease enters the collection system from restaurants and homes. When proper grease traps are installed in restaurants, grease is not a serious problem. When there are no grease traps or they are not maintained, excessive amounts of grease enter the collection system. Grease can reduce the flow velocity in the line causing the wastewater to go septic. The grease can also be a major contributor to blockages. Excessive grease in the wet well of a lift station can foul the level control system preventing the pumps from operating properly.

Safety considerations

Introduction

There are four common problems associated with entry into manholes and lift stations. They are:

- Atmosphere
- Engulfment
- Falls
- Disease

Atmosphere

There are four common atmospheric problems in manholes and lift stations; oxygen, hydrogen sulfide, methane and other explosive gases.

- Normal oxygen level in the atmosphere is approximately 21%. When the oxygen level is below 19.5% it is considered a hazardous atmosphere. When the oxygen level is above 23% the atmosphere is said to be enriched and is also not safe for entry.
- When the hydrogen sulfide level is above 10 ppm the space should not be entered.
- When the hydrogen sulfide level is above 0.5% an explosive condition exists and the space should not be entered.
- The presence of other explosive vapors such as gasoline represent an explosive condition.

Engulfment

When entering into a manhole downstream of a lift station, the operator could become engulfed with water if the lift station is discharging.

Falls

Most manholes are shallow. However, when a manhole or lift station is deeper than 5 feet, a ladder or other fall protection equipment should be used.

Disease

When working in wastewater, the operator is exposed to bloodborne pathogens, the most dangerous of which is hepatitis. To prevent contracting hepatitis, the operator should practice good personal hygiene.

Arctic Considerations

Introduction

The Arctic and subarctic offer special considerations for the operation and maintenance of collection systems. These conditions are explained in the Introduction of this text. Below is a brief review of the points that impact O & M the most.

Remoteness

The remoteness of most of the rural villages and communities makes it difficult to obtain O & M information, share information with other operators or obtain help from the various agencies. This remoteness means that the operator usually has to determine how to do things on his/her own.

Transportation

The cost of transportation and the delay between vendors and the community makes it difficult to obtain needed repair parts and materials and drastically increases the cost of acquiring materials. The transportation costs also are a deterrent to obtaining training and observing how others do the same task.

Climate

The long cold winters make normal construction nearly impossible. The climate limits the months that routine maintenance can be done to the busiest time of the year. This places an extra burden on the operator to make all needed repairs in a very short period of time. If parts are not available, this condition coupled with the transportation problems may make routine maintenance nearly impossible.

Ground Conditions

Arctic conditions cause the development of permafrost and frost heave. Permafrost can cause the freezing of the lines. Frost heave can damage pipe, pipe joints, manholes and lift stations.

Inspection of Manholes

Nine Conditions

Manholes should be inspected at least once every three years. Under normal conditions there are nine conditions that should be checked.

Joints

The joints between the base and risers, between each riser, between the riser and the cone and between the cone and the lid ring should be checked for leakage.

Cracks

Inspect for cracks in the barrel (risers).

Flow Conditions

Observe the flow conditions, depth and appearance. High levels of clear water are an indication of I & I problems. Black color is an indication of septic conditions.

Roots

Roots entering through the cracks will, as they grow, increase the size of the cracks and thus increase infiltration.

Flow Channel

The flow channel should be smooth and clean. A buildup of material in the flow channel will contribute to plugging and create septic conditions. A rough flow channel can cause sewage to be thrown up onto the slope of the manhole base during high flows. This sewage can then become septic and contribute to deterioration of the manhole.

Steps

The steps should be inspected for corrosion. Corrosion is most likely to occur next to the wall of the barrel of the manhole.

Lid and Lid Ring

Inspect the lid for proper fit and the lid ring for cracks. Improper fitting lids can fly off when run over by a vehicle. Cracks in the lid ring can cause the lid to not fit properly and allow surface water to enter the collection system.

Appearance

Look for grease, gravel and other **debris**[38] in the flow channel and on the slope of the base. This can contribute to a slowing of the flow. Thus, causing septic conditions. Gravel in the flow channel of the manhole is an indication of a broken pipe.

Listen

Listen to the flow. One of the common line breakages occurs just outside of the manhole. A broken pipe can usually be identified by the sound of cascading water.

Inspection of Lines

Reasons

Lines are inspected to determine their condition in order to prevent or control I & I problems, septic conditions, exfiltration and blockages.

Types of Inspection

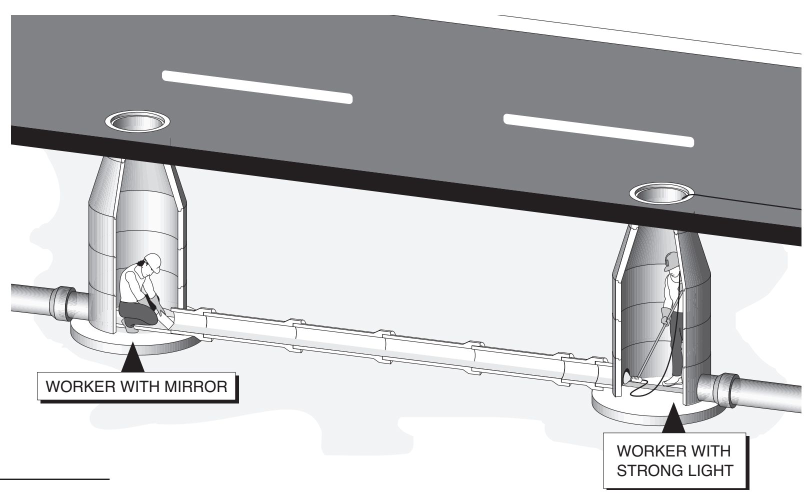
There are five common methods used to evaluate the conditions of the collection system lines. They are:

- Lamping
- Dye test
- Smoke testing
- Closed circuit TV
- Flow test

Lamping

Lamping is an older method used to identify blockages, major damage and the straightness of large lines. The process requires three people, two entrants

In the following drawings, safety equipment and traffic control requirements have been removed in order to provide a clear view of the basic equipment and procedure.



38 **Debris** - (de-BREE) - Any material in wastewater found floating, suspended or moving along the bottom of a sewer.

and an attendant. One worker enters a manhole and shines a high-powered light through a section of line. A second entrant enters another manhole and using a mirror observes the condition of the line.

Dye Testing

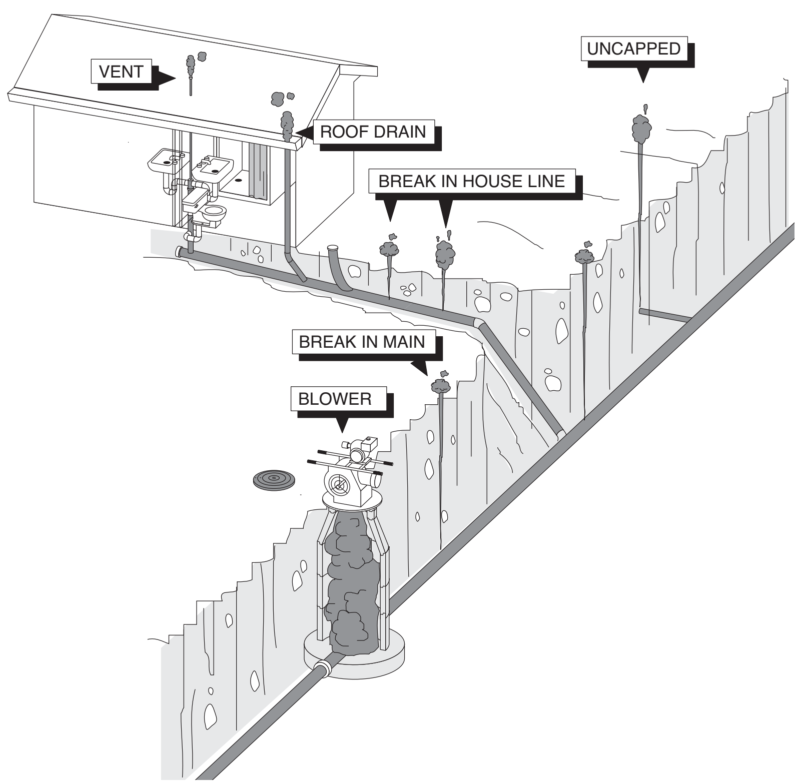
Dye testing can be used to verify a service connection, locate roof drain connections, find connections to storm drains and find illegal floor connections. A highly visible non-toxic dye is mixed with water and flushed down the toilet or poured down the suspected connection. The operator observes the downstream manhole for the appearance of the dye. In some cases this process can be used to identify exfiltration.

Smoke Testing

Most Common

One of the most common collection system testing tools is the smoke test. Smoke testing is used to identify:

- Breaks in the line
- Prove that a building is connected to the system
- Locate surface water inflow sources
- Find lost manholes
- Identify illegal connections
- Find connections to the storm sewer
- Identify crushed lines next to manholes or building foundations.



Process

The test is conducted by first isolating a section of line that includes three manholes. Sawdust bags or traffic cones are used to block the upstream and downstream manholes. A squirrel cage blower operated by a gas engine is used to blow non-toxic smoke into the center manhole and at the same time increase the pressure in the line. The escaping of smoke can be observed by the operator.

Observations - Good News

What is expected is:

- Smoke exiting out of the vents of those facilities that are connected to the system.
- Smoke exiting out of the vents in manhole lids.

Observations - Bad News

What is not expected is:

- Smoke exiting out of the street or ground. This is an indication of a broken line, an uncapped service connection or a buried manhole.
- Smoke exiting out of floor drains or roof drains. This shows an illegal connection.

Closed Circuit Television

Function

While closed circuit TV (**CCTV**[39]) is the most expensive method of inspecting a sewer line, it is the most effective. This method can be used to:

- Verify service connection locations
- Identify & document infiltration and exfiltration
- Identify bad or damaged pipe joints
- Evaluate the condition of the pipe and identify deteriorated pipe
- Determine if there are low points (bellies) in the pipe where solids may be deposited and turn septic
- Identify and document **circumventional**[40] and **longitudinal**[41] breaks

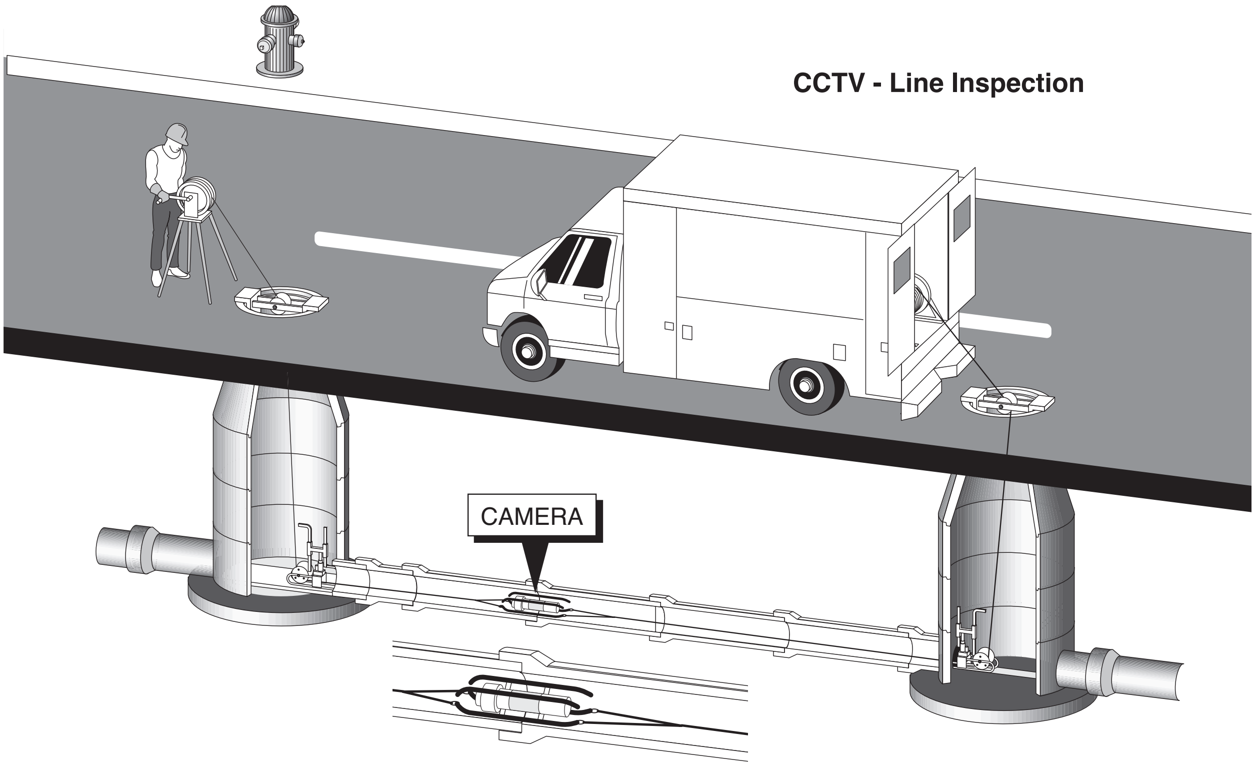
Contracted Out

Because the CCTV equipment is expensive and evaluation of the data complicated, most small utilities rely on specialty contractors to provide this service.

Basic Process

CCTV is accomplished by pulling a high quality camera through the line, with the flow of wastewater, and recording the findings on video tape and on paper. Using these findings, a report is produced on the conditions of the system. Lines as small as two inches in diameter can be inspected using CCTV.

39 **CCTV -** Closed Circuit Television - used to inspect the interior of pipelines.
40 **Circumventional** - A break in a line that travels around the circumference of the pipe. The break does not have to travel the complete circumference.
41 **Longitudinal** - Cracks or breaks that run the direction of the length of the pipe.



Flow Testing

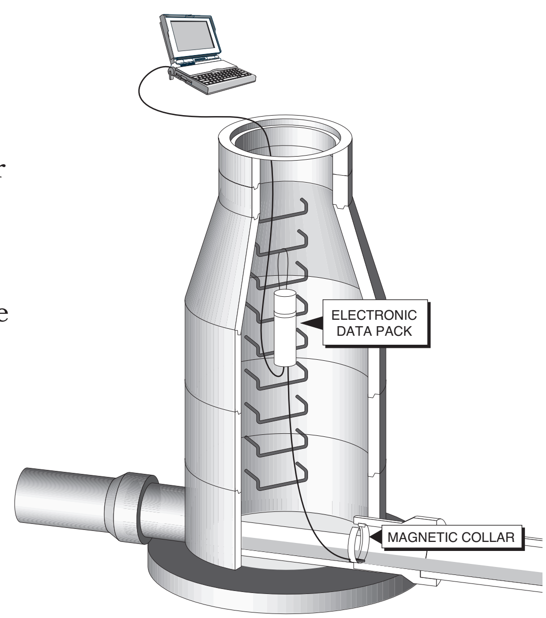
Purpose

Flow testing is used to develop a historical record of flows through key manholes in the system. This data is used to determine the general location of I & I and document changes in flow conditions.

Process

There are at least four types of flow measuring devices used in wastewater collection systems.

- Those that measure the level of water behind a primary measuring device such as a **weir**[42] or **flume**[43].



[42] **Weir -** A vertical obstruction, such as a wall, or plate, placed in an open channel and calibrated in order that a depth of flow over the weir (head) can easily be measured and converted into flow in cfs, gpm or MGD.

[43] **Flume** - An open conduit of wood, masonry, metal, or plastic with a defined constriction that allows the measurement of head. The height of the head can be directly converted to flow based on the shape and size of the flume.

- Those that measure the depth in the flow channel and use that information to determine flow.
- Those that use a magnetic collar placed in the pipe and determine velocity and depth electronically.
- Those that measure velocity. This reading is used in conjunction with previous measurements to determine flow.

Depth Measurements

The most popular devices are those that measure the depth of water (head). This can be accomplished physically by installing a **staff gauge**[44] in the flow channel, using a sonic device that sends and receives a signal similar to radar to an electronic recorder or those that use some type of float mechanism connected to a recorder. Most of these devices are used in conjunction with some type of primary measuring device such as a weir or flume.

When to Measure

Flow measurements should be taken during low flows and high flow conditions. High flow conditions would exist at break-up, during a heavy rain or at high tide.

What is Done With the Information?

The flow data once collected, can be used by the design engineer to identify which portions of the system need further study to determine the sources of I & I.

Mechanical Cleaning

Introduction

The methods used to clean collection system lines can be divided into two groups; mechanical cleaning devices and hydraulic cleaning devices. The first group we will discuss are the four types of mechanical cleaning devices:

- Power Rodders
- Hand Rodders
- Snakes
- Bucket Machines

Power Rodders

Power rodders have been widely used in collection system maintenance for several years. They are efficient in the removal of:

- **Stoppages**[45]
- Roots
- Grease
- Heavy deposits in the bottom of the line

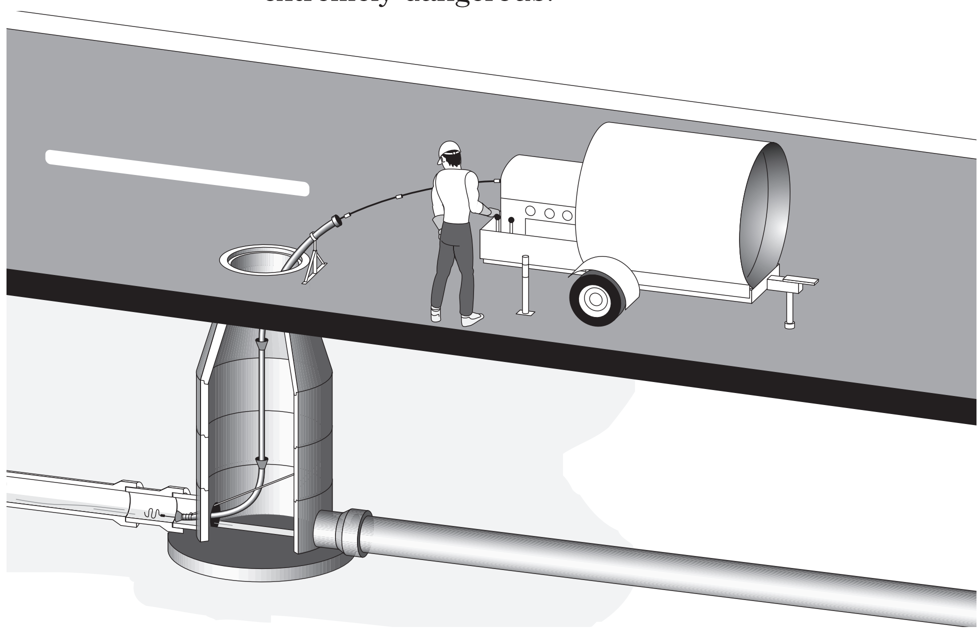
The power rodder consists of an internal combustion engine, steel rod gear head for rotating the rod and a spool mounted on the end of the rod. This rod may be sectional or continuous. The rod is rotated and pushed mechanically through one section of pipe at a time. A

[44] **Staff Gauge** - A vertical graduated scale placed on a wood or metal plate, used to determine the height of fluid above a specified point.

[45] **Stoppage** - Another name for a blockage. When a sewer system or sewer becomes plugged and the flow backs up, it is said to have a stoppage.

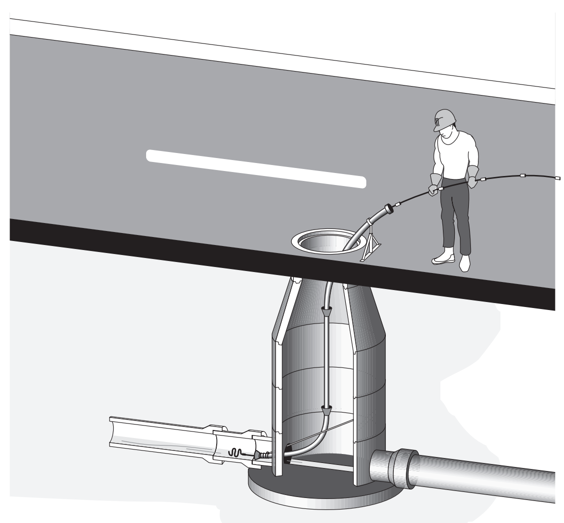
wide variety of special tools have been developed to allow the rodder to perform specific tasks.

The rodder must be kept clean and inspected after each use. If a rod is damaged it should be removed from service. Breaking a rod during use is extremely dangerous.



Hand Rodders

A hand rodder uses the same type of rod and tools as the power rodder. The rotation and pushing action is provided by the operator. A special tool is used to turn and push the rod.



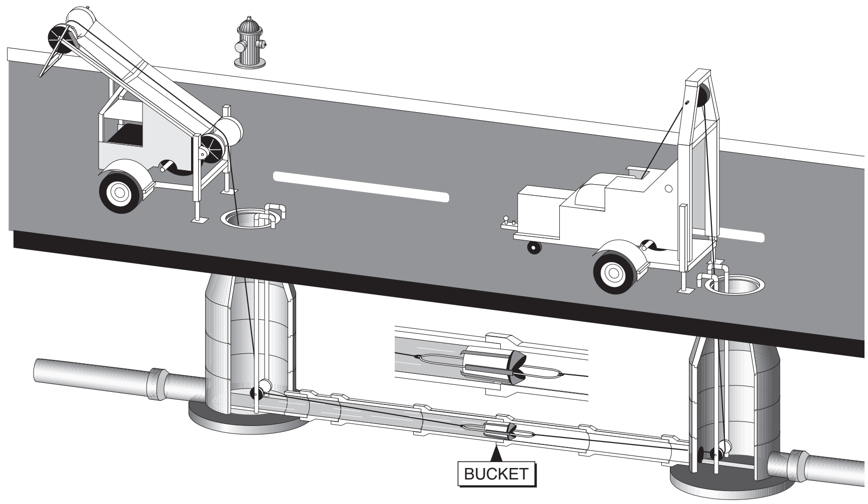
Snake

A snake is a poor mans rodder. Rather than a rod a corrugated steel tube is used. This tube has a small tool on the end. The snake is rotated and pushed by hand or by a small gas powered engine. This tool is fairly effective in removing stoppages in small lines (up to six inches).

Bucket Machine

Description

A bucket machine is an older method of cleaning heavy material such as sand from a collection system line. There are two common tools used with this system, the porcupine and the bucket.



Process

A bucket machine is composed of two mechanical units that pull a bucket or porcupine back and forth through a line. The biggest problem is connecting a cable between two manholes when there is a lot of material in the line. Once the cable is installed it is connected between two machines, one located at each manhole.

- When the problem is grease or normal buildup a porcupine is pulled back and forth through the pipe.
- When the problem is a heavy deposit of material like sand, a bucket is used. The bucket is drug through the line bringing with it the material. The bucket is either removed and returned to the starting point or dumped and pulled back through the line to the starting point.

Hydraulic Cleaning

Introduction

The second group of cleaning devices or techniques is the hydraulic cleaning methods. There are five hydraulic cleaning methods:

- Flushing
- Sewer balls
- Kites and bags
- Scooters
- High velocity cleaners (**HVC**[46])

[46] **HVC - High Velocity Cleaner** - A machine designed to remove grease and debris from the interior of sewer lines with jets of high velocity water.

Flushing

Introduction

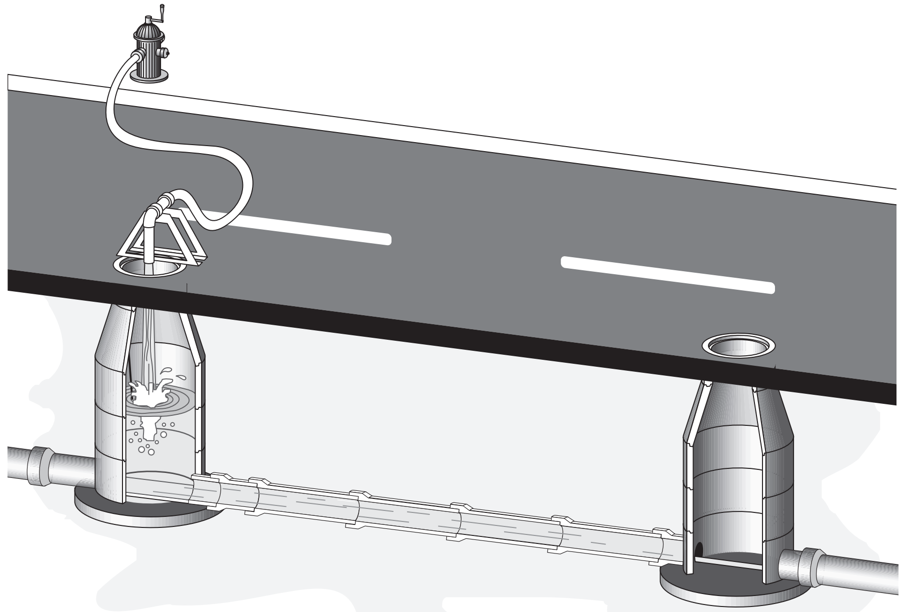
Although flushing may be the least effective method of cleaning, it is the most used and the easiest. If this method is used with the correct frequency and applied properly, it can be used to maintain a line that has been recently cleaned by other means.

Use

Flushing is used to remove small deposits of material, small blockages and in some cases grease from a collection system line.

Process

The process starts by placing some type of debris collecting device, such as several tire chains suspended from a rope, in the outlet of the downstream manhole.



A large volume of water is then dumped in the upstream manhole. The high velocity of the water, coupled with the volume of water will flush debris to the downstream manhole where it must be removed.

Prevent Cross Connection

One of the major considerations when using a flushing system is to protect the drinking water system from a **cross connection**[45] with the wastewater. This is best accomplished by using an air gap at the manhole. The air gap must be twice the diameter of the discharge pipe above the rim of the manhole.

Flooding

A second consideration is the flooding of basements. If the water level in the manhole is allowed to reach too high a level, basements connected to the downstream line may be flooded.

[47] **Cross connection -** Any physical arrangement whereby a public water supply is connected, directly or indirectly, with a non-potable or unapproved water supply or system.

Sewer Ball

Introduction

One of the most effective sewer line cleaning methods is the sewer ball. This method can be used on small and large diameter lines with a high level of effectiveness. Some large communities use this system as their primary means of cleaning lines.

Equipment

The equipment needed is fairly simple, it includes:

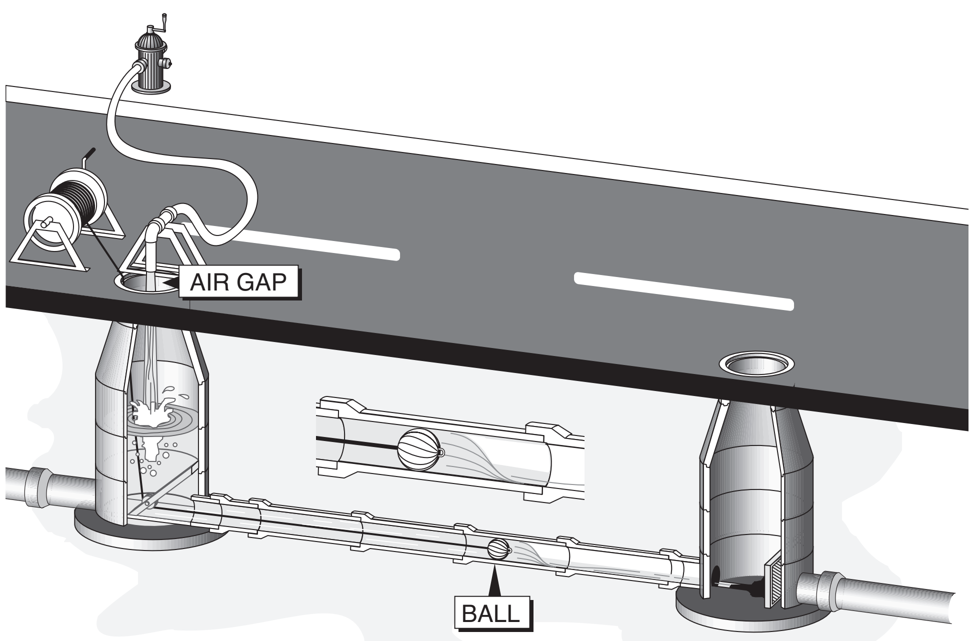
- A special ball with grooves and a swivel connection
- A rope or cable winch with a built in brake
- Water
- Some means of collecting the material that is washed to the downstream manhole. One common tool is several sections of tire chain connected to a rope. These chains are placed in the outlet of the downstream manhole.

Process

The ball is placed in the downstream line of the upstream manhole. Water is allowed to build up behind the ball. The forward motion of the ball is controlled by the winch and brake.

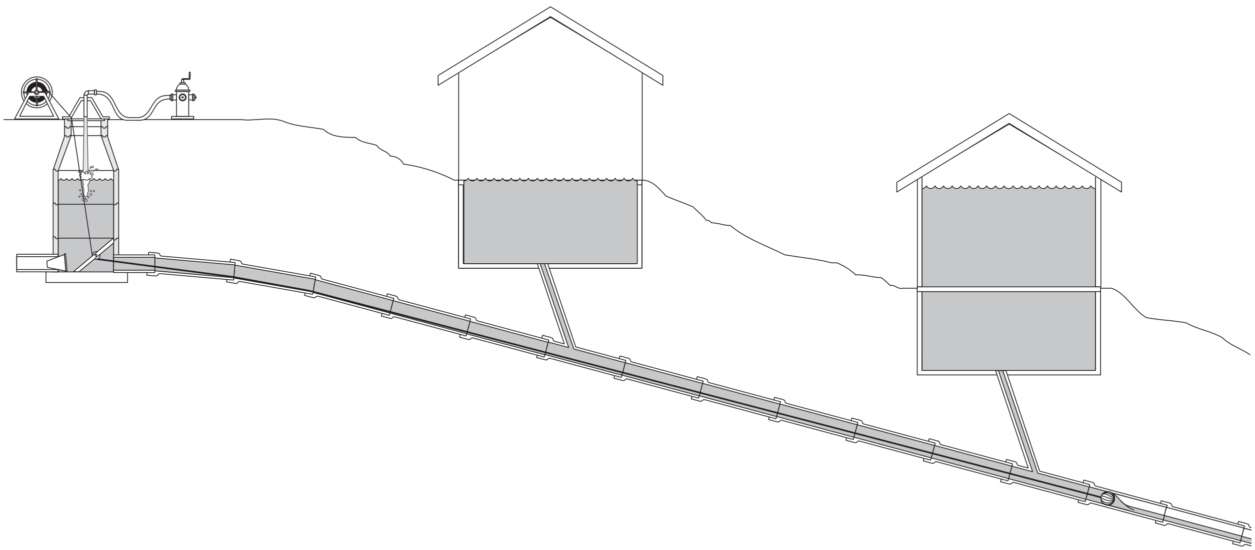
When there is sufficient water pressure behind the ball it moves forward with a rotating motion. Debris is washed ahead of the ball by the high velocity of the water traveling around the ball.

If the forward motion should slow, the winch brake is used to hold back on the ball or the winch is used to pull the ball backward slightly. This causes the ball to elongate and water to flow past it washing the material that has stacked up in front of the ball down the line.



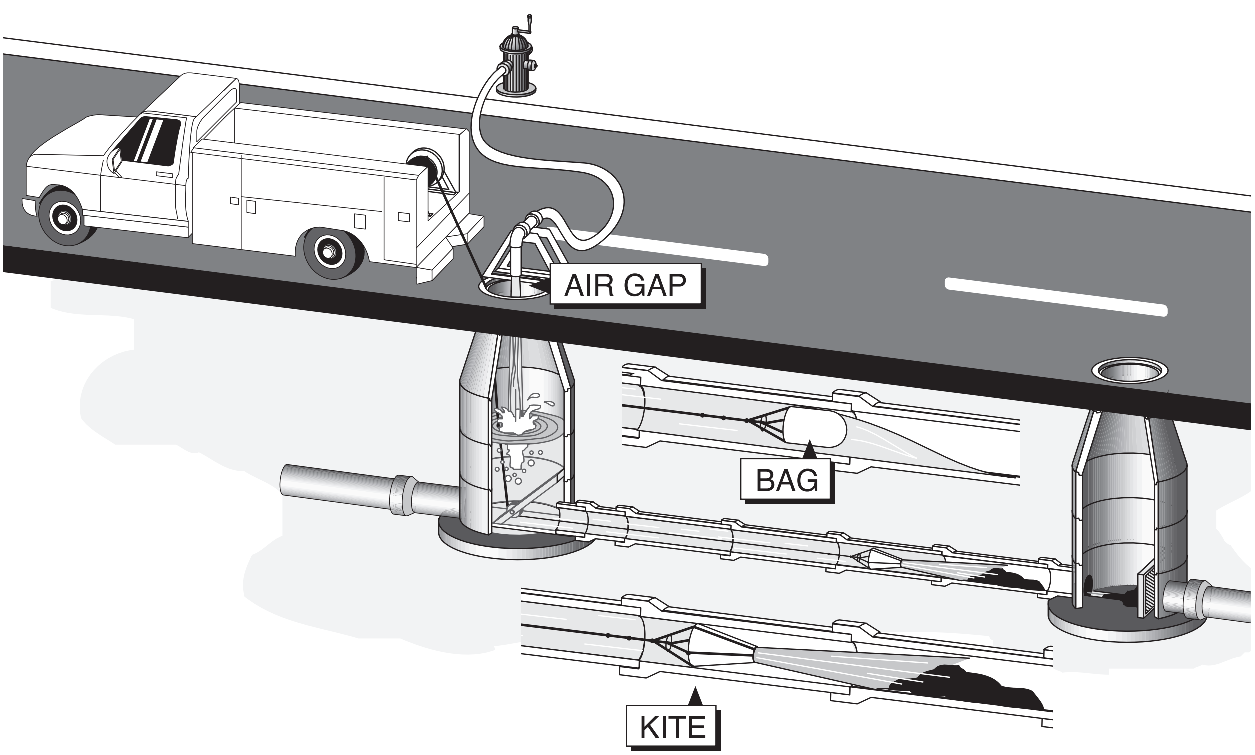
Considerations

As with the flushing, there are two special considerations. Prevention of a cross connection between the drinking water system and the wastewater and prevention of flooding of downstream basements.



Kites & Bags

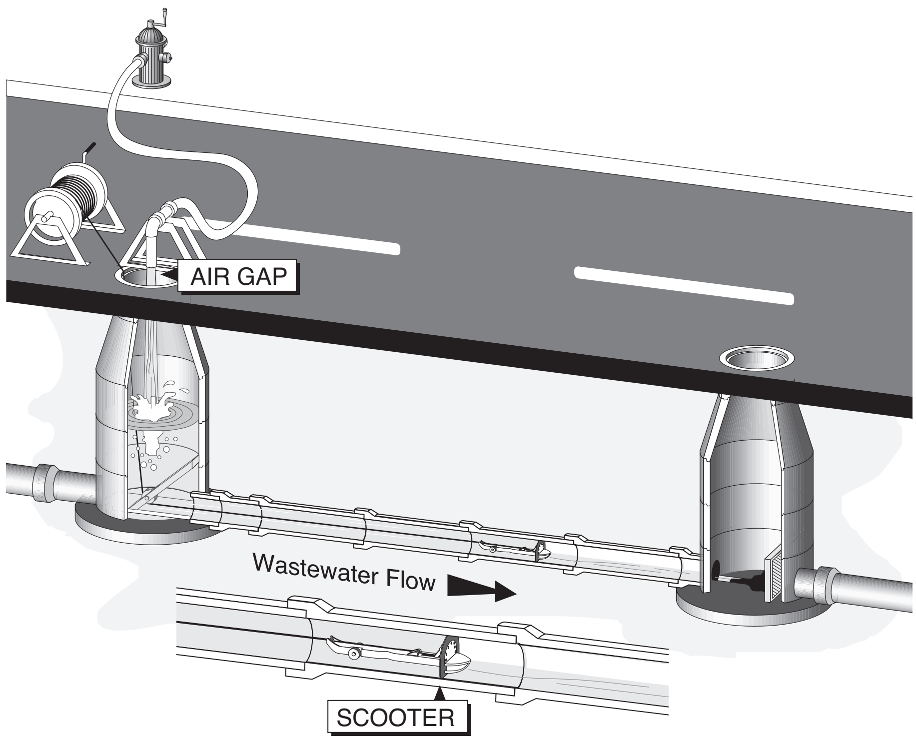
Kites and bags are older technologies that are used to clean large lines. Both devices are made of a fabric. The operation of the devices is similar to the sewer ball process. The major difference between the two devices is the use of a nozzle built into the kite.



Scooter

Old Technology

The sewer scooter is the Model "A" of the sewer cleaning business. While effective with large and small lines this device is seldom used today.



HVC

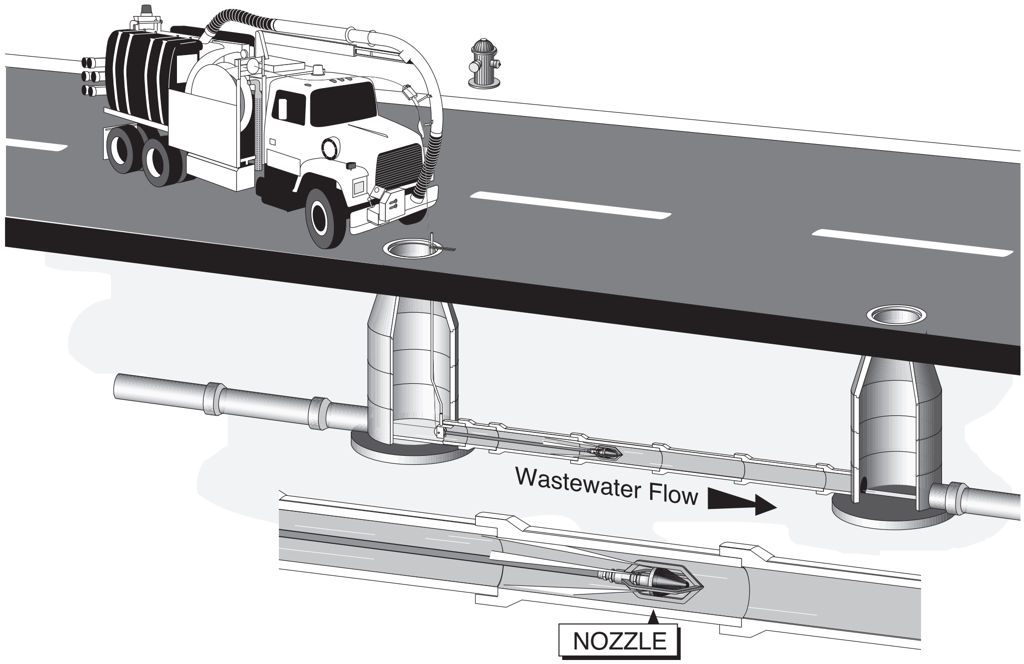
Most Effective

The high velocity cleaner (HVC) can be the most effective cleaning device available. However, it is also the most costly and requires the highest level of technical expertise to properly operate. Of all of the methods available the HVC is the most effective in clearing a blockage.

Equipment

A HVC is composed of special equipment. This equipment might include:

- A truck or trailer with a tank of water, usually 1,000 gallons. Connected to the tank is a high pressure piston pump. Pumps used for this purpose will produce 2000 to 3000 psi at a flow of 30 to 60 gpm.
- An electric or hydraulic reel with several hundred feet of flexible "rubber" hose connected to the pump.
- A special nozzle has been designed for these devices. The most common nozzles are composed of several nozzle openings. These openings direct the flow of water backwards.
- A down rigger pulley assembly is used in the manhole to protect the hose and a debris trap is installed in the downstream manhole.



Special Small System HVC

An Anchorage company has produced a small trailer mounted HVC system that can be used for thawing and clearing frozen or blocked sewer mainlines up to eight inches in diameter. This unit utilizes a gas engine which drives a 2800 psi 4.5 gpm piston pump. In addition, an oil fired boiler is included to heat water for thawing frozen lines.

Fire Hose & Nozzle

Should Not be Used

A common method used by some small communities to clean a sewer line is a fire hose and a special rotating nozzle. When a fire hose is connected to a fire hydrant in order to obtain adequate water a cross-connection has been made. This process represents a significant health risk and should never be done.

Summary

Cleaning Direction

Flushing, balls, kites, bags, scooters and the HVC all clean the line by hydraulic action. The direction of cleaning is from upstream to downstream. That is, the cleaning is always done in the direction of the flow.

Safety Concerns

With the exception of the HVC, all of the other devices require entry into a manhole to install the device and remove the material from the downstream manhole. The HVC requires entry into the downstream manhole to remove the material cleaned from the line. The exception to this is the use of one of the new vacuum or high velocity air removal trucks. This piece of equipment allows the operator to “suck” the material out of the manhole with a device that is very much like a large vacuum cleaner.

Chemical Cleaning

Special Consideration

There are various chemicals that can be used by operators to help with the operation and maintenance of the collection system. These include, chlorine, masking agents to cover odor, hydrogen peroxide, degreasers, copper sulfite and herbicides. However, before purchasing and using any of these chemicals the following should be considered:

- What impact will the chemical have on the effectiveness of the treatment plant and receiving body?
- Will another method work just as effectively?
- What are the safety considerations in transporting and handling the chemical?
- What is the cost of the chemical and the cost of safety equipment needed to handle the chemical?
- Is any special training required?
- How effective has the chemical been under similar circumstances?
- How long after you use the chemical should it be before you see the effects?
- How will temperature impact the performance of the chemical?

Uses of Chemicals

Root Control

Aquatic Herbicides

The most common chemical treatment for root control is the use of aquatic herbicides. Some of the root control chemicals are also classified as pesticides. These chemicals are typically applied as a foam using a special attachment to a high velocity cleaner of commercially by specially designed application devices.

Effectivness

The chemicals kill roots that extend into the sewer and stunt the growth of additional roots for 12 to 36 months.

Safety and Health Concerns

Before selecting a chemical for root control, verify that it is registered with the state environmental agency and with the US EPA. While there is little evidence of damage to the sewage treatment process by these chemicals, it is critical to notify the treatment plant operator of the intent to use these chemicals. The MSDS should be consulted to determine the appropriate personal protective equipment needed for handling and using these chemicals.

Grease Control

The Problem

Grease buildup in lines can contribute to a stoppage. Grease buildup in lift station wet wells interferes with the operation of the level controls.

Cause of the Problem

There are three sources of grease in a collection system, they are:

- Small amounts that are dumped down the sink in homes.
- Restaurants where grease traps are not installed or not maintained. This is the major source.
- Illegal dumping of oil by an auto repair shop or service station.

Solutions - Lines

The most effective means of solving the restaurant grease problem is to implement and enforce a grease trap ordinance. However, if there is still a buildup of grease, the sewer ball or HVC can be very effective.

Solutions - Lift Station

Grease buildup in a lift station wet well may be removed by physically breaking up the grease with a stick and fire hose and then using the pumps to remove the material. Recently there have been several commercial products that have proven very effective in cleaning lift station wet wells.

Odors

Hydrogen Sulfide

The most common odor problem associated with collection systems is hydrogen sulfide. Customers do not appreciate the "rotten egg" odor that it produces.

Production Process

Hydrogen sulfide is produced by anaerobic bacteria that live in the slime buildup on the interior of the pipe and in low spots in the line where wastewater becomes anaerobic. In addition to the odor problem, hydrogen sulfide when mixed with water will produce sulfuric acid that can damage concrete pipes and metal manhole steps.

Best Control Method

The best method to control hydrogen sulfide is frequent and effective line cleaning.

Chemicals

The following common chemicals can also be used for odor control:

- Chlorine - added upstream of the problem, usually at a lift station.
- Hydrogen peroxide - added upstream of the problem, usually at a lift station.
- Air - A blower can be placed in a lift station and used to aerate the wet well in order to discourage anaerobic activity.
- Masking Agents - Chemical masking agents that smell like vanilla, apples, oranges or other pleasant

odors, are sometimes used to mask odors. While these can have some positive public relations impact they do not solve the problem and frequently create an obnoxious odor when mixed with the sewage.

Consideration - Chlorine

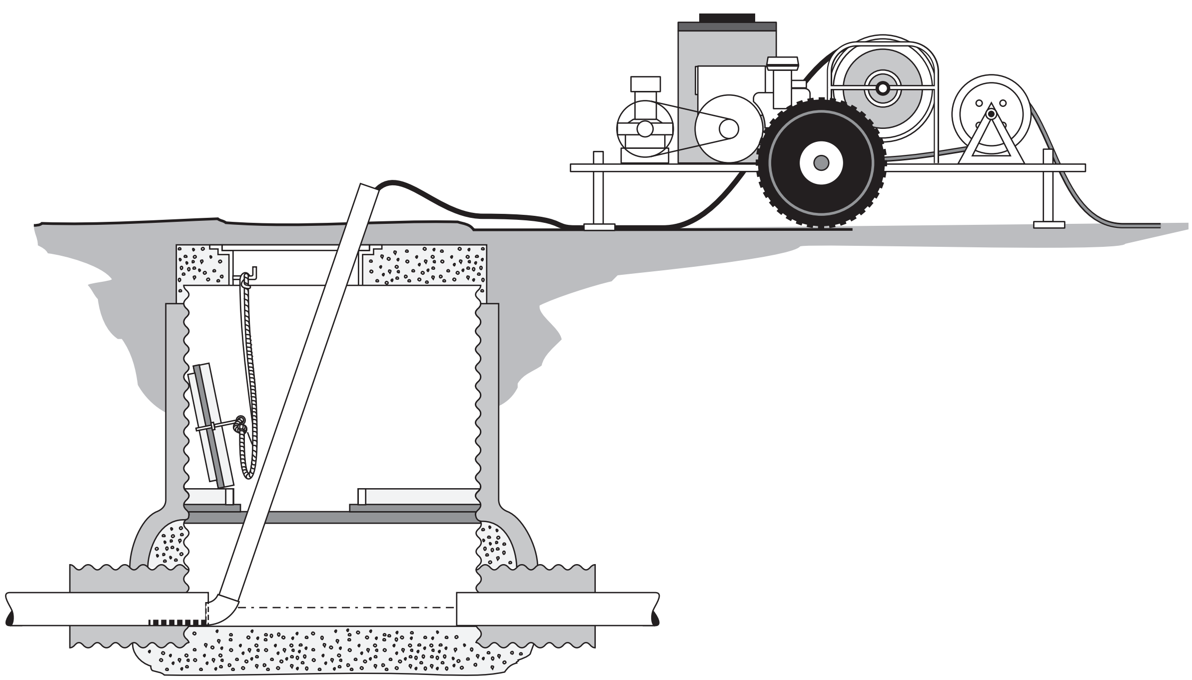
The handling and use of gas chlorine presents a wide variety of safety problems. Gas chlorine is classified as a poison and an inhalation hazard. As such, there are special requirements for storage, handling and transportation. The result of these concerns makes the use of calcium or sodium hypochlorites more desirable than chlorine gas.

Frozen Lines

Avoiding Frozen Lines

Frozen sewer lines are not common as most are installed below the frost level. In addition, wastewater collection systems in the Arctic and subarctic are specially designed for cold weather (heat tape, Arctic pipe, Arctic manhole, insulated and heated utilidors, etc.) freezeups will occasionally occur. The potential for freezing problems can be minimized by:

- Preventing blockages by pressure cleaning or flushing lines prior to winter.
- Checking each Arctic manhole to be sure that frost lids are properly positioned.



Thawing Buried Lines

Normal Occurrence

Even if well maintained, system freezeups occur. What can you do if the system freezes?

High Velocity Cleaner

The most effective means of thawing frozen lines is with the high velocity cleaner. One of the most effective HVC units is the small unit described in the HVC section of this text. This unit allows the use of high pressure hot or cold water. If the line is PVC or HDPE then high pressure hot or cold water can be used.

Thawing Procedure

Thaw the line by starting at the last downstream manhole that is clear and work the nozzle upstream into the frozen section of the line.

Steam and Arc Welders

Steam should only be used on PVC and HDPE if the temperature can be reduced to below 230°F. Arc welders only work on metal pipes but should be avoided because of the possibility of causing a house fire, and other hazards.

Lift Station Inspection

Inspection

Why Inspect?

Lift stations are inspected in order to assure that they are operating properly and to identify and correct potential problems before they occur.

Conditions

A typical inspection would include the following:

- Look for a buildup of grease in the wet well
- Observe the appearance of the piping. Check for leaks and deterioration.
- Check for leaks at valve stems.
- Check the quantity of leakage at the stuffing box of pumps with packing. When a mechanical seal is being used there should be no leakage from the stuffing box.
- Check for odors in the wet well. This is a good way to determine if the sewage is going septic or if there has been an accidental or illegal dump of fuel into the collection system.

Inspection Frequency

The frequency of visitation to a station is based on the condition of the station and the problems that a station failure would cause. In general each station should be visited at least three times a week. A typical routine would be three visits a week, Monday, Wednesday and Friday. If the station is in poor condition or can cause a major health or public relations problem if it fails, daily visits are advised.

Operational Considerations

Clean Wet Well

Once a year the wet well should be cleaned. This requires dewatering the wet well, removing the buildup of solids and washing down the walls.

Screens

If there is a bar screen or a screen basket in the wet well it should be cleaned at least two to three times each week. The material collected on the screen should be placed in a plastic bag, treated with lime and disposed of at the landfill. In freezing conditions it may be desirable to allow the material to freeze before it is transported to the landfill.

Data Collection

Why Collect Data?

The primary data that is collected at a lift station is associated with the pumping system. This data is collected in order to evaluate the conditions of the pumps. From an evaluation of the data it is possible to reduce failures, assist with troubleshooting, and reduce the overall maintenance cost.

What Data is Collected?

In order to evaluate the performance of a pump the following data should be collected.

Data	**Frequency**
Observe status lights	Each visit
Power consumption	Weekly
Hour meters	Record on each visit or at least once a week
If seal water has a filter, clean	Weekly
Amperage and voltage	At least quarterly. Each visit when panel mounted meters are used
Check the position of H-O-A switch	Each visit
Change lead/lag pumps	Weekly or Monthly *(assumes no alternator in circuit)*
Test status of light bulbs	Quarterly
Test pump discharge pressure	Twice a year
Measure pump flow by doing draw down test on wet well	Twice a year

Frequency of Line O & M

Overview

The following is a brief listing of the frequency of performing routine maintenance procedures on collection system lines and manholes:

Lines

Clean at least every 3 years minimum, once a year is best.

Flow testing - twice a year during wet and dry flows.

Other testing - based on data gathered from flow tests and from observations.

Manholes

Once every 3 years is minimum, once a year is best.

Collection Systems

Worksheet

1. The two functions of a collection system are to prevent ____________________ and improve the ______________________ of the community.

2. Describe the three types of collection systems.

   a. Sanitary sewers ____

   b. Storm sewers ____

   c. Combined sewers ____

3. What is the most common health problem associated with honey bucket systems? What causes this problem?

4. What are the two most common operational problems with haul systems?

   a. ________________________________

   b. ________________________________

5. What is the most common health concern associated with the haul system? How can this problem be dealt with effectively?

6. There are at least eight (8) special considerations for operation and maintenance of collection systems in the Arctic. Name four.

   a. ________________________________

   b. ________________________________

   c. ________________________________

   d. ________________________________

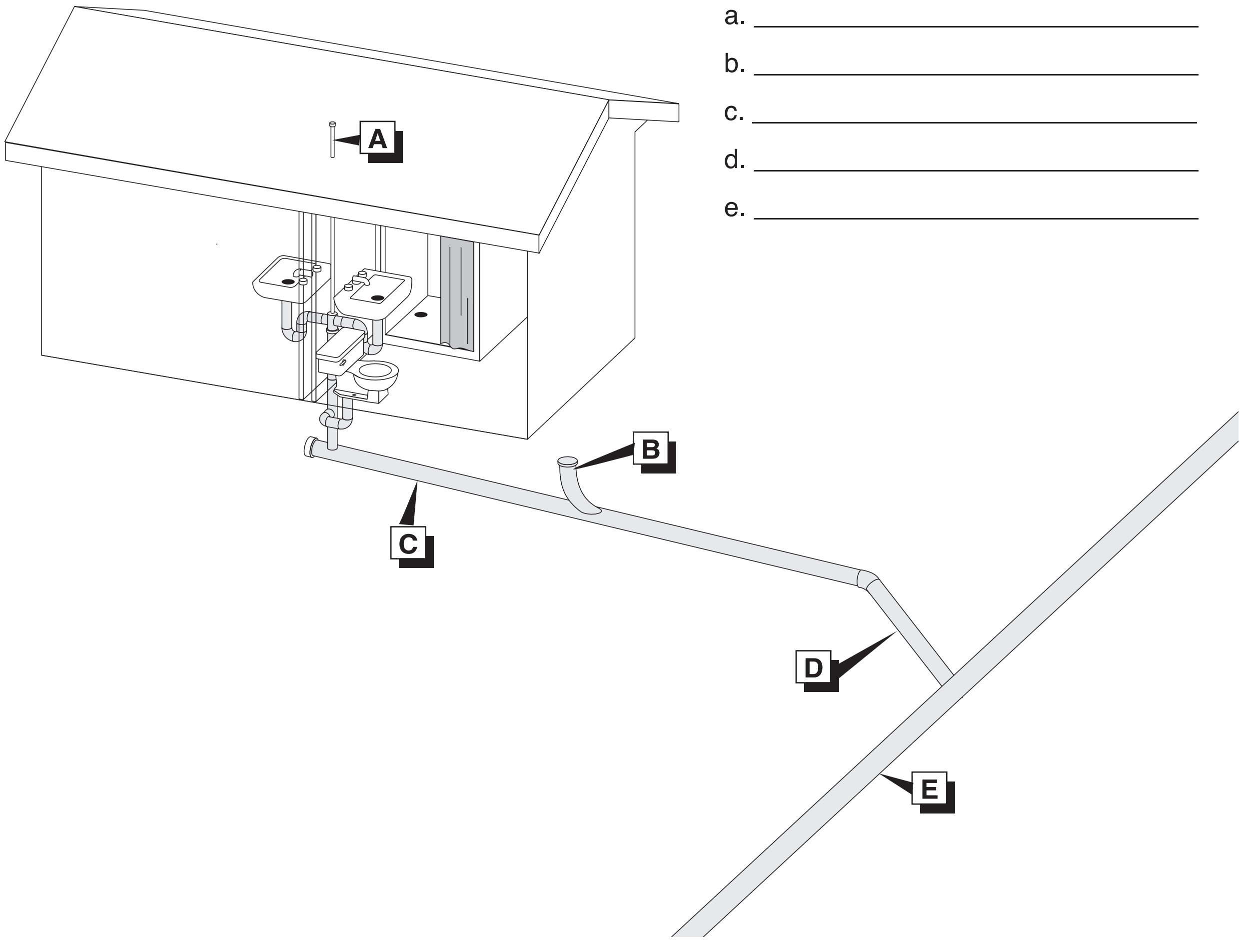
7. The building sewer usually extends ______ feet to ______ feet from the building.

8. A _______________________ sewer collects sewage from one or more laterals.

9. A main sewer connects into a ___________________ sewer at a __________________.

10. The pressurized line leading away from a lift station is called a ___________________ main.

11. Identify the components indicated below.



a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________

12. The velocity in a collection system should not drop below ______________ feet per second. Why?

13. The interior pipe in an Arctic pipe is called the ______________________.

14. The two most common methods of heating a utilidor are:

a. ______________________________

b. ______________________________

15. Identify the items shown below.

a. ______________________________

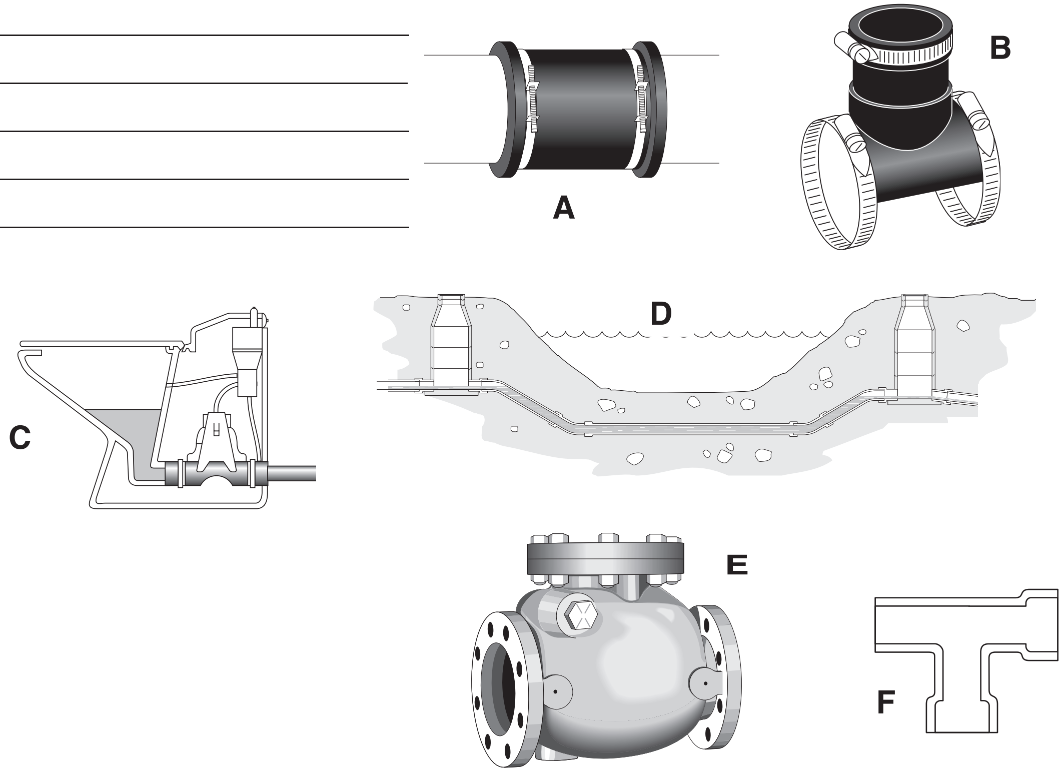
b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________

f. ______________________________



16. List the three common types of manholes used in Alaska.

a. ______________________________

b. ______________________________

c. ______________________________

17. Identify the manhole components shown to the right.

a. ______________________________

b. ______________________________

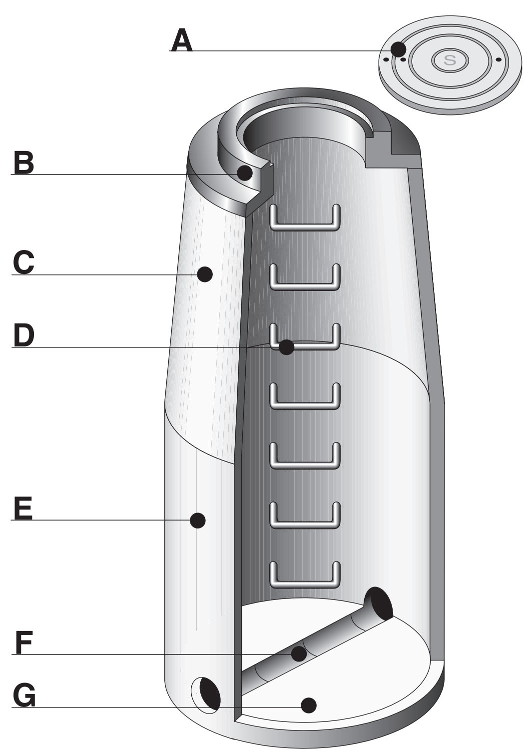
c. ______________________________

d. ______________________________

e. ______________________________

f. ______________________________

g. ______________________________

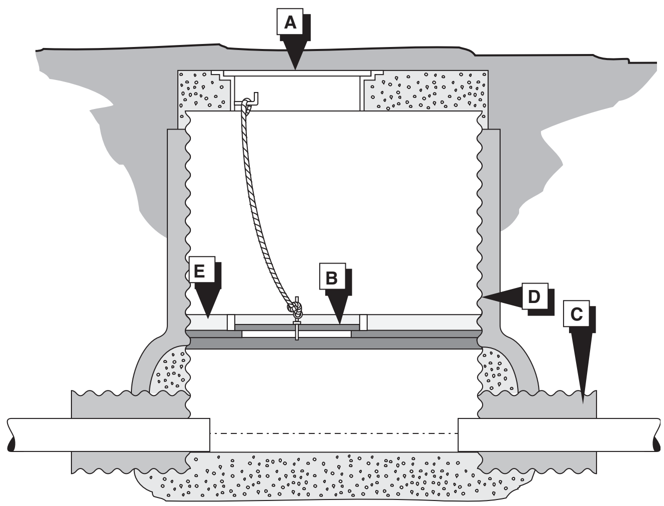


18. What is the function of a lift station?

19. Manholes are located at every ________________ in direction, change in _________________ and at _________________ ____. On straight runs of lines less than 15 inches in diameter manholes are located every _____________ feet.

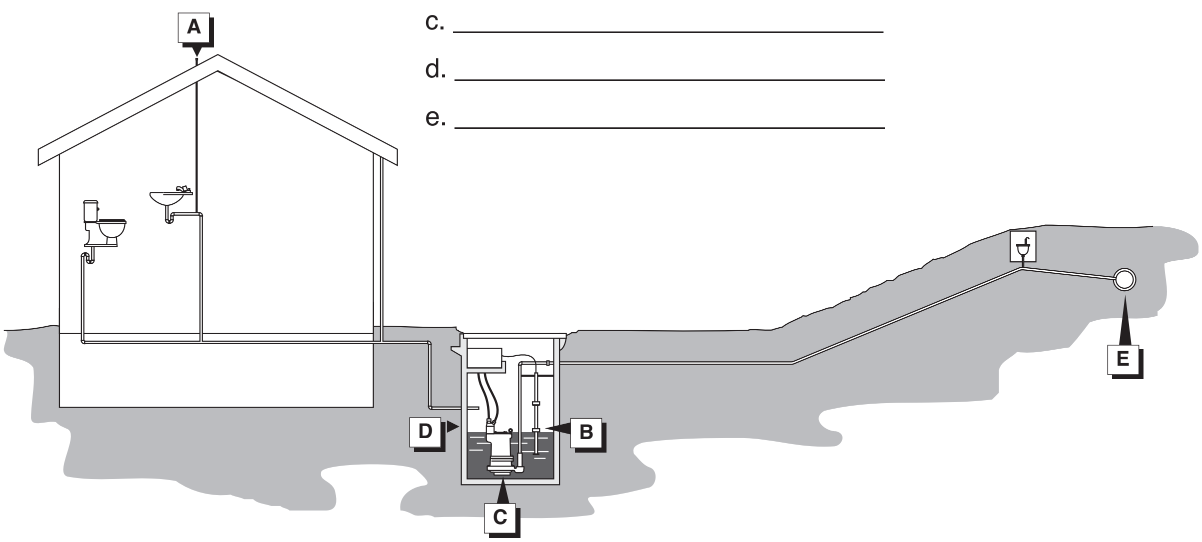
20. Identify the Arctic manhole components shown below.

    a. ________________________________
    b. ________________________________
    c. ________________________________
    d. ________________________________
    e. ________________________________



21. Identify the items indicated on the drawing below.

    a. ________________________________
    b. ________________________________
    c. ________________________________
    d. ________________________________
    e. ________________________________



22. Identify the items indicated on the drawing below. (**vacuum system)**

a. ______________________________

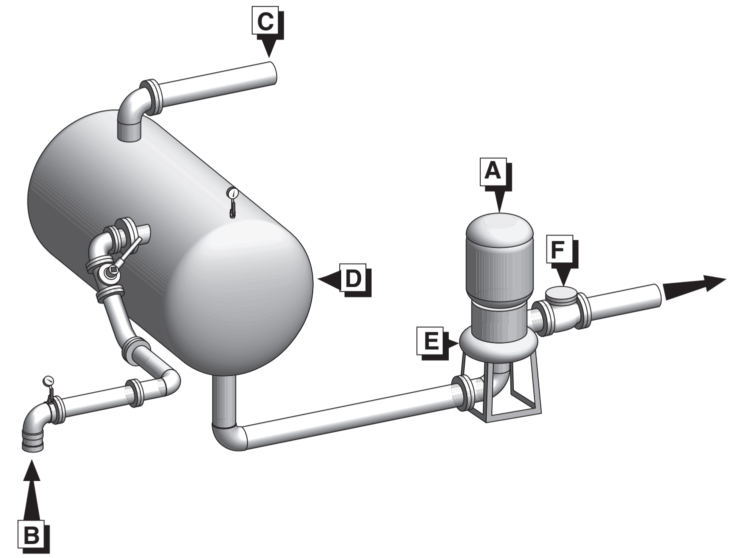
b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________

f. ______________________________



23. Using the drawing below, identify the various types of sewers

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________

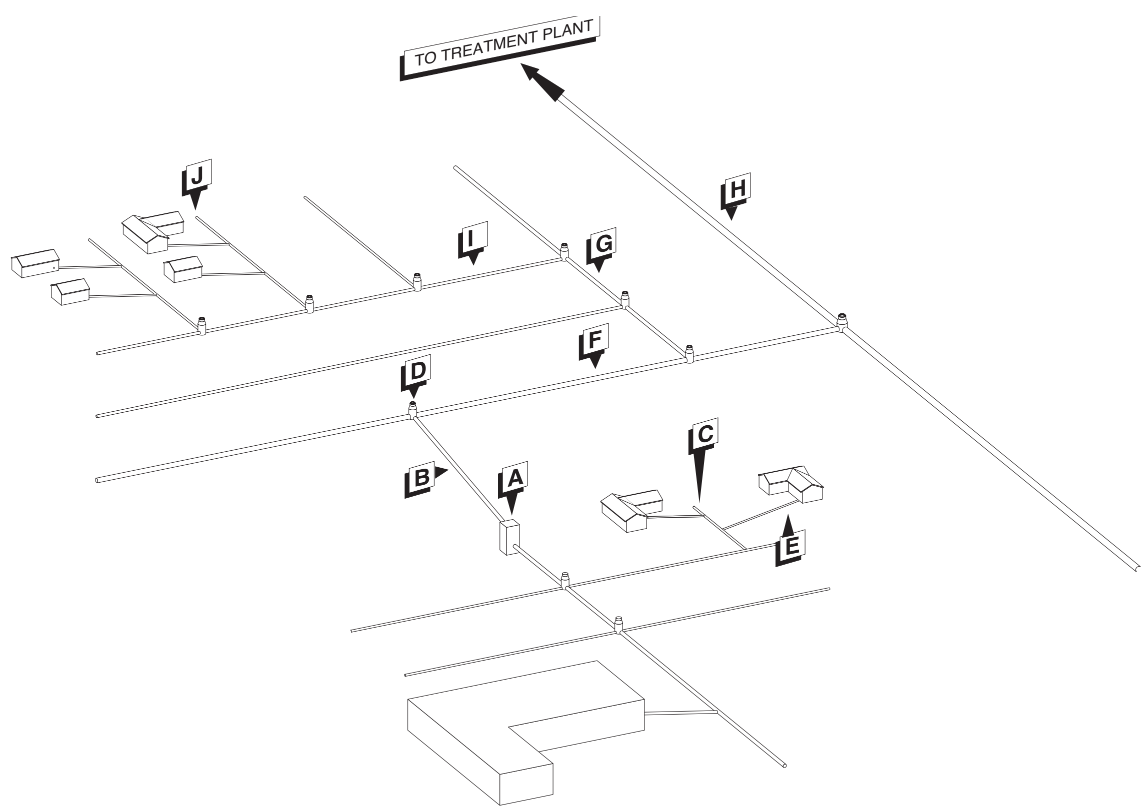
f. ______________________________

g. ______________________________

h. ______________________________

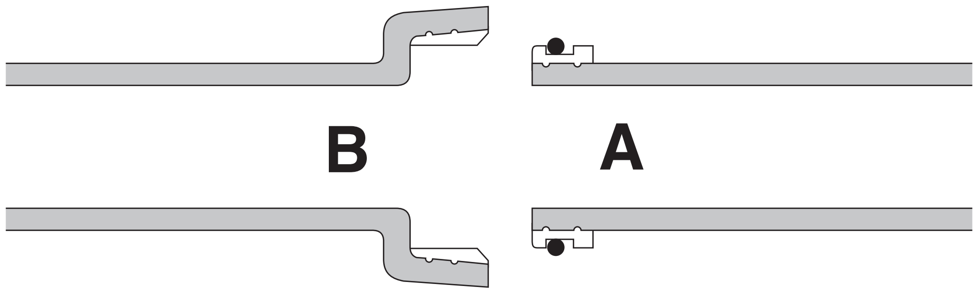
i. ______________________________

j. ______________________________



24. Of all of the piping materials which one (s) are not severely damaged by freezing?

25. On the drawing of the pipe below, identify the bell and the spigot.



26. Using the drawing below, identify the components indicated. (**storm sewer)**

a. ______________________________

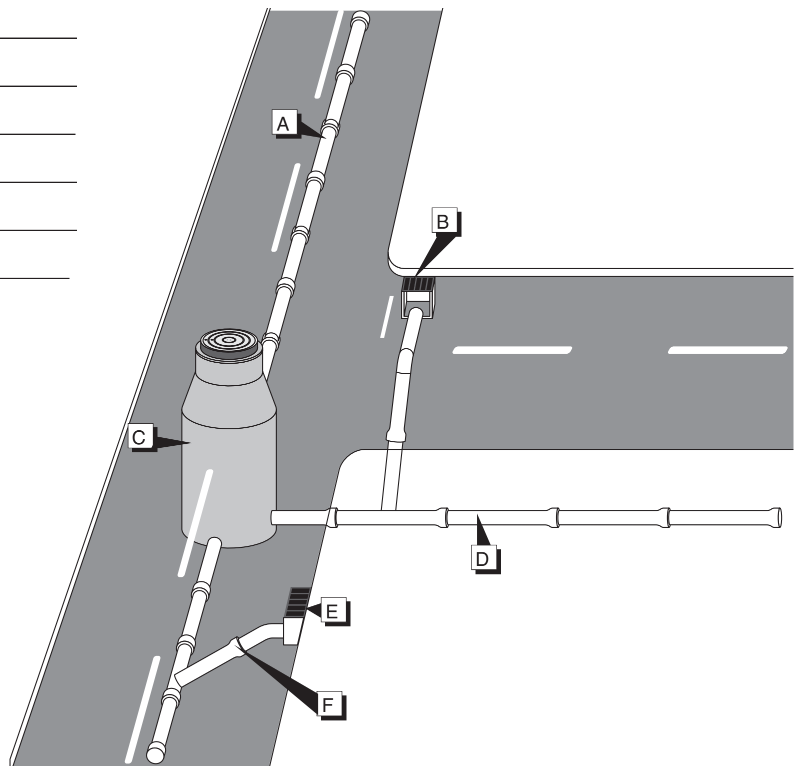
b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________

f. ______________________________



27. When the eye of the impeller of a pump is placed below the water it is pumping from, the pump is said to be in a suction _______________ condition.

28. What is the major physical difference between a wet well and a dry well lift station.

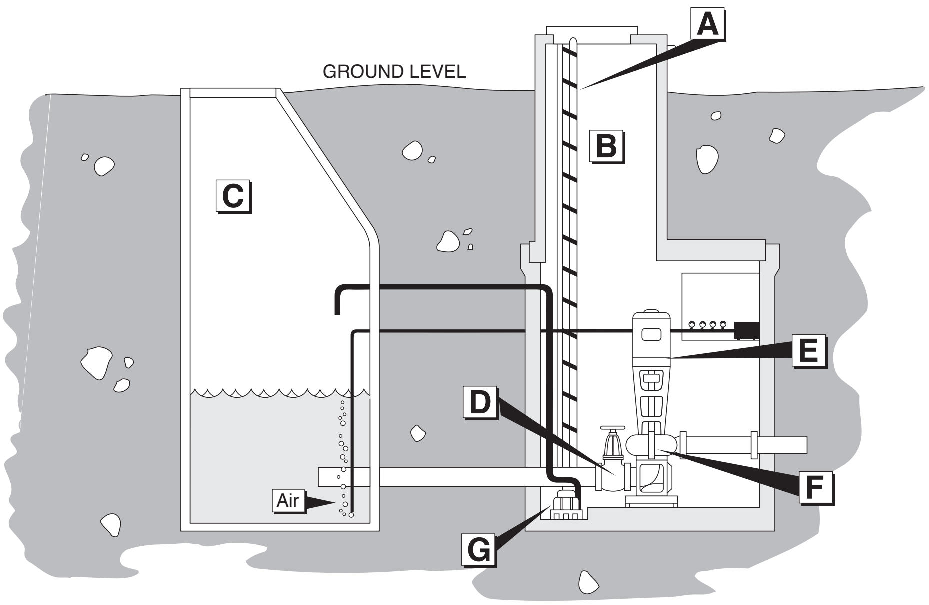
29. Using the drawing of the lift station below, identify the major components .

a. ______________________________ e. ______________________________

b. ______________________________ f. ______________________________

c. ______________________________ g. ______________________________

d. ______________________________



30. The most common pump used in a lift station is the ______________ ____________ ______________________.

31. There are four common level control systems used in lift stations. They are:

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

32. Which of the following are confined spaces?

______ a. Wet well of a lift station

______ b. Dry well of a lift station

______ c. Manhole

33. Define the following words.

    a. Inflow ____

    b. Infiltration ____

    c. Exfiltration ____

34. The connection of a roof drain to the collection system is an example of:

    ______ a. Inflow

    ______ b. Infiltration

35. The flow of water into a collection system through the holes in a manhole cover is an example of:

    ______ a. Inflow

    ______ b. Infiltration

36. Why is exfiltration a concern?

37. The gas that mixes with water to form an acid that can damage concrete pipes and manhole ladders is: ______________________________

38. What condition(s) would have to exist to allow roots to enter a collection system?

39. Why is the buildup of grease in a collection system a problem?

40. What problem is caused by excessive grease in a lift station?

41. There are four common safety problems associated with entering and working in manholes and lift station wet wells. They are:

    a. ________________________________

    b. ________________________________

    c. ________________________________

    d. ________________________________

42. Any time the oxygen level in a manhole is below __________ % entry should not be attempted.

43. A manhole should not be entered when the hydrogen sulfide level is above _______ ppm.

44. Why should manholes be inspected routinely?

45. There were eight conditions identified that should be checked when inspecting a manhole. List four of these.

    a. ________________________________

    b. ________________________________

    c. ________________________________

    d. ________________________________

46. Lamping is used to identify two conditions, they are:

    a. ________________________________

    b. ________________________________

47. There are two simple methods of confirming a connection to a collection system. They are:

    a. ________________________________

    b. ________________________________

48. When smoke testing, which of the following items would indicate that the system is in good condition and all connections are proper.

    ______ a. Smoke from manhole lid vents

    ______ b. Smoke from roof drains

    ______ c. Smoke from floor drains

    ______ d. Smoke from roof vents

    ______ e. Smoke from along side of a manhole

49. CCTV is used for a variety of uses. List three basic functions:
    a. ________________________________
    b. ________________________________
    c. ________________________________

50. What is the function of flow testing?

51. What are the four mechanical cleaning devices?
    a. ________________________________
    b. ________________________________
    c. ________________________________
    d.________________________________

52. List the five most common hydraulic cleaning methods.
    a. ________________________________
    b. ________________________________
    c. ________________________________
    d. ________________________________
    e. ________________________________

53. When using a hydraulic cleaning method, what is used to do the cleaning?

54. What is one of the major customer concerns when using a hydraulic cleaning method?

55. What are two collection system conditions that can be controlled with chemicals?

56. Hydrogen sulfide should be controlled in a collection system because its presence can cause deterioration to ______________, it is ______________ to operators entering the system and it causes a _________________ relations problem.

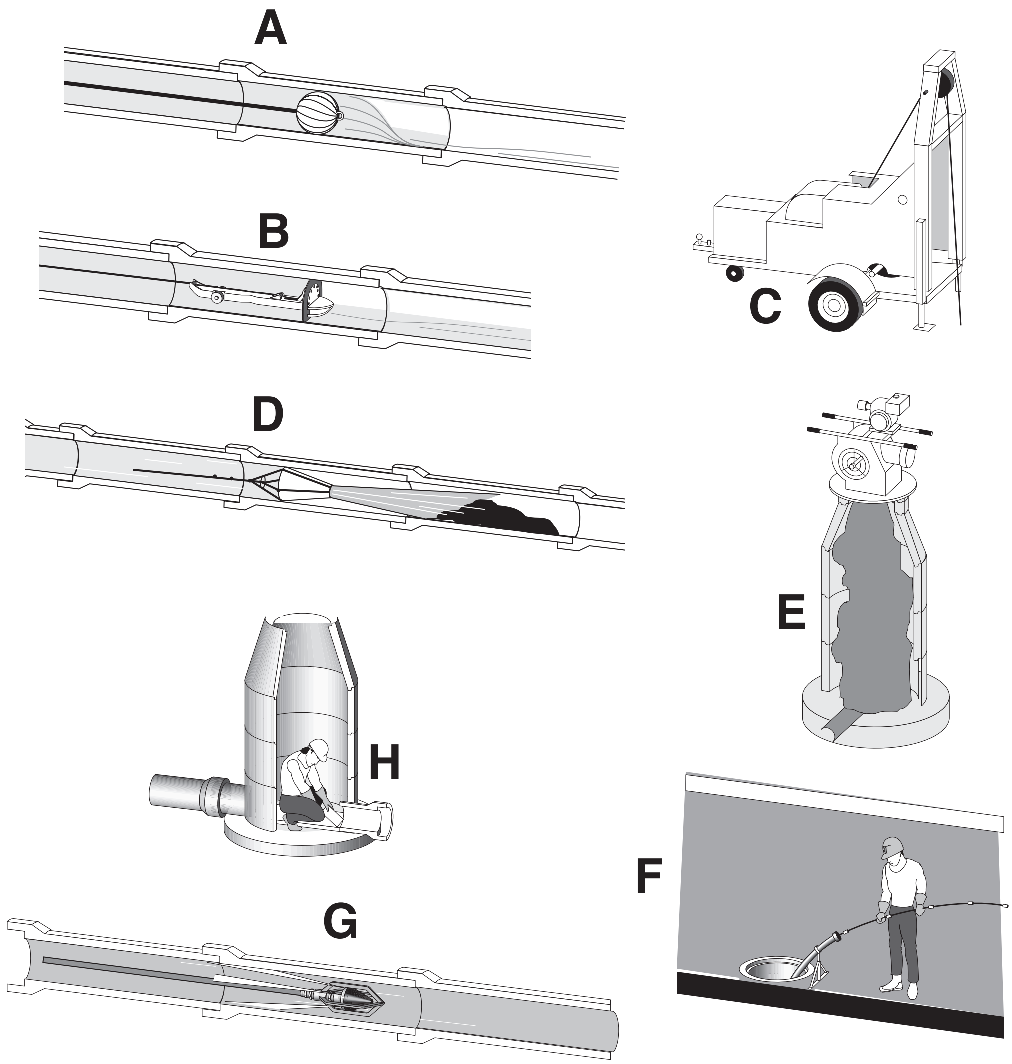
57. Identify the testing and cleaning methods shown below.

a. ______________________ e. ______________________

b. ______________________ f. ______________________

c. ______________________ g. ______________________

d. ______________________ h. ______________________



58. What is the best method for controlling hydrogen sulfide production?

59. What are two chemicals that can be used to control hydrogen sulfide?

a. ______________________

b. ______________________

60. How can you determine the frequency of inspection of a lift station?

61. Lines should be cleaned every ______________________________.

62. Manholes should be inspected every __________________________.

63. Prior to winter the collection system operator should __________ the lines and check the ____________ ____________ in the Arctic manholes to minimize the potential for freezing.

64. The __________ is one of the most effective tools for clearing a frozen line.

65. When attempting to clear a frozen blockage in a collection system line you should work, ❑ upstream or ❑ downstream into the frozen section.

Wastewater Treatment Techniques

What is in this Lesson?

1. The type of material that makes up grit
2. Typical grit disposal processes
3. The mechanical components used in preliminary treatment and their function
4. The average velocity through a grit chamber
5. The processes that may be included in preliminary treatment
6. The material that would normally be removed by screens
7. The functions of preliminary treatment
8. The reason for removal of grit
9. The concentration of primary sludge
10. The treatment process provided by a primary clarifier
11. Those items that would affect settling in a primary clarifier
12. The sludge and liquid flow through a primary clarifier
13. The normal detention time of primary clarifier
14. The removal percentages in a primary clarifier for BOD, TSS, SS and bacteria
15. The two functions of a primary clarifier
16. Typical problems in the inlet channel of a primary clarifier
17. The various zones of a clarifier
18. The components of a clarifier
19. The function of baffles in a basin
20. The routine operational duties associated with a septic tank system
21. The components of a septic tank system
22. The treatment process provided by a septic tank
23. The aerobic treatment process as provided by secondary treatment
24. The removal percentages for TSS, SS and BOD provided by secondary treatment
25. The typical detention times in the various biological treatment processes
26. How a trickling filter works
27. The air and water flow through a trickling filter
28. The components of the film found on the media in a trickling filter
29. The function of a trickling filter and the type of process
30. The components of a trickling filter
31. Basic trickling filter problems
32. The depth of rocks in a trickling filter
33. The one operational control change that an operator can make in a trickling filter plant

34. Media, other than rocks, that can be used in a trickling filter
35. Two reasons for recirculation in a trickling filter
36. The treatment process used in an RBC
37. The function and components of an RBC
38. The components of an RBC system
39. How activated sludge is developed
40. How solids concentration is controlled in an activated sludge plant
41. How the sludge blanket level is controlled in an activated sludge plant
42. A description of the activated sludge process
43. The appearance of MLSS in a properly operated activated sludge plant
44. The basic process used in each of the process units in a typical activated sludge facility
45. The biological process used in activated sludge
46. The biological response of microorganisms to high and low volumes of food
47. The characteristics of normal settling activated sludge
48. The difference between a typical activated sludge plant and what is commonly called a package plant
49. The difference between conventional treatment, extended air and contact stabilization activated sludge plants
50. The flow of mixed liquor, air and return sludge through an activated sludge plant
51. The food chain and function of basic components of the chain in an activated sludge process
52. The function of aerators in an activated sludge facility
53. The function of the return sludge in the activated sludge process
54. The impact of adjusting MLSS on the return sludge
55. The impact of high flow on an activated sludge facility
56. The impact of plugged diffusers in an aeration tank on mixing
57. The settling response of activated sludge under various conditions
58. The components of an activated sludge plant
59. The components of an oxidation ditch
60. The components of a package plant and describe the hydraulic flow path through the plant
61. The cause of low DO in an aeration basin
62. The DO range in an aeration basin
63. The three process control changes that an operator can make in an activated sludge plant
64. The type of biological process used in activated sludge treatment
65. The sources of organic loading
66. Common package plant problems
67. The treatment process provided in a secondary clarifier

68. The cause of rising sludge by a secondary clarifier
69. The normal detention time in a secondary clarifier
70. The difference of an aerobic, anaerobic and facultative waste pond
71. The natural aeration process of lagoons
72. The problems associated with operating a lagoon that is frozen for several months of the year
73. The treatment process that takes place in a stabilization pond
74. The mechanical equipment used to aerate lagoons
75. The difference in depth between an aerobic, anaerobic and facultative pond
76. The changes in the oxygen content and the various zones of a lagoon between winter and summer
77. The components of a stabilization pond
78. Why accurate flow measurements are needed at a WWTP
79. The process used by weirs and flumes to measure flow
80. Various types of weirs and flumes used to measure flow in a wastewater treatment plant

Key Words

- Activated Sludge Process
- Aeration
- Aeration Basin
- Agglomeration
- Bacteria
- Baffle
- Barminutor
- BOD
- Comminutor
- Denitrification
- Detention time
- Diffuser
- Digestion
- Dissolved Oxygen
- Distributor
- Effluent
- Extended aeration
- F/M Ratio
- Flights
- Freeboard
- Grit
- Grit Removal
- Hydraulic loading
- Inorganic
- mg/L
- Microscreen
- Mixed liquor
- MLVSS
- MLSS
- Nitrification
- Organic
- Overflow rate
- Oxidation
- Pathogenic Organisms
- Pin floc
- Preliminary treatment
- Primary treatment
- Protozoa
- Return activated sludge
- Scum
- Secondary treatment
- Septic
- Shock load
- Short circuiting
- Sidestream
- Sloughings
- Sludge
- Sludge age
- Sludge blanket
- Solids
- Straggler floc
- Surcharge
- Symbiosis
- Tertiary treatment
- Trickling filter
- Waste Activated Sludge
- Weir
- Zoogleal film

Wastewater Treatment Techniques

Introduction

From Collection System to Treatment

After the wastewater has traveled through the collection system, the process of removing the **organics**[1], **inorganics**[2], and as many **pathogenic organisms**[3] as possible begins.

Function of Treatment

This lesson will cover the physical and biological treatment processes used to stabilize wastewater to produce an **effluent**[4] that can be discharged harmlessly into the environment.

Solids Treatment

A subsequent lesson will deal with the **solids**[5] that are produced as the wastewater treatment process is accomplished. Solids that are removed from the wastewater are called **sludge**[6] and require further treatment to reduce the risk from pathogens.

Treatment System

A treatment plant may be composed of a combination of the following stages; **preliminary treatment**[7], **primary treatment**[8], **secondary treatment**[9] and **tertiary treatment**[10].

Selection of Stages

The selection of which stages belong in a specific treatment plant is determined by the design engineer. This selection is based on the effluent requirements that are established by state and federal regulations. These requirements are listed in a permit that is issued by either the state or the federal EPA. The state permit is called a wastewater discharge permit. The federal EPA permit is called a NPDES (National Pollution Discharge Elimination System). Each state has made an agreement with EPA on who is to issue permits for each type and size of treatment plant.

1 **Organic -** Chemical substances of animal or vegetable origin, made basically of carbon structure.

2 **Inorganic** - Chemical substances of mineral origin.

3 **Pathogenic Organisms** - Bacteria, virus and protozoa which can cause disease.

4 **Effluent** - Sewage, water , or other liquid , partially or completely treated, or in its natural state, as the case may be, flowing out of reservoir, basin, or treatment plant, or part thereof.

5 **Solids** - As it pertains to wastewater - Suspended and dissolved material in wastewater.

6 **Sludge** - The accumulated settled solids deposited from sewage or industrial wastes, raw or treated, in tanks or basins, and containing more or less water to form a semi-liquid mass.

7 **Preliminary treatment** - The process of grinding material that can clog equipment, removing rags with screens and the removal of grit. Preliminary treatment is commonly a part of primary treatment.

8 **Primary treatment** - The first major (sometimes the only) treatment in a sewage treatment works. This process takes place in a rectangular or circular tank and allows those substances in wastewater that readily settle or float to be separated from the water being treated.

9 **Secondary treatment** - A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated. Usually a biological treatment process.

10 **Tertiary treatment** - Any process of water renovation that upgrades treated wastewater to meet specific reuse requirements. May include general cleanup of water or removal or specific parts of wastes insufficiently removed by conventional treatment processes. Typical processes include chemical treatment and pressure filtration.

Preliminary Treatment

First Stage

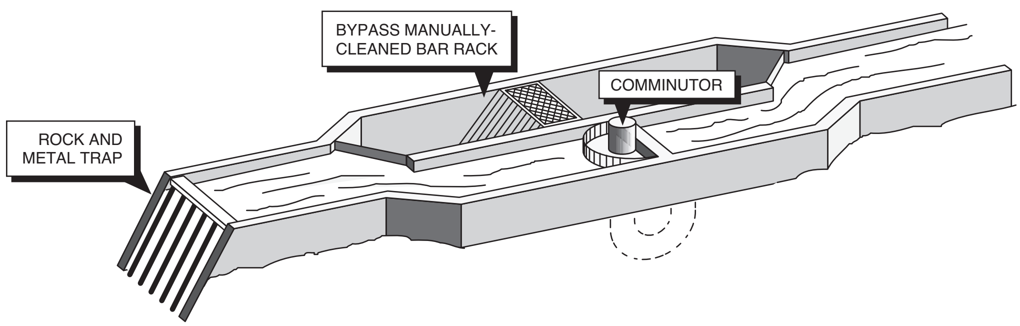
The first stage of a wastewater treatment plant is called preliminary treatment and may include screening, grinding, **grit removal**[11] and pre-aeration. Preliminary treatment is beneficial as it makes the sewage homogeneous, removes large untreatable material, and reduces the inorganic solids in the flow.

The Headworks

At the treatment plant, the area that contains the equipment to carry out the preliminary treatment is called the headworks. There are many different styles of headworks. Below are examples of just two common headworks configurations. Bar screens, grinders, grit removal equipment and flow devices are all pieces of equipment that can be found in the headworks of the plant.

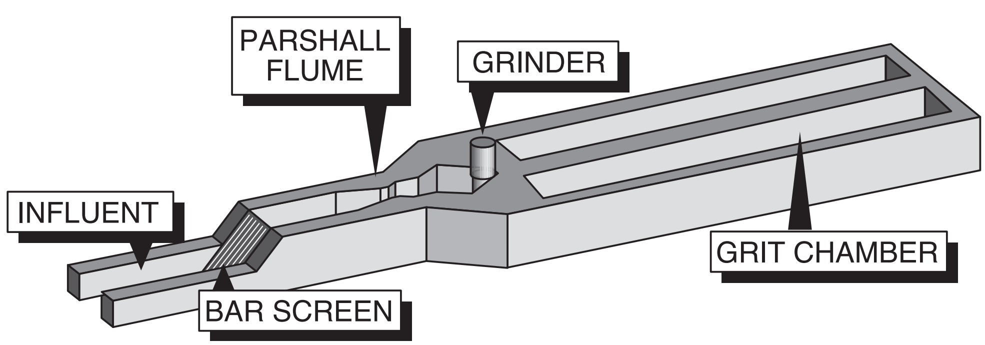
Headworks #1

The headworks below contains a bar screen, **comminutor**[12] and grit channel. There is a by-pass built around the comminutor. By changing the position of the stop log, flow is diverted to the second bar screen allowing maintenance to be performed on the comminutor.



Headworks #2

In the headworks below, a parshall flume has been added in order to measure the flow through the facility. There is no by-pass around the grinder.



11 **Grit Removal** - Accomplished by providing an enlarged channel or chamber which causes the flow velocity to be reduced and allows the heavier grit to settle to the bottom of the channel where it can be removed.

12 **Comminutor** - A device to reduce the size of the solid chunks in wastewater by shredding (comminuting). The shredding action is like many scissors cutting or chopping to shreds all the large influent solids material.

Screening

Function of Screens

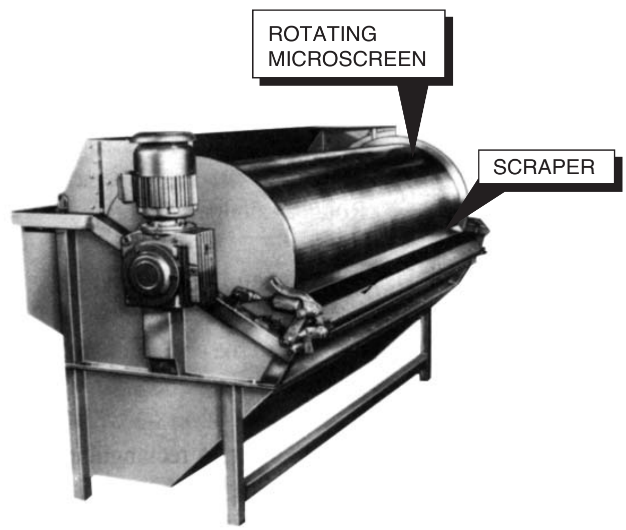
The first stage in most preliminary treatment is screening. Screens are used to remove large objects such as sticks and rags which may damage or plug pumps and piping, or which are aesthetically undesirable in the effluent. Two types of screens are used in preliminary treatment; coarse screens and fine screens.

Course Screens

Coarse screens (commonly called a trash rack or bar screen), are made of vertical steel bars spaced from 3/4 to 6 inches apart. The screens are usually installed at an angle, up to 15°, to facilitate manual cleaning. In larger plants the screens can be mechanically cleaned.

Fine Screens

Fine screens, sometimes called **microscreens**[13] can be used to serve two purposes. They can be used to remove rags and sticks just as bar screens and they can be used to remove smaller solids that would



normally be removed by the primary clarifier. In this later case they may be installed in a small plant as a substitute for the primary clarifier. One common fine screen is the rotating microscreen. With this device a fine screen drum is placed into a tank. Raw sewage flows into the tank and through the rotating drum. A scraper is used to remove the solids that collect on the screen. The sewage flows through the drum and on to the next treatment process. The screenings are placed into a container or dump truck for later disposal.

13 **Microscreen** - A device with a fabric straining media with openings usually between 20 and 60 microns. The fabric is wrapped around the outside of a rotating drum. Wastewater enters the open end of the drum and flows out through the rotating screen cloth. At the highest point of the drum the collected solids are backwashed by high pressure water jets into a trough located within the drum.

Screening Operations

Maintenance Requirements

During dry weather periods, coarse trash racks should be cleaned daily. During storm periods, they should be cleaned two to five times per day to maintain a free flow of sewage through the process.

Results of Poor Maintenance

Failure to clean the screens can result in one or more of the following:

1. The wastewater stream may go **septic**[14] upstream of the screening process.
2. Blocking of the screens could cause a **surcharge**[15] of sewers upstream of the screens.
3. Once the screens have been cleared a **shock load**[16] could upset the hydraulics of the plant.

Screening Disposal

Burial or Incineration

Disposal of screenings may be by burial, incineration, or **digestion**[17]. Burying and incinerating are the usual methods of disposal because they are the most economical methods. It is common for small plants to dispose of the screenings from a bar screen by burial at the plant site or at the landfill. The screenings should be kept covered and removed to disposal at least twice a week. Fine screenings from small plants are usually disposed of at the landfill or a dedicated disposal area. Disposal by burying or placement in the landfill should only be done with the approval of DEC.

Lime Application

When burying screenings, odors may be prevented by mixing the screenings with an equal volume of "milk of Lime" (see solids handling or disinfection for more information on milk of lime). An earth cover of one to two feet will usually give the best results for bacterial activity.

14 **Septic** - This condition is produced by anaerobic bacteria. If severe, the wastewater turns black, gives off foul odors, contains little or no dissolved oxygen and creates a heavy oxygen demand.

15 **Surcharge** - Sewers are surcharged when the surface of the wastewater in manholes is above the top of the sewer pipe. The sewer is then placed under pressure rather than being at atmospheric pressure. This condition contributes to exfiltration and the backup of sewage into individual homes.

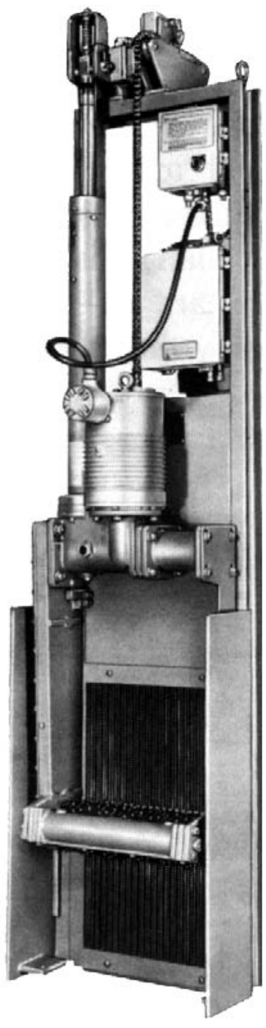
16 **Shock load** - The arrival at a plant of a waste which is toxic to organisms in sufficient quantity or strength to cause operating problems. Possible problems include odors and sloughing off of the growth or slime on the trickling filter media. Organic or hydraulic overloads also can cause a shock load.

17 **Digestion** - The biological decomposition of organic matter in sludge, resulting in partial gasification, liquefaction, and mineralization.

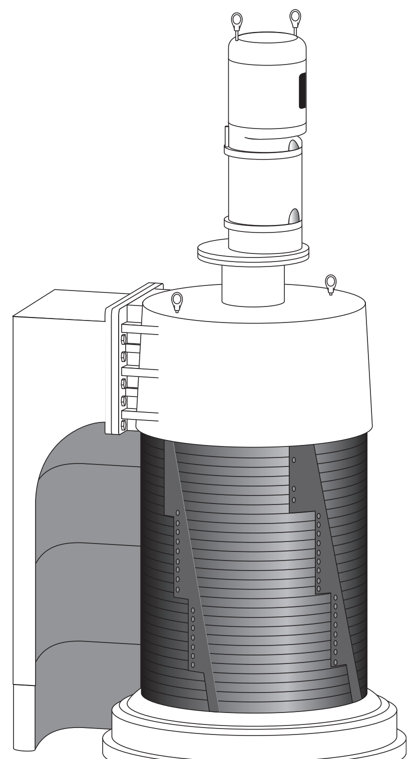
Grinding

Devices and Function

The next stage of preliminary treatment is usually grinding. Comminutors, **barminutors**[18], and macerator are names used by different manufacturers to identify shredding or grinding devices. These pieces of equipment are used to shred and grind large material into pieces small enough to pass through the screens of the grinding unit. Shredders should be installed with a by-pass equipped with a bar screen to facilitate removal of settled material and allow inspection of the equipment components such as the cutting edges.



Barminutor



Comminutor

Grinder Location

Grinding devices are normally operated continuously and are usually located ahead of the grit removal units.

18 **Barminutor** - (bar-mi-NEW-ter) A bar screen of standard design fitted with an electrically- operated shredding device that sweeps vertically up and down the screen cutting up material retained on the screen.

Grit Removal

What is Grit?

Grit[19] such as egg shells, sand, stones and gravel finds its way into a sewer system and is carried by the sewage to the treatment plant.

Quantity of Grit

In an average community, 3 to 8 cubic feet of grit can be collected per million gallons of sewage. The grit must be removed before it is carried into the primary clarifier or **aeration basin**[20].

Reason for Grit Removal

The grit removal device can reduce unnecessary maintenance more than any other unit. If the grit removal equipment is malfunctioning, the result will be plugged lines, worn pump impellers, and grit accumulation in the sedimentation basins and other treatment tanks, reducing their efficiency.

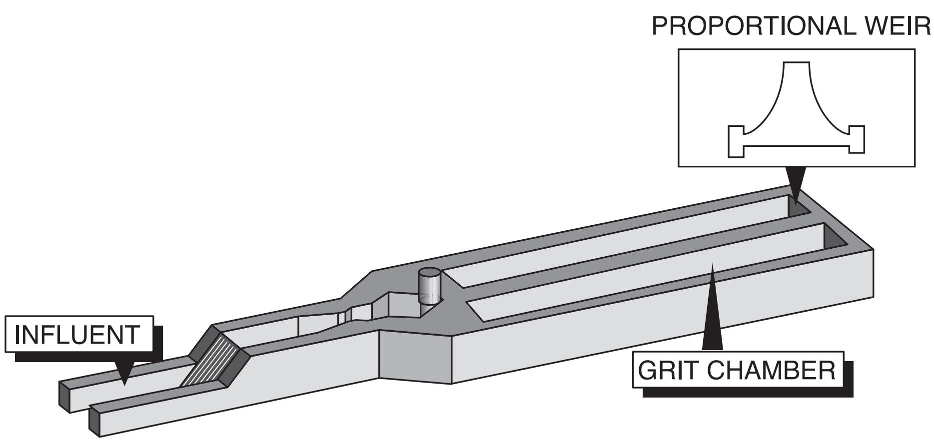
Location of Grit Removal Devices

Grit removal units are installed after screening equipment and prior to the primary clarifier. There are many different grit removal devices available. With small treatment plants the most common devices are:

- Grit channels
- Aerated grit chambers
- Centrifugal Separators

Grit Channels

Grit particles will settle faster than organic solids because they are heavier. Grit channels are designed to maintain a velocity of 1 foot per second at design flow. At this velocity, 0.2 mm size sand and all heavier particles will settle to the bottom of the channel. This velocity is sufficient to keep the organic matter in suspension. Grit channels are usually rectangular and velocity control is achieved by installing a proportional **weir**[21] at the effluent end of the channel.



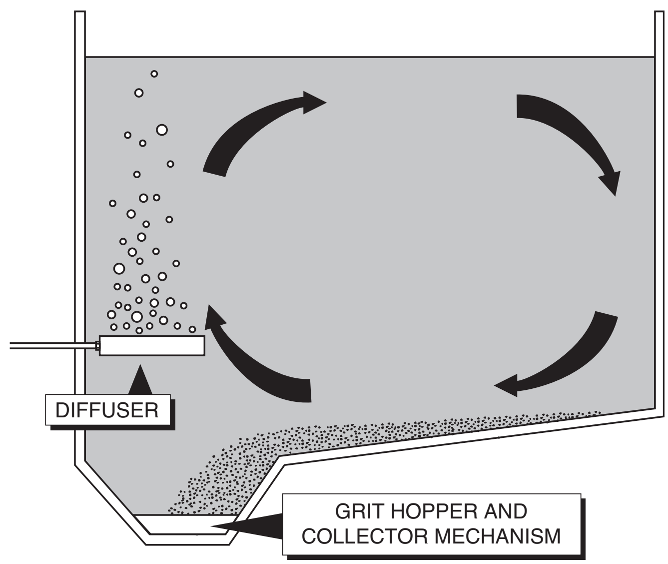
19 **Grit** - The heavy mineral material present in wastewater, such as sand, eggshells, gravel, and cinders.

20 **Aeration Basin** - A basin where raw or settled wastewater is mixed with return sludge and aerated. The same as aeration bay, aerator, or reactor.

21 **Weir** - A vertical obstruction, such as a wall, or plate, placed in an open channel and calibrated in order that. 1) a depth of flow over the weir (head) can easily be measured and converted into flow in cfs, gpm or MGD, 2) velocity through the channel can be controlled.

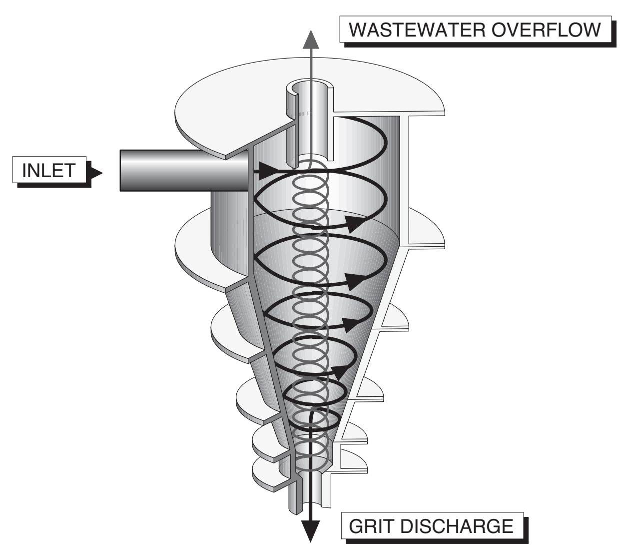
Aerated Grit Chamber

Aerated grit chambers use air to reduce the specific gravity of the wastewater and thus allow the heavier grit to settle and separate from the water and the lighter material. Wastewater flows into the aerated grit chamber and the heavier particles settle to the bottom as the sewage rolls in spiral motion from entrance to exit. The lighter organic particles eventually roll out of the tank. The grit at the bottom of the tank is directed to a grit hopper where it is removed by buckets or air lift pumps.



Centrifugal Separators

Centrifugal separators, also called cyclones, use centrifugal force to separate grit from the wastewater. The wastewater is introduced tangentially into a cylindrical conical housing. The heavier, larger particles of grit are thrown by centrifugal force to the outside wall and collected for disposal in the underflow. The wastewater leaves the center of the housing as overflow.



Grit Disposal

The disposal of grit is usually done by burial at a landfill site. Larger facilities use a grit washer to remove the majority of the organic material that may be accumulated with the grit. At small plants this unwashed grit should be stored in covered containers and removed to the disposal site daily.

Pre-aeration

Location and Reasons

While seldom used in small treatment plants, pre-aeration may be provided by aeration basins either preceding or following screening and grit removal. In general, pre-aeration tanks are designed for detention times of 5 to 15 minutes for one or more of the following purposes:

1. To remove gases from the sewage, especially hydrogen sulfide, which create odor problems and increase the chlorine demand.
2. To promote flotation of excessive grease, which then can be removed from the raw sewage at an early stage in treatment. **Aeration**[22] increases the amount of skimmings or grease because the rising air bubbles attach themselves to heavier-than-water particles causing buoyancy. This buoyancy holds the grease particles in the surface flow.
3. To aid in the coagulation of the colloids in the raw sewage resulting in a higher removal of suspended solids by primary settling.

22 **Aeration** - The process of adding air. In wastewater treatment, air is added to freshen wastewater and to keep solids in suspension. With mixtures of wastewater and activated sludge, adding air provides mixing and oxygen for the microorganisms treating the wastewater.

Primary Treatment

Function and Names

Following preliminary treatment, sewage flows into rectangular or circular basins where the wastewater flow is slowed further to allow the removal of those solids that will either float or settle out of suspension in a short period of time. This process is called sedimentation or clarification. The device used to provide this function is called a primary clarifier or primary sedimentation basin. Many small treatment plants are designed without a primary clarifier or may be designed with a microscreen instead of a primary clarifier. This portion of the treatment plant, primary clarifier or microscreen is called primary treatment.

Primary Treatment Plants

The primary treatment portion of the treatment plant should not be confused with primary treatment plants. A primary treatment plant usually includes preliminary and primary treatment. In addition a community septic tank is classified as primary treatment.

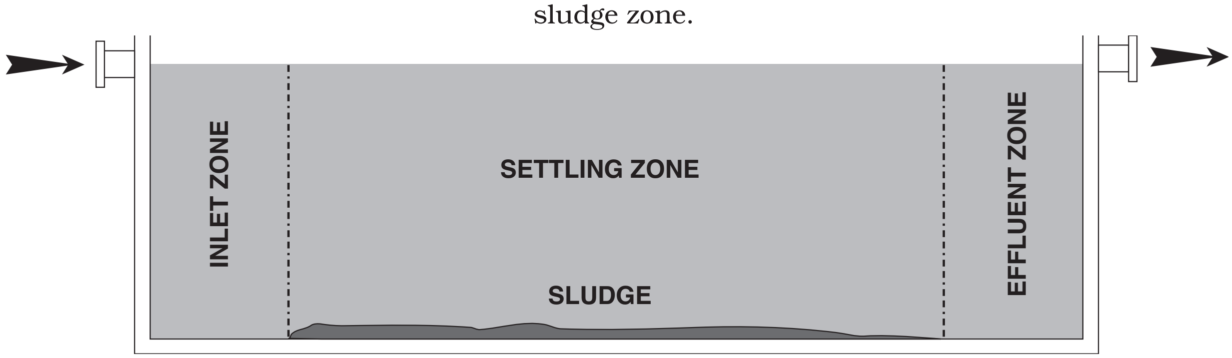
Sedimentation

Theory of Settling

The theory of settling is best described by looking at a rectangular tank. According to the theory, the wastewater enters one end of the tank and forms a prism across the tank. It then flows from one end of the tank to the other, coming back together at the far end and exiting the tank.

Tank Zones

In the theory of settling, the tank is divided into four zones; the inlet zone, settling zone, effluent zone and sludge zone.



Clarifier Zones

Removal of Solids

Liquid travels from the inlet to the outlet of the clarifier at a steady velocity. This velocity is dependent on the size of the clarifier and the rate of flow. As the liquid flows through the basin, solids settle to the bottom. If a solids particle is large enough to fall to the bottom of the basin in the length of time it takes the fluid to flow through the basin, then it will be removed. Most clarifier designs assume that the removal will be accomplished through the settling zone, the influent and effluent zones are turbulent, thus preventing settling in these zones.

Rectangular Clarifiers

Types of Clarifiers

There are two common types of primary clarifiers used in wastewater treatment, rectangular and circular. While the rectangular clarifier is seldom used in small treatment plants, a discussion is provided here because its description makes it easier to understand the function of the circular clarifier.

Wastewater Flow

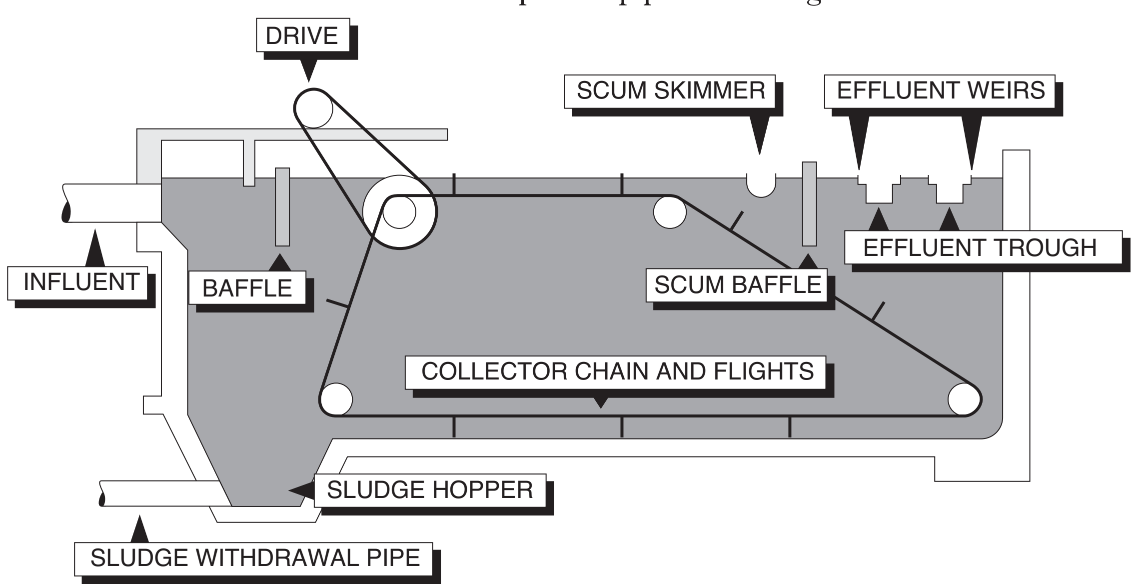
In a rectangular clarifier, raw wastewater enters through a series of ports near the surface along one end of the tank. A short **baffle**[23] dissipates the influent velocity directing the flow downward. Water moves through at a very slow rate and discharges from the opposite end by flowing over a sawtooth metal plate called the effluent weir and into a trough.

Sludge Flow Path

Settled solids are scraped to a sludge hopper at the inlet end by wooden **flights**[24] that are attached to endless chains riding on sprocket wheels. These flights extend completely across the width of the clarifier. Sludge of 5% to 7% solids is withdrawn periodically from the sludge hopper and sent to the digester.

Scum Removal

Besides being used to remove sludge, the flights are also used to push floating matter to a cylindrical tube with a slit along the top which is placed in front of the effluent weir. This tube is called a skimmer. The material that it collects is called **scum**[25]. The skimmer is manually or mechanically rotated, to allow scum collected on the surface to flow through the slot into the tube that slopes toward a scum pit. From the scum pit it is piped to the digester.



23 **Baffle** - A flat board or plate, deflector, guide or similar device constructed or placed in flowing water, wastewater, or slurry systems to cause more uniform flow velocities, to absorb energy, and to divert, guide, or agitate liquids.

24 **Flights** - Scraper boards, made from redwood or other rot-resistant woods or plastic, used to collect and move settled sludge or floating scum.

25 **Scum** - A mass of sewage matter which floats on the surface of sewage.

Circular Clarifiers

Wastewater Flow Path

Raw wastewater enters through ports in the top of a central vertical pipe. The forward velocity is dissipated against a influent baffle that also directs the flow down and outward radially to an effluent weir which is mounted along the outside wall of the tank.

Sludge Flow Path

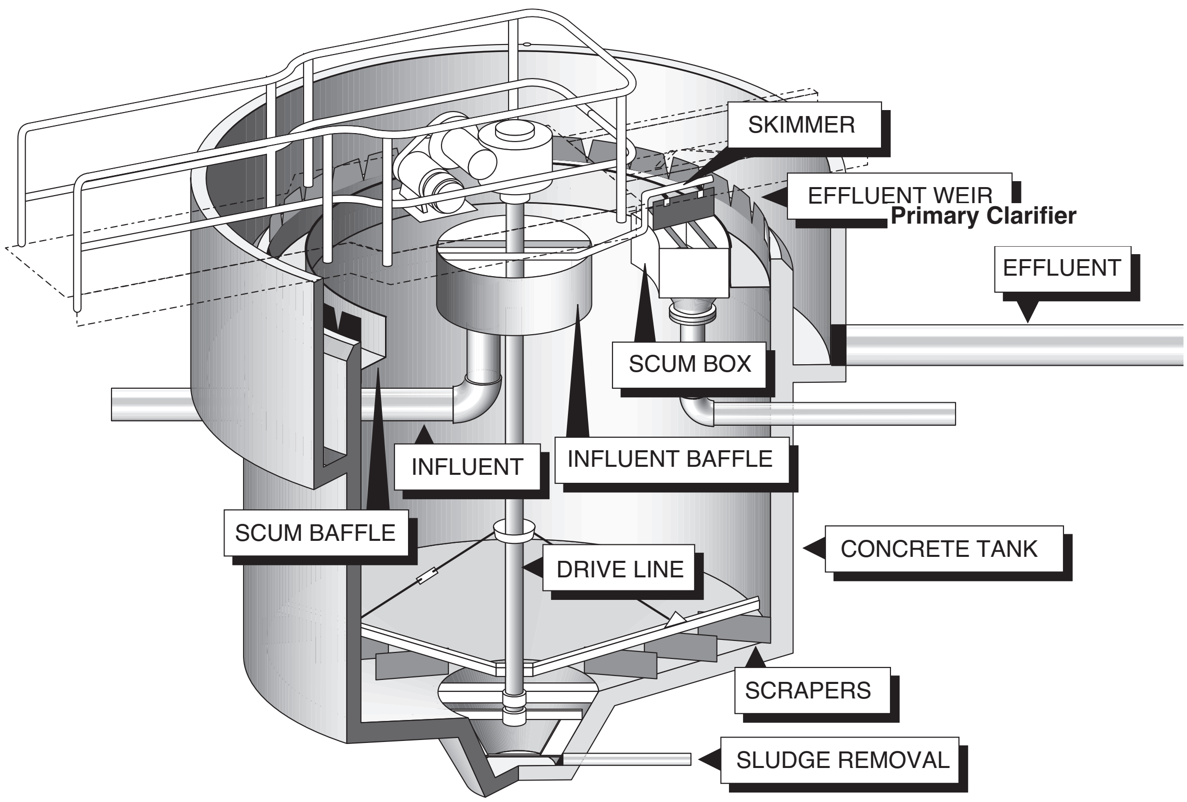
Solids settle to the bottom of the clarifier and form sludge. A slow rotating collector arm plows settled solids to the sludge drawoff hopper at the center of the clarifier.

Scum Collection

Floating solids migrating toward the outer edge of the tank are prevented from going out the effluent by a baffle in front of the weir. A skimmer attached to the arm collects scum from the surface and drops it into a scum box that drains outside the tank wall.

Mechanical Drive

The sludge scraper and skimmer are rotated by a single gear head and small electric motor placed in the center of the tank.



Primary Clarifier

Primary Clarifier Design Criteria

Criteria

Criteria for sizing settling basins include **overflow rates**[26] (called surface settling rates - SSR), tank depth at the sidewall, weir overflow rates (WOR) and **detention time**[27]. From an operational standpoint, the surface settling rate, weir overflow rate and the detention time are the most important.

SSR

Definition of SSR

Surface settling rate (SSR) is defined as the average daily overflow divided by the surface area of the tank, expressed in terms of gallons per day per square foot (gpd/ft^2). Area is calculated by using inside tank dimensions, disregarding the central stilling well or inboard weir troughs. The quantity of overflow from the primary clarifier is equal to the wastewater influent, since the volume of sludge withdrawn from the tank bottom is negligible.

Typical Ranges for SSR

Overflow rates for primary clarifiers fall in a range between 400 and 800 gpd/ft^2, with 600 being a common design value. At these **hydraulic loadings**[28], a 30 to 40 percent **BOD**[29] removal in settling raw domestic wastewater is possible.

SSR and Effectiveness

Effectiveness of sedimentation depends largely on the character of the wastewater. With SSRs of less than 600 gpd/ft^2, the settled solids tend to thicken properly in the bottom of the tank and are removed by the slow moving collector arms or flights. Rates in excess of 800 gpd ft^2 may create turbulence in the tank that inhibits the solids from settling and forming compact sludge that can be removed by the collector devices.

Weir overflow

Description

Weir loading or weir overflow rate (WOR) is the hydraulic flow over an effluent weir. Weir overflow rate is determined by dividing the daily flow through the clarifier by the lineal feet of weir.

Typical Ranges

For primary clarifiers, weir loadings are not to exceed 10,000 gpd/lin-ft for plants of 1 MGD or smaller and preferably not more than 20,000 gpd/ft for design flow above 1 MGD. These values limit the water velocity approaching the effluent weir to minimize carry over of suspended solids.

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26 **Overflow rate** - One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Overflow rate in gpd/ft^2 equals flow in gallons/day divided by surface area in square feet.

27 **Detention time -** The time required to fill a tank at a given flow or the theoretical time required for a given flow of wastewater to pass through a tank.

28 **Hydraulic loading** - Refers to the flows (MGD or cu m/day) to a treatment plant or treatment process. Detention times, surface loading and weir overflow rates are directly influenced by flows.

29 **BOD** - Biochemical Oxygen Demand - The quantity of oxygen required by microorganisms when stabilizing decomposable organic matter under aerobic conditions at 20° C.

Detention Time

Definition

Detention time is computed by dividing the water volume of the clarifier by the influent flow expressed in hours. Numerically, it is the time that would be required to fill the tank at a uniform rate equivalent to the designed average daily flow.

Typical Ranges

Detention time is generally not a specified criterion for sizing primary clarifiers, since it is already defined by overflow rate and depth of the clarifier. For example, an overflow rate of 600 gpd/ft^2 and a depth of 7 feet, yields a detention time of 2.1 hours. Typical ranges for detention time are from 90 to 150 minutes.

Operational Considerations

Sidestreams

The supernatant from digesters, filtrate from belt presses, centrate from centrifuges and water from floor drains are often piped back to the headworks of the plant. These flow streams are called **sidestreams**[30] and can contain significant BOD and TSS. These sidestreams can cause several problems with the operation of the primary clarifier and secondary treatment system.

Rising Sludge

If the clarifier sludge becomes too old, the clarification process can be upset. This could occur if the sludge is allowed to stay in the clarifier too long. In addition, a high volume sidestream can increase the effective age of the sludge in the clarifier (the sidestream contains old material). Storing sludge in a clarifier too long can also upset clarification. Microorganisms decomposing the waste organics, produce gas that makes the solids more buoyant, thus expanding the **sludge blanket**[31] and reducing the solids concentration. Detrimental biological activity is characterized by foul odors, floating sludge, and a darkening of the wastewater color.

Slime Buildup

The one major operational problem with primary clarifiers is the buildup of algae and organic slime in the inlet channel and on the weirs and in effluent troughs. This should be removed daily with a hose and long handled brush.

Summary

Design Parameters

Hydraulic loading- Average - gpd/ft^2- 400 to 800

Hydraulic loading - Peak flow - gpd/ft^2 - 1,200 - 2,500

Detention Time - Minutes - 90 - 150

WOR - gpd/ft - 10,000 to 20,000

Removal Efficiencies

TSS 40% to 60%

BOD 30% to 40%

Settleable Solids 90% to 95%

Solids Concentration 5% to 7%

30 **Sidestream** - Wastewater flows that develop from other storage or treatment facilities. This wastewater may or may not need additional treatment. For instance the water from a belt press that is piped back to the front of the plant is called a sidestream.

31 **Sludge blanket** - That portion of the clarifier containing sludge.

Claigesters

Combination

A claigester is a primary treatment device that combines a primary clarifier and an unheated anaerobic digester in a single tank. This type of primary treatment is popular and effective in tropical climates.

Flow

Sewage flows into the center well of the clarifier and settles to the bottom where the rake arms move it to a center hopper. The sludge drops through the center hopper into the digester. Primary effluent exits over the clarifier weirs and into the effluent channel.

Scraper and Rake Arms

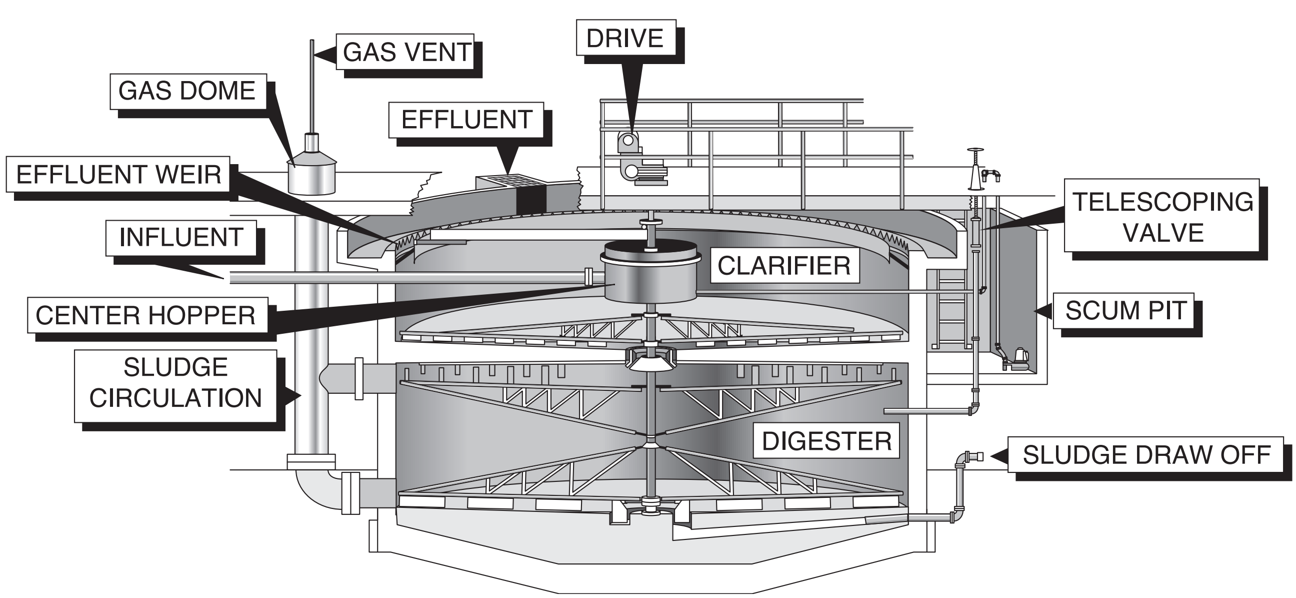
The clarifier scraper arms, the scum arm, and the digester rake arms are rotated by an electric motor and gear drive located on the catwalk at the center of the clarigester. In the digester, the upper rake arm prevents the formation of a sludge cake and the lower arm moves sludge to the center hopper in the floor for draw off.

Supernatant Control

As the sludge is stabilized in the digester, supernatant is formed. The supernatant is drawn off the top of the digester and into the scum pit through a telescoping valve. The hydraulic head difference between the liquid level in the clarifier and the opening in the telescoping valve, coupled with the size of the opening in the valve, controls the rate of supernatant draw off. The supernatant is returned to the center well of the clarifier using a pump. The amount of supernatant drawn from the digester controls the depth of the sludge blanket in the clarifier.

Gas and Sludge

Gas formed in the digester is collected and vented through the gas dome. The line leading to the gas dome doubles as a sludge circulation device, helping to maintain circulation of sludge in the digester.



On-Site Treatment Systems

Introduction

Approximately 18 million housing units, or 25% of all housing units in the United States dispose of their wastewater using on-site or community on-site treatment systems. These systems may include a variety of components and configurations, the most common being the septic tank/soil absorption system that is discussed here.

Primary Treatment

The septic tank is classified as a primary treatment system. It removes those solids that will float or sink and provides some degree of anaerobic digestion of the solids.

Subsurface Soil Absorption

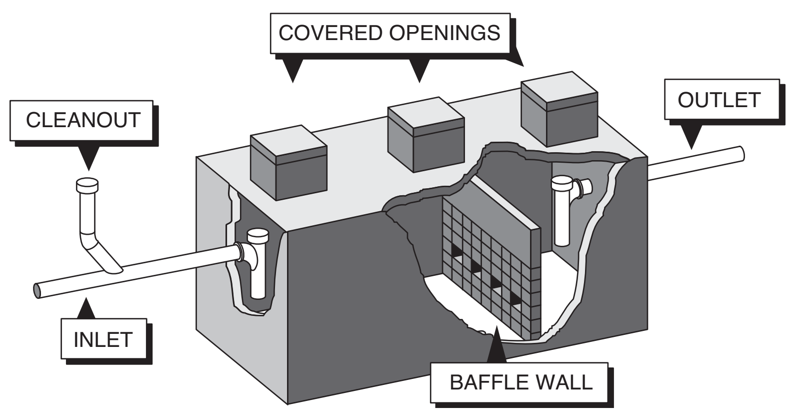
Traditionally, subsurface soil absorption has been used almost exclusively for the disposal of septic tank effluent. This process has the ability to meet the public health and environmental criteria without the necessity for complex design or high cost. A properly designed, constructed, and maintained subsurface absorption system performs reliably over a long period of time with little attention. This is because of the large natural capacity of the soil to assimilate the wastewater pollutants.

Soil Problems

Unfortunately, some areas do not have soils suited for conventional subsurface soil absorption fields. If soil absorption cannot be utilized, an alternative effluent disposal method or more costly treatment may be required.

Community Septic Tanks

In very small communities, community septic tanks are often used to treat an entire community's wastewater. A variety of tank effluent disposal options are used including stream and ocean outfalls.



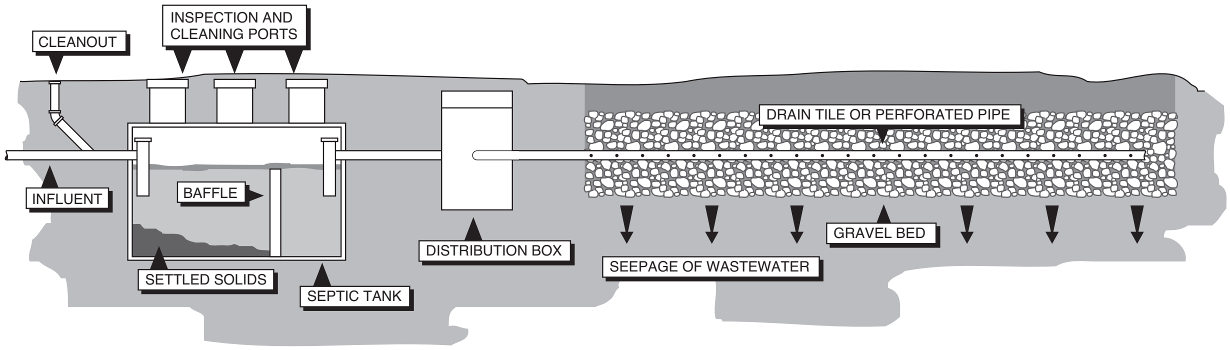
Advantages of Septic Tanks

One of the major advantages of the septic tank is that is has no moving parts and, therefore, needs very little routine maintenance. A well-designed and maintained concrete, fiberglass, or plastic tank should last for 50 years. Because of corrosion problems, steel tanks can be expected to last 10 years or less.

Septic Tank Description

General Description

Septic tanks are buried, watertight receptacles designed and constructed to receive wastewater from a home, rural school, or commercial establishment. Septic tanks separate solids from the liquid, provide limited digestion of organic matter, store solids, and allow the clarified liquid to discharge for further treatment and disposal.



Solids Decomposition

Settleable solids and partially anaerobically decomposed sludge settle to the bottom of the tank and accumulate. A scum of lightweight material (including fats and grease) rise to the top.

Liquid Flow Path

The partially clarified liquid is allowed to flow through an outlet structure just below the floating scum layer. Proper use of baffles, tees, and ells protect against scum outflow.

Effluent Disposal

Clarified liquid can be disposed of to soil absorption systems, soil mounds, lagoons, ocean outfalls or other disposal systems.

Operation & Maintenance

Control Factors

Factors affecting septic tank performance include geometry, hydraulic loading, inlet and outlet arrangements, number of compartments, temperature, and operation and maintenance practices. If a tank is hydraulically overloaded, retention time may become too short and solids may not settle or float properly.

Inspection Frequency

Tanks should be inspected at least every 2 years to determine the rates of scum and sludge accumulation. If inspection programs are not carried out, a pump-out frequency of once every 3 to 5 years is reasonable. Once the characteristic sludge accumulation rate is known, inspection frequency can be adjusted accordingly.

Where to Measure

Actual inspection of sludge and scum accumulations is the only way to determine definitely when a given tank needs to be pumped. When a tank is inspected, the depth of sludge and scum should be measured in the vicinity of the outlet baffle.

Determining Scum Depth

Scum can be measured with a stick to which a weighted flap has been hinged, or with any device that can be used to feel the bottom of the scum mat. The stick is forced though the mat, the hinged flap falls in a horizontal position, and the stick is raised until resistance from the bottom of the scum is felt. With the same tools, the distance to the bottom of the outlet device can be determined.

Determining Sludge Depth

Sludge depth can be determined by using a long stick wrapped with a rough white towel. The device is slowly lowered to the bottom of the tank, just behind the outlet device, thus avoiding interference with the scum layer. Upon removal the depth of the sludge can be easily identified on the towel.

When to Clean

The tank should be cleaned whenever (1) the bottom of the scum layer is within 3 inches of the bottom of the outlet device; or (2) the sludge level is within 8 inches of the bottom of the outlet device. The efficiency of suspended solids removal may start to decrease before these conditions are reached.

Results of Not Pumping Solids

One cause of septic tank problems involve a failure to pump out the sludge when required. As the sludge depth increases, the effective liquid volume and detention time decrease. This increases the liquid velocity through the tank. As a result solids are scoured from the tank bottom and carried out the effluent. The only way to prevent this is by periodic pumping of the tank.

Special Considerations

Following is a list of considerations pertaining to septic tank operation and maintenance:

1. A septic tank is a permit required confined space. Because of the possible lack of oxygen and the presence of toxic and explosive gases, entry is very dangerous. Follow confined space and manhole removal procedures when entering the tank. Entry should be avoided if at all possible.
2. The manhole, not the inspection pipe, should be used for pumping so as to minimize the risk of harm to the inlet and outlet baffles. Removal of the solids will be difficult under the best circumstances.
3. Leaving solids in the septic tank or adding special chemicals to start activity is not necessary.
4. When pumped, the septic tank must **not** be disinfected, washed, or scrubbed.
5. Materials not readily decomposed (e.g. sanitary napkins, coffee grounds, cooking fats, disposable diapers, facial tissues, cigarette butts) should never be flushed into a septic tank. They will not degrade in the tank, and can clog inlets, outlets, and the disposal systems.
6. Septic sludge is a Type C sludge. Disposal procedures are described in the solids handling lesson.

Secondary Biological Treatment

Primary Treatment Plants

A treatment plant that is configured solely of grinding, grit removal and primary sedimentation is termed a primary treatment plant.

Secondary Treatment

Treatment plants that contain primary treatment, followed by biological treatment, are called secondary treatment plants. A secondary treatment plant adds the biological process to further reduce organics in the wastewater.

Treatment with Bacteria

Utilizing aerobic **bacteria**[32] and other organisms to reduce the organics in the wastewater and developing a sludge that can be settled easily is the operational objective of secondary treatment.

Types of Secondary Treatment

There are many types of secondary biological treatment plants including **trickling filters**[33], RBCs, activated sludge, and lagoons.

Trickling Filters

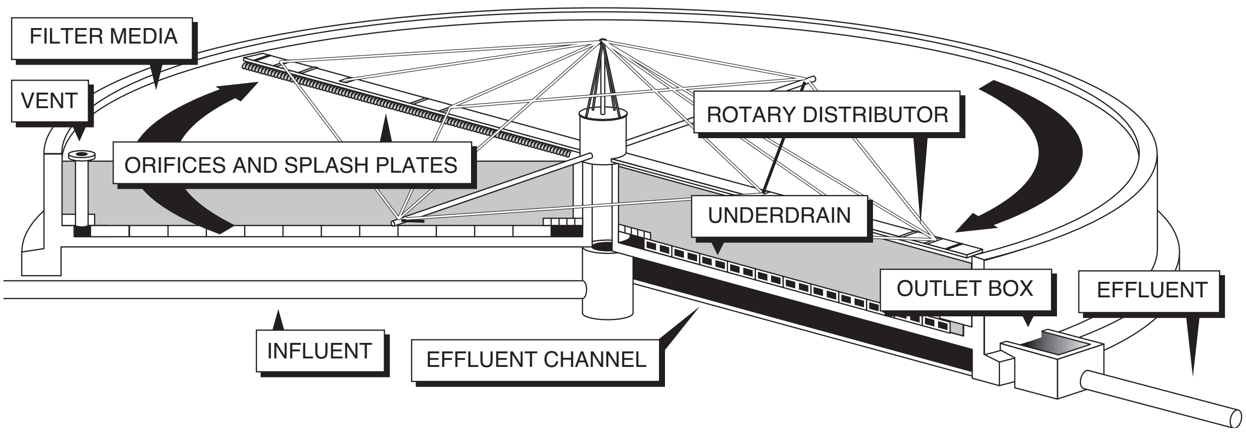
General Description

A trickling filter is an aerobic secondary treatment process that utilizes a fixed film media to grow an aerobic biological slime that is used to treat the wastewater.

Equipment

Media

The heart of the trickling filters is its media. The most common media is a bed of relatively large size river-run rock, crushed stone or synthetic media which is placed over a concrete collection system. The rock beds are usually less than 10 feet deep. Other media such as plastic and redwood slats can also be used. These beds are typically 20 feet or more deep. The media may be placed in a pile on the collection system or contained in a concrete tank. This collection system (the underdrain) serves to collect the treated waste-water and allows air to circulate through the filter media.



32 **Bacteria** - Living organisms, microscopic in size, which consist of a single cell. Most bacteria utilize organic matter for their food and produce waste products as the result of their life processes.

33 **Trickling filter** - A treatment process in which the wastewater trickles over media that provide the opportunity for the formation of slimes or biomass which contain organisms that feed upon and remove wastes from the water treated.

Water Flow

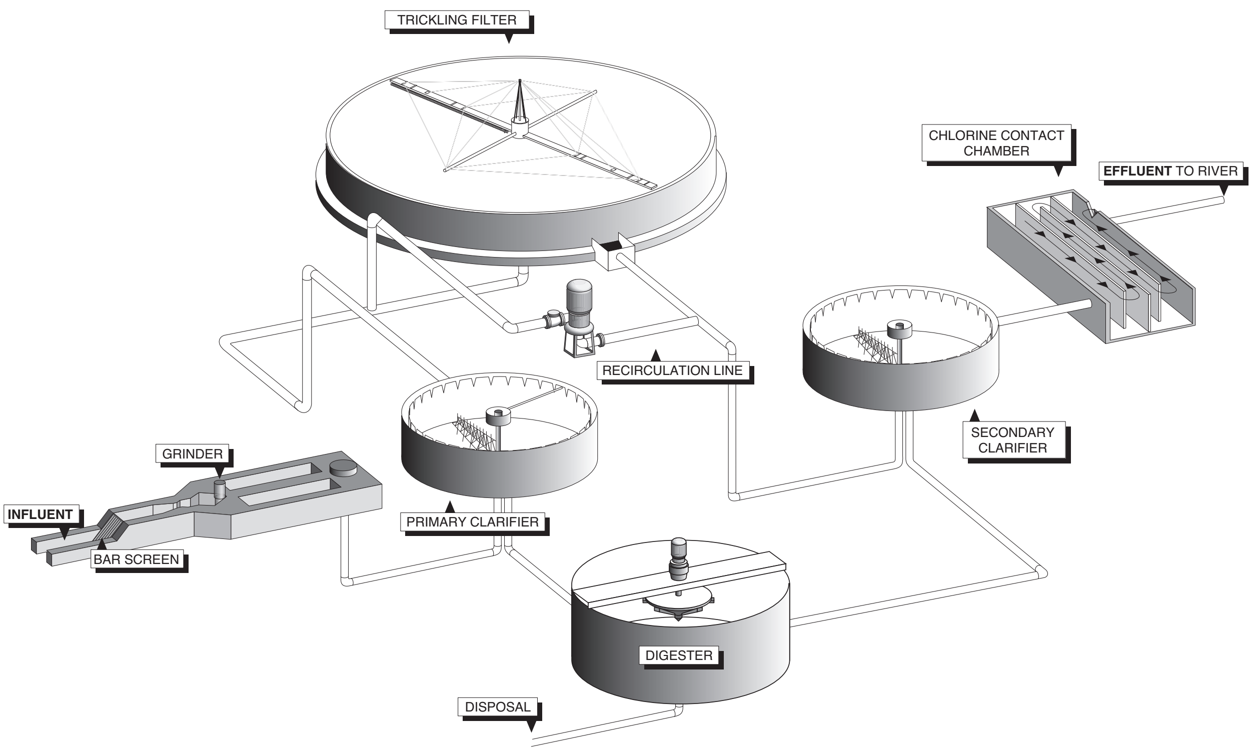
Wastewater is applied to the media bed through orifices placed on fixed piping or in a rotating **distributor**[34] arm. Splash plates are placed in front of or under the orifices to ensure even wastewater distribution onto the media. The hydraulic power of the wastewater leaving the orifices along the distributor arm causes the arm to rotate. As a result of turning, sewage is applied evenly over the surface of the media.

Air Flow

Air flows down the vents and up through the media or down through the media and up through the vents, depending of the difference between air temperature and the temperature inside of the media.

Piping

Besides the normal influent and effluent piping, a trickling filter commonly has a recirculation pumping and piping system. The recirculation system pumps water from the effluent of the filter back to the influent of the filter. This system is used to maintain a constant flow over the media as well as improve removal efficiency.



Theory of Operation

General Description

The purpose of trickling filters is to remove nonsettleable suspended and dissolved organic matter from settled sewage. This is accomplished by a biological slime growth on the filter media. Aerobic biological activity reduces the organics in the raw wastewater and produces a settleable sludge.

34 **Distributor** - A rotating mechanism that distributes the wastewater evenly over the surface of a trickling filter or other process unit.

Zoogleal Growth

Contents of Film

Organisms such as bacteria, **protozoa**[35], fungi, and algae, attach themselves to the available surface area of the media and become what is called the **zoogleal film**[36]. These organisms require at least two essential elements for life: food and oxygen.

Food Source

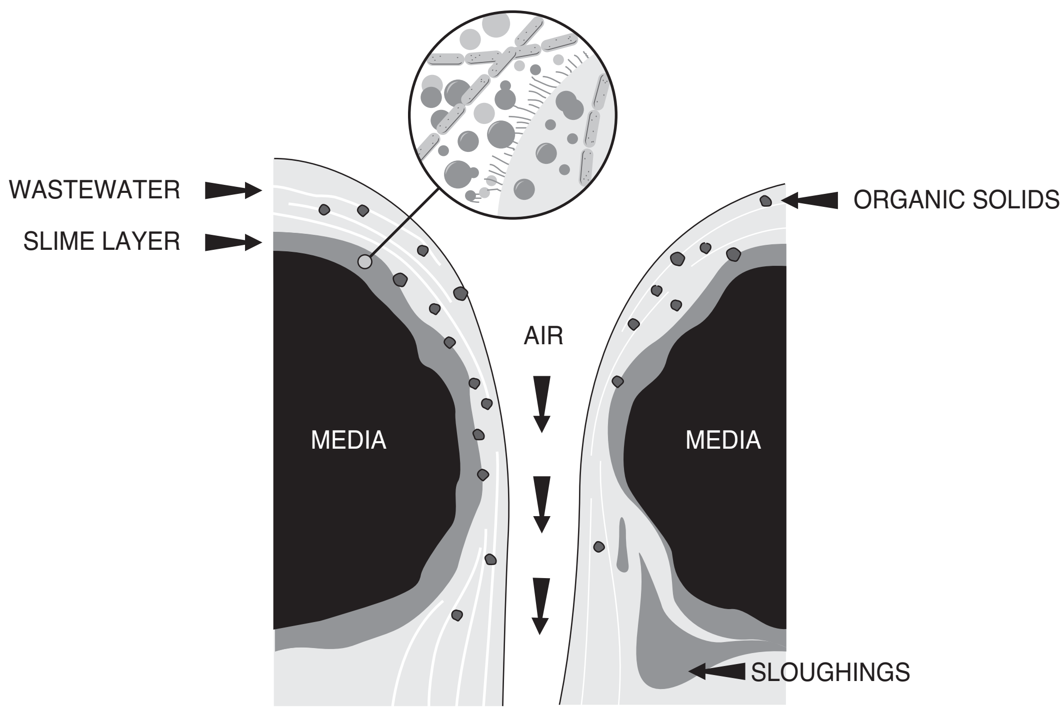
Food is supplied in the form of sewage which is distributed on the surface of the filter and allowed to trickle through the voids, passing over the zoogleal film on the media.

Oxygen and Air Movement

Oxygen is supplied in the form of air which may pass either upward or downward through the filter depending on the difference in temperature of the sewage and surrounding air.

Production of Sloughings

As the sewage trickles over the organisms growing in the film or slime, some of the organic matter in the sewage is converted by the organisms to energy and some to produce new organisms, carbon dioxide, water and mineral solids. As the organisms grow they produce more and more slime. When the slime becomes too thick it "sloughs" or breaks off and is carried by the sewage flow to the final settling basin. The slime that breaks off is called **sloughings**[37].



35 **Protozoa** - A small one-celled animal including, but not limited to, amoebae, ciliates, and flagellates.

36 **Zoogleal film** - A complex population of organisms that form a "slime growth" on the trickling filter media and break down the organic matter in wastewater. These slimes consist of living organisms feeding on the wastes in wastewater, dead organisms, silt, and other debris.

37 **Sloughings**- Trickling filter slimes that have been washed off the filter media. They are generally quite high in BOD and will lower effluent quality unless removed.

Classification of Filters

Criteria for Classification

Trickling filters are classified according to the applied hydraulic and organic (BOD) loadings. The hydraulic loading is the total volume of sewage, including recirculation, applied to the trickling filter per day per square foot of filter surface area. This number is expressed as gallons per day per square foot (gpd/ft^2). Organic loading is the pounds of BOD per 1,000 cubic feet of filter media volume.

High Rate vs. Low Rate

Loading Criteria

Trickling filters are grouped into two classifications; standard or low-rate filters and high-rate filters. The hydraulic loading for the standard filter is 25 to 100 gallons per day per ft^2 and 200 to 1,000 gpd/ft^2 for the high-rate filter. The organic loading for standard filters is 5 to 25 pounds of BOD per 1,000 ft^3, and 25 to 300 for high-rate filters.

Recirculation Requirements

In a standard rate trickling filter, the biological **oxidation**[38] is accomplished in one pass of the wastewater through the filter. With the higher loadings of the high-rate filter, it is usually necessary to recirculate filter effluent to the incoming sewage from one to three additional passes through the filter.

ABF Towers

One variation to the trickling filter that was very popular in the late 1970's was a device called an ABF tower. This device used a deep bed of redwood slats and fixed distributors. Sludge from the secondary clarifier was pumped back over the media to help produce a heavy biological growth on the media. Due to limitations in removal, these devices did not prove to be as effective as was originally assumed.

Process Control

Control of Removal

The only process control that is available with a trickling filter is the quantity of recirculation. In addition, trickling filters operate best if the flow over the media does not vary from day to day. Recirculation rates can be varied to assure that the flow rate is changed very little between wet weather and dry weather conditions.

Recirculation

The operator has control of one of the processes, that is recirculation. Recirculation accomplishes two things:

- It increases the efficiency of removal through the filter and,
- It helps to reduce the thickness of the zoogleal film. If this film becomes too thick, it can cause plugging of the filter media.

38 **Oxidation** - The addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In wastewater treatment, organic matter is oxidized to more stable substances.

Operational Problems

Introduction

There are four common trickling filter operational problems:

- Reduction of treatment efficiency
- Air temperature
- Odor
- Filter flies

Organic Loading

The average BOD removal efficiency of a single-stage filter plant is about 85 percent. Therefore, to achieve an effluent BOD of 30 **mg/L**[39], the raw wastewater must be essentially a domestic waste with a BOD not greater than 200 mg/L. If a municipal wastewater contains organic loading greater than this, the final effluent quality may deteriorate and the filter may produce offensive odors.

Temperature

In northern climates, the temperature of air and wastewater passing through the filter may be considerably lower in the winter and may adversely influence BOD removal. Covers can be placed over trickling filters to help maintain temperature during cold weather which could improve seasonal variations in effluent quality.

Odor

The microbial zone immediately adjacent to the surface of the media is anaerobic and capable of producing offensive odors. If voids in the media become filled with excess biological growth, foul odors can be emitted during spring and fall when air temperatures reduce natural air circulation through the bed. In addition, the filter may become partially plugged, resulting in ponding of water on top of the filter media. The newer synthetic media in use today greatly reduce the odor problems as aeration is improved.

Filter Flies

Filter flies, or *Psychoda*, are a nuisance problem associated with trickling filters during warm weather. They breed in sheltered zones of the media and on the inside surfaces of the retaining walls. Although wind can carry these small flies considerable distances, their greatest irritation is to operating personnel. Periodic spraying of the peripheral area and walls of the filter with a chlorine or herbicide solution help disrupt their hatching cycles.

39 **mg/L** - Milligrams per liter. A unit of the concentration of a constituent in wastewater. It is 0.001g of the constituent in 1,000 mL of wastewater. mg/L has replaced the PPM (parts per million) in reporting results in wastewater.

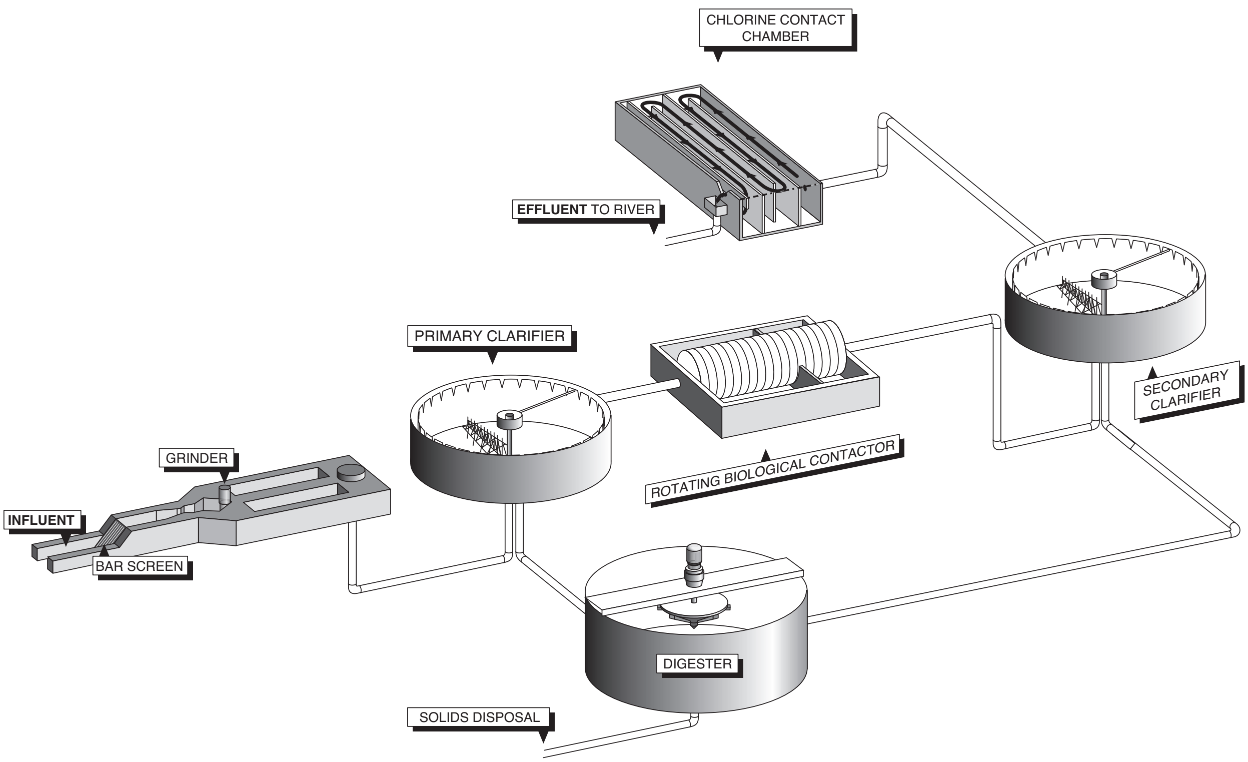
RBC-Rotating Biological Contactors

General Description

A popular small plant, fixed media system is the RBC or rotating biological contactor. This is a secondary, aerobic biological treatment system that utilizes the theory of the trickling filter to treat wastewater.

Basic Components

RBCs are constructed of bundles of plastic media attached radially to a shaft forming a cylinder of media. This media is called a contactor. The contactor is mounted on two pillow block bearings and rotated by an electric motor, gear head and chain drive. A concrete tank allows slightly less than one half of the diameter of the contactor to be submerged in wastewater. Large facilities will usually have two or more contactors that can be operated in series or parallel. In small plants there may be only one contactor. In this case, a movable baffle is commonly installed between one half and two thirds of the distance along the contactor.



Hydraulic Flow

The contactor shaft is slowly rotated in a tank of wastewater so that the media is approximately 40 percent submerged. The contactor surfaces are spaced so that during submergence wastewater can enter the voids in the media. When rotated out of the tank, the liquid trickles out of the voids between the media surfaces and is replaced by air.

Process

Treatment Process

A fixed-film biological growth, similar to that on trickling filter media, adheres to the contactor surface. Alternating exposure to organics in the wastewater and oxygen in the air during rotation is like dosing a trickling filter with a rotating distributor. Excess biomass sloughs from the media and is carried out to the secondary clarifier.

Plant Configuration

A treatment system consists of primary clarification preceding and final clarification following the rotating biological contactors. Since recirculation through RBC units is not normally practiced, only sufficient underflow from the final clarifier is returned to the headworks to allow removal of excess biological solids in primary sedimentation.

Waste Sludge

Waste sludge, similar in character to that from a trickling filter plant, is withdrawn from the secondary clarifier and sent to a digester.

Troubleshooting

The following are some of the operational challenges of operating an RBC plant.

Loping

Observation

Organic overloads applied to a RBC can cause uneven growth on the media. This uneven weight distribution causes the RBC to become unbalanced (heavier on one side than the other).

Result of Loping

This imbalance causes the rotation speed of the contactor to vary resulting in some sections of the media being submerged for longer periods of time than others and thus the uneven growth pattern making the imbalance worse. This variation in speed is called loping.

Results of Excessive Loping

Excessive loping can stop the contactor rotation and can cause breakage of the shaft.

Basic Cause of Loping

The cause of loping is organic overloading of the contactor. Immediate improvement can be made by reducing or eliminating the organic load. This may be accomplished by reducing the quantity of wastewater entering this contactor. If the plant is small and contains only one contactor, then an alternate procedure using chlorine may be required.

Using Chlorine

Chlorine or other oxidants can be used to help lighten the shaft load by killing off some of the biomass. The RBC is covered with literally millions and millions of organisms and it takes a long contact time with chlorine to effect significant reduction in the biomass.

Do Not Drain

Under no circumstances should the RBC tank be drained. The weight of the biomass without the buoyancy of the water will further stress the shaft and could cause it to break.

Measuring Loping

Marking the RBC shafts in quarters and timing the rotation speed of each quarter once a month is the best indicator of early trouble. At the first sign of loping, take corrective action.

BEGGIATOA

Results

Influent characteristics, including oxygen levels and the presence of hydrogen sulfide, should be monitored at an RBC plant. RBCs are very susceptible to an infestation of a filamentous organism known as Beggiatoa. Beggiatoa outbreaks dramatically reduce the ability of the RBC to affect BOD removal.

Observations

The indication of Beggiatoa outbreaks on RBC is a white growth dominating the media surface, a stronger than normal odor and a reduction in effluent quality. Microbial observation will show a definite filamentous organism in predominance.

Prevention

In order to prevent a Beggiatoa outbreak, the sulfides must be eliminated from the food source to the RBCs. Beggiatoa requires hydrogen sulfide in order to survive. Hydrogen sulfide is produced by sulfide bacteria that thrive on older, septic sewage. Keeping sewage fresh and free of sulfides is the only way to prevent Beggiatoa problems. Preaeration can reduce the sulfide loading to the RBCs.

Activated Sludge

General Description

Aerobic Process

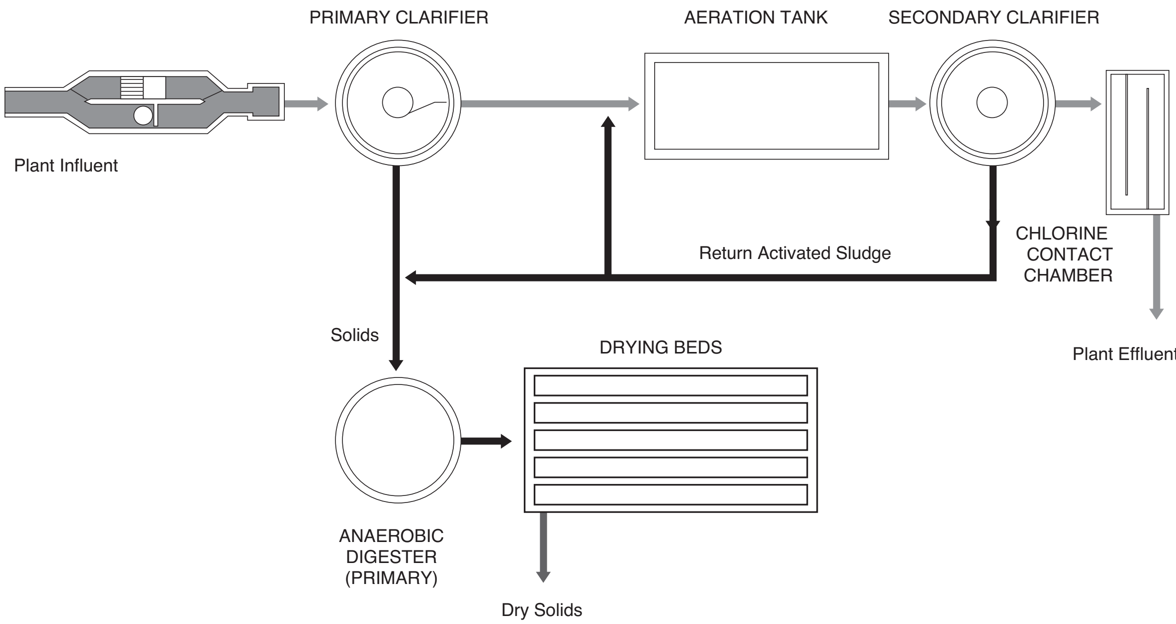
The **activated sludge process**[40] is a suspended film, aerobic, secondary, biological treatment process. In this process, favorable microbial growth conditions are maintained in a tank creating an active microbial mass called activated sludge. The organisms in this biomass oxidize soluble and suspended solids not removed by previous treatment, converting them to settleable solids.

Basins

An activated sludge plant consists of one or more tanks called aeration basins that follow preliminary and/or primary treatment. These basins are usually rectangular. Air is added to the basin by one of several processes. (Details on aeration systems are found later in this section). The basin is followed by a secondary clarifier.

RAS & WAS

A portion of the sludge from the bottom of the secondary clarifier is piped back to the aeration basin and a portion is piped to the digester. The portion that is piped back to the aeration basin is called **return activated sludge**[41] (RAS). The portion that is sent to the digester is called **waste activated sludge**[42](WAS).



40 **Activated Sludge Process** - A biological wastewater treatment process which speeds up the decomposition of wastes in the wastewater being treated. Activated sludge is added to wastewater and the mixture (mixed liquor) is aerated and agitated. After some time in the aeration tank, the activated sludge is allowed to settle out by sedimentation and is disposed of (wasted) or reused (returned to the aeration tank) as needed. The remaining wastewater then undergoes more treatment.

41 **Return Activated Sludge** - The settled mixed liquor that is collected in the clarifier underflow and returned to the aeration basin.

42 **Waste Activated Sludge -** The excess growth of microorganisms which must be removed to keep the biological system in balance.

Mixed Liquor

Since the activated sludge process depends on maintaining microorganisms in aeration basins in an active state, the microbial populations under aeration must be carefully controlled. The contents of the aeration tank which include return activated sludge and influent wastewater is called the **mixed liquor**[43].

Control of Mixed Liquor

A portion of the activated sludge is purposely removed by wasting it from the process. The wasting of sludge is necessary to maintain the desired quantity of microorganisms in the process. The quantity of microorganisms in the aeration basin is called the mixed liquor suspended solids (**MLSS**[44]). Wasting is necessary because the microorganisms grow and multiply as they eat the food supply in the wastewater.

Balancing Food & Microorganisms

The basic idea behind successful operation of an activated sludge system is to balance the amount of microorganisms in the aeration basin with the amount of food in the wastewater and provide adequate air for them to breathe and nutrients for them to maintain a healthy life. An imbalance in food, oxygen or nutrients can cause the organisms to produce an undesirable sludge that will not settle satisfactorily in the clarifier.

Microorganisms

While the bulk of the treatment in an activated sludge process is provided by bacteria, operators use the presence of specific protozoa as an indication of effective treatment.

Cycle Operation

In the activated sludge process, the microorganisms in the mixed liquor pick up the food and start their digestion process. With the food collected they are sent to the clarifier to finish their digestion process and rest to that they are ready to eat again. Once rested they are returned to the aeration basin to collect more food and start the process over.

Summary

Now that we have provided a general discussion of the basic activated sludge process, it is time to go back and discuss a few more specifics of some of the key equipment items, namely, the aeration system.

Aeration Systems

Function

In an activated sludge facility, aeration serves the dual purpose of providing **dissolved oxygen**[45] and mixing of the mixed liquor in the aeration tank. This mixing provides an increased probability of contact between the bacteria and the food supply.

Two Basic Types of Systems

Aeration is usually provided by either diffused air or mechanical aeration systems. Diffused air systems consist of a blower and a pipe distribution system that

43 **Mixed liquor** - When the activated sludge in the aeration tank is mixed with primary effluent or the raw wastewater and return sludge, this mixture is then referred to as mixed liquor as long as it is in the aeration tank. Mixed liquor also may refer to the contents of mixed aerobic or anaerobic digesters.

44 **MLSS** - Mixed Liquor Suspended Solids - suspended solids in the mixed liquor of an aeration tank.

45 **Dissolved Oxygen** - Molecular oxygen dissolved in water or wastewater, usually abbreviated DO.

is used to bubble air into the mixed liquor. Mechanical aeration systems consist of either a pumping mechanism or a large brush that disperses water droplets through the atmosphere.

Diffused Aeration

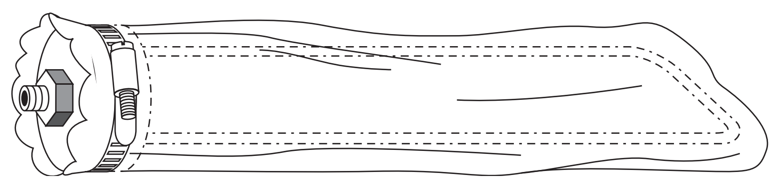
Location of Diffusers

Diffused air systems are the most common type of aeration systems used in activated sludge plants. The distribution system consists of numerous **diffusers**[46] generally located near the bottom of the aeration tank. The diffusers are located in this position to maximize the contact time of the air bubbles with the mixed liquor so that more of the oxygen dissolves into the wastewater (oxygen transfer).

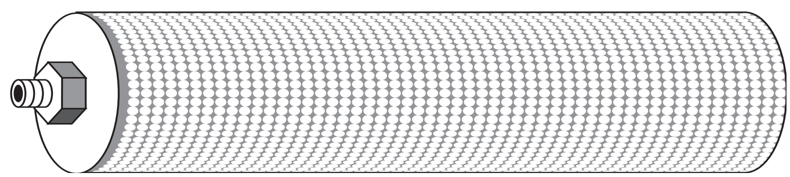
Fine Bubble Diffusers

Diffusers are designed to either produce fine or coarse bubbles. Fine bubble diffusers operate under the theory that the smaller the bubble, the more available it is to the microorganisms. Fine bubble diffusers are a challenge to use as they tend to clog, requiring on-going maintenance.

Cloth Diffuser



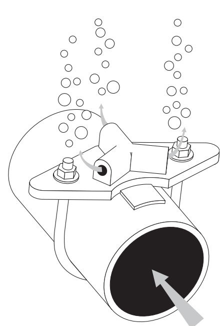
Ceramic Diffuser



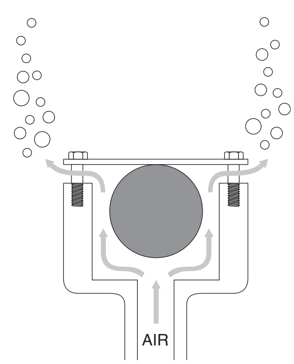
Coarse Bubble Diffusers

Coarse bubble diffusers are usually made by drilling holes in pipes or by loosely attaching plates or discs to a supporting piece of pipe. Coarse bubble diffusers have lower oxygen transfer efficiencies than the fine bubble diffusers.

Sparger



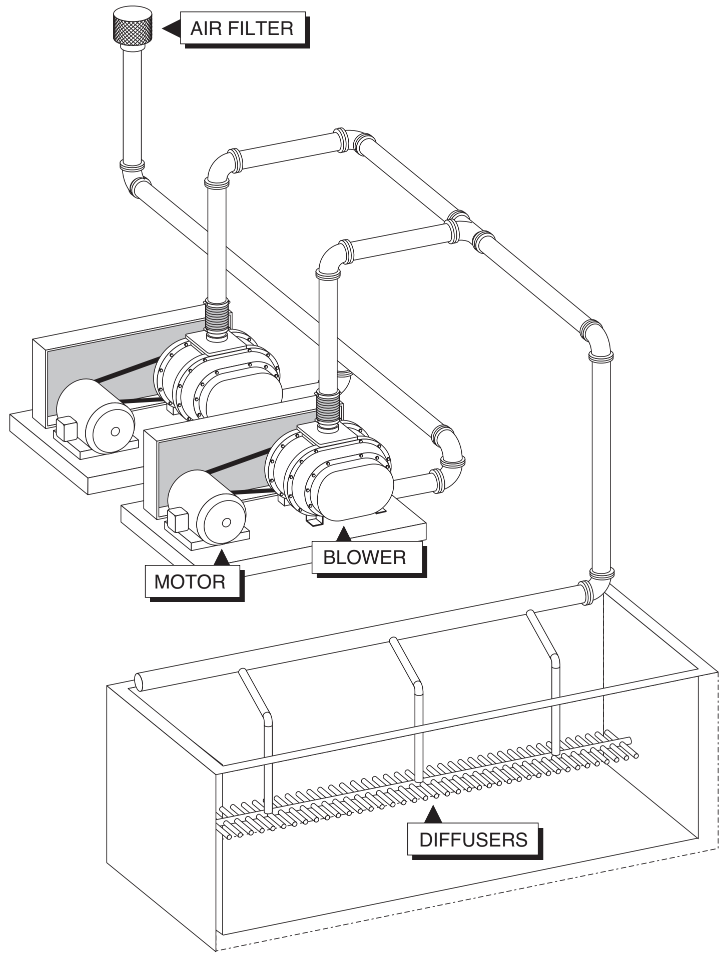
Valved Orifice



46 **Diffuser** - A device (porous plate, tube, bag) used to break the air stream from the blower system into fine bubbles in an aeration tank or reactor.

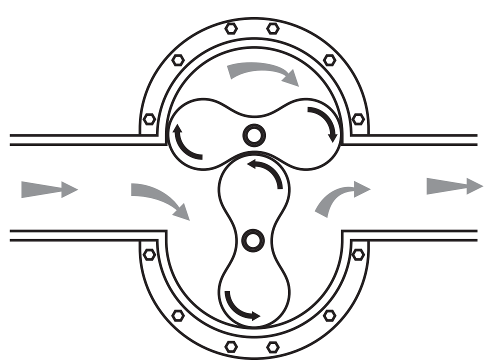
Blowers

Air for the diffusers is supplied by a mechanical blower. There are two types of blowers, lobe and centrifugal. The lobe blower is the most common in small plants.



Lobe Blower

The lobe blower consist of two sets of lobes that rotate together. As the blower turns, air on the downstream side of the lobe is compressed, creating a negative pressure on the upstream side of the lobe. This negative pressure causes atmospheric pressure to be forced into the blower and the cycle is repeated.



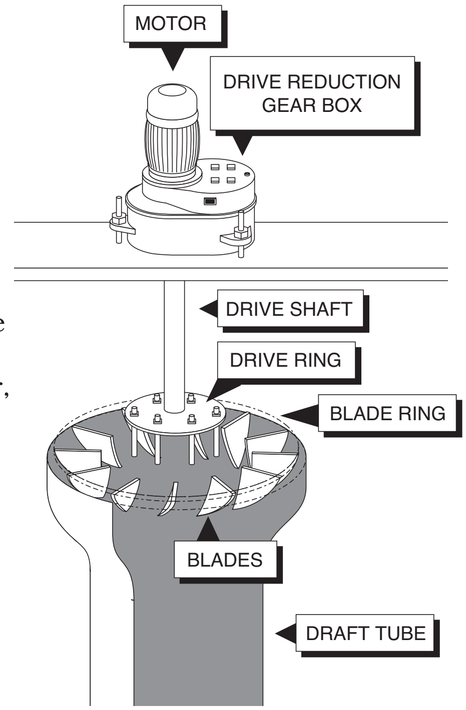
Mechanical Aeration Systems

Location

Mechanical aerators are aerators that are mounted directly over the material to be aerated. These aerators include propeller type, aspirator type, turbine type, and jets.

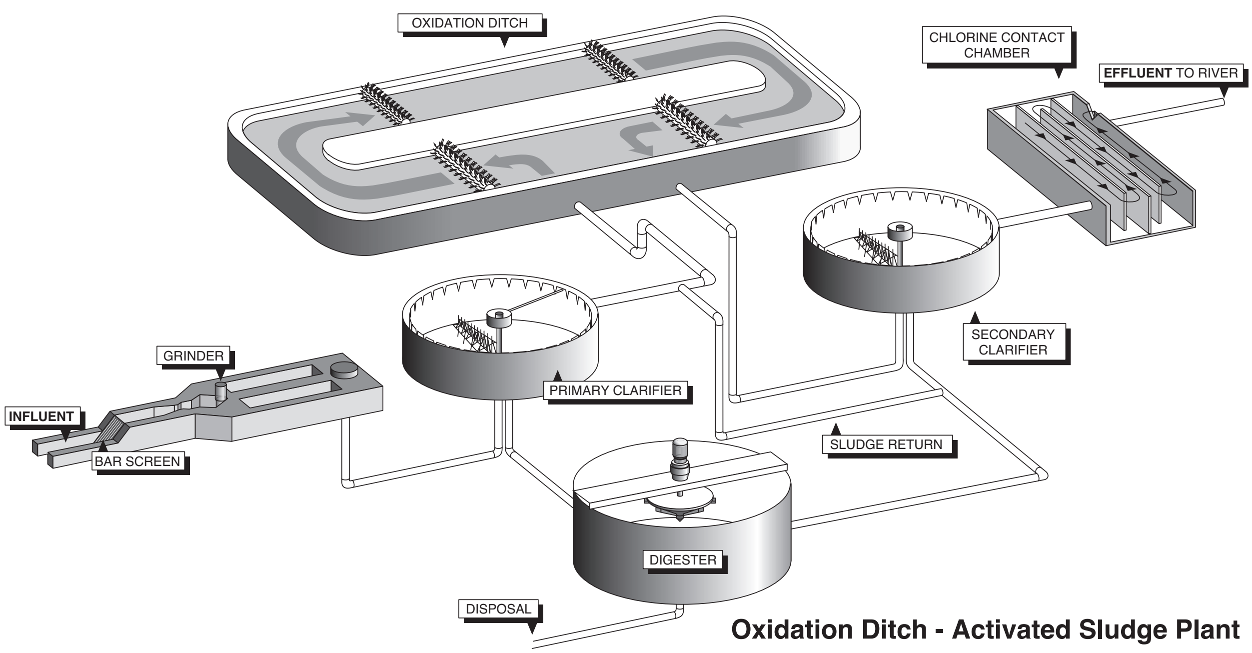
Surface Aerators

Surface aerators either float or are mounted on supports in the aeration tank. The oxygen transfer efficiency of a surface aerator increases as the submergence of the propeller is increased. However, power costs also increase because more water is sprayed.



Brush Aerators

Another type of surface aerator is the brush aerator used in special types of activated sludge aeration basins called oxidation ditches. The brush is a horizontally mounted brush located with the lower half of the brush below the water surface. The brush is rotated rapidly in the water to supply mixing and aeration. This type of system is often called a “race track.”



Oxidation Ditch - Activated Sludge Plant

Activated Sludge Process

Set the Stage - Assumptions

In order to understand how to control the activated sludge process, it is important to understand the biological response that takes place in the aeration basin and final clarifier. In order to develop this understanding, assume for a few minutes that the aeration tank has just been filled with sewage and there is enough flow to allow circulation from the aeration basin to the secondary clarifier and back to the aeration basin.

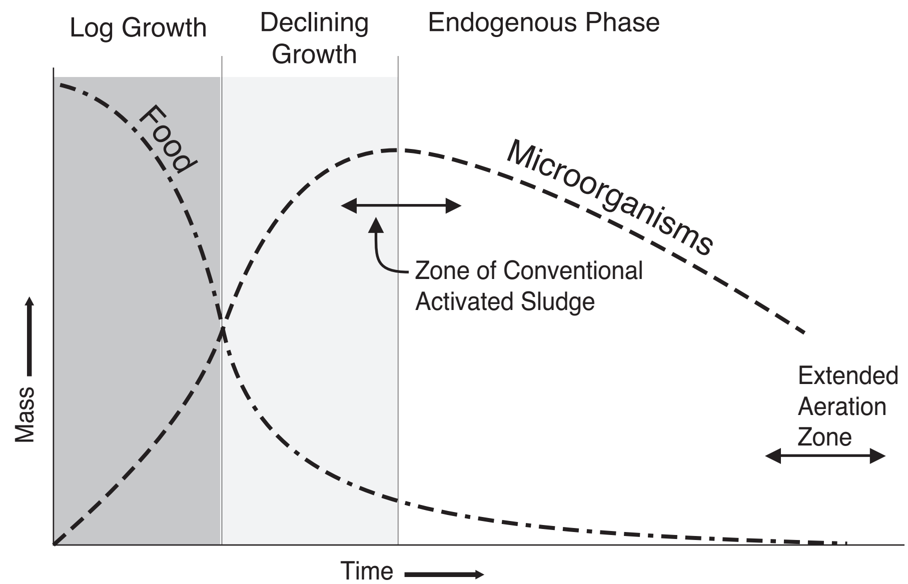
High Food - Low Microorganisms

At the start of this process, the wastewater contains a high quantity of food and a low quantity of bacteria. While the activated sludge process relies on bacteria and protozoa to treat the waste, the work horse is the bacteria. Bacteria, like most microorganisms will respond to the available food supply. That is, if there is a large food supply, they will increase their numbers in order to utilize the food supply.

Growth Phase

In this high food condition, the bacteria numbers will increase very quickly, some bacteria are able to double their numbers every 20 minutes. This type of growth cycle is called a logarithmic growth phase.

Growth curve
Relationship between food and microorganisms



Microbial Observations

During this high growth phase there will be an increase in the number of ciliates and stalked ciliate protozoa. Because these protozoa use bacteria as their main food source they will increase their numbers in order to take advantage of the increased numbers of bacteria.

Polymers

Bacteria are contained in a self-produced slime layer. This layer is used to collect food. When the bacteria are young most of their energy is placed into producing new bacteria and less into producing a slime layer. It is thought that the slime layer contains organic compounds called polymers. The presence of these polymers are considered one of the reasons that the food sticks to the bacteria. This process of connecting food and bacteria together produces clumps of sludge in the mixed liquor. It is in these clumps of sludge that the protozoa graze.

Settling

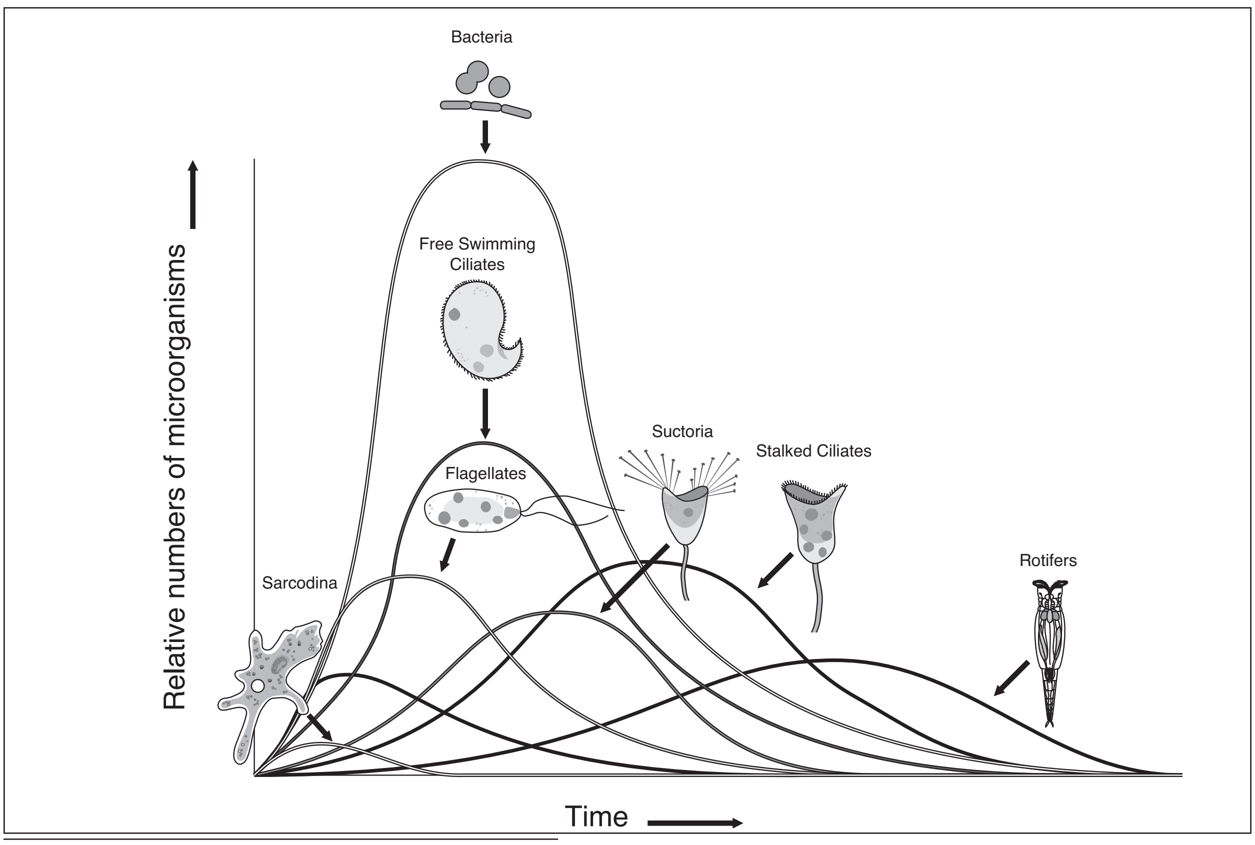
When the mixed liquor is placed in the clarifier and allowed to settle, the polymers produced by the bacteria, aid the clumping together of the sludge particles into components that are heavy enough to sink. This process is called **agglomeration**[47].

Young Sludge Appearance

At the start of this cycle, the mixed liquor would appear gray in color. As time moves on, the gray would turn to a light brown and a large volume of white billowy foam would be produced. At this point the mixed liquor (sludge) is said to be young.

Young Sludge and Settling

When this young sludge is placed in the clarifier it does not settle easily. It has a tendency to fill the clarifier and be carried over the weirs. When this occurs, operators say they have "bulking sludge." When there are small amounts of this bulky sludge going over the weirs it is called **straggler floc**[48].



47 **Agglomeration** - The growing or coming together of small scattered particles into larger flocs or particles which settle rapidly.

48 **Straggler floc** - At times, small, almost transparent, very light fluffy, buoyant sludge particles (1/8 to 1/4 inch in diameter) may rise to the clarifier surface near the outlet weirs.

Normal Growth Phase

As the sludge reaches maturity, the bacterial energy is more evenly divided between production of new microorganisms and energy to move around. During this stage, the slime layer that is produced increases in size and contains more polymers. Mixed liquor and sludge produced during this phase is called normal sludge.

Microbiological Appearance

When observed under a microscope, normal sludge would contain an abundance of free swimming and stalked ciliates and a few rotifers.

Normal Sludge Appearance

An aeration basin containing normal sludge would appear as light to dark brown in color and contain a small amount of crisp white foam.

Normal Sludge Settling

When normal mixed liquor is placed into a clarifier, it begins to agglomerate immediately, forms a discrete interface near the top of the clarifier and settles evenly. As the sludge settles, it acts like a big sponge. Clear water contained in the sludge is slowly squeezed out and exits over the effluent weirs. The sludge settles to the bottom of the clarifier and is returned to the aeration basin.

Dying Conditions

If the same batch of mixed liquor is continuously mixed and no additional food is added, the microorganisms will eventually deplete the food supply. As this happens, the microorganisms reduce their production of new microorganisms and focus their energy on survival. As the food supply starts to diminish, the bacteria first utilize their slime layer for food and when this is gone, they die and break open. This process releases food into the mixed liquor for the remaining microorganisms. Mixed liquor and sludge produced during this portion of the cycle is called old sludge.

Microbial Appearance

When old sludge is observed under a microscope, there will be very little, if any, protozoa action. A few stalked ciliates may be present, but their action will be sluggish or nonexistent. There may be several rotifers and a few worms.

Old Sludge Appearance

When viewing an aeration basin containing old sludge, the sludge would appear dark brown in color and the foam would look dirty and greasy.

Old Sludge and Settling

Even though the slime layer is gone, old sludge settles quickly. However, it does not agglomerate well and settles as discrete sludge particles leaving behind considerable debris. This debris is commonly called "**pin floc**[49]" and contains the bodies of many dead bacteria.

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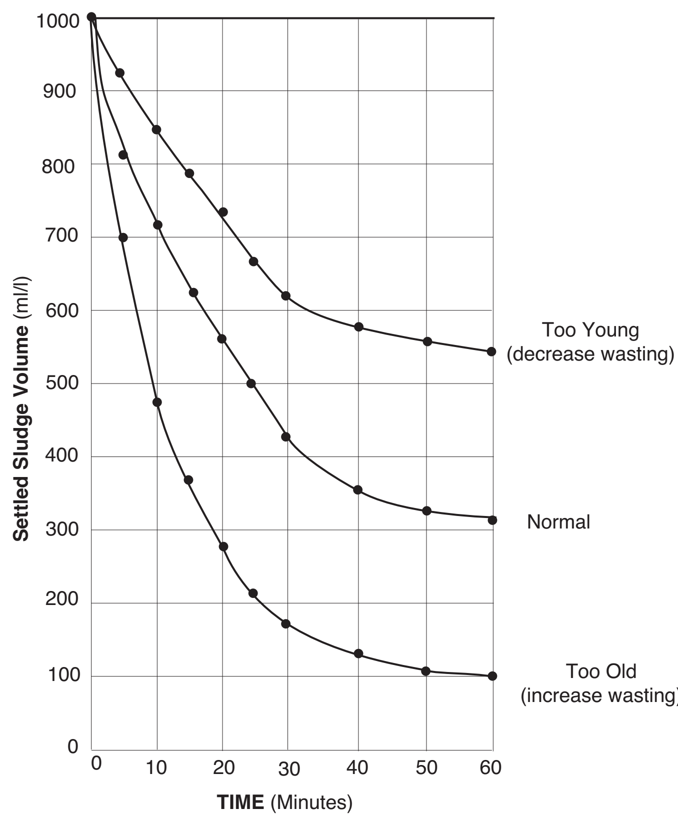
49 **Pin floc** - Very small compact floc, usually less than 1/32" in diameter, may be observed suspended throughout moderately turbid final clarifier supernatant.

Process Control

Requirements

The efficiency of the activated sludge process depends on settling the mixed liquor so that active organisms can be returned to the aeration tank to stabilize the organic material in the incoming wastewater. When this condition occurs, the plant is said to be producing a high quality sludge. This high quality sludge will be produced when there is the proper relationship between the food and the microorganisms (sludge) and the microorganisms are maintained in the aeration basin long enough to consume the food and allowed to rest for a sufficient amount of time in the clarifier. The amount of time the sludge is in the system is called **sludge age**[50].



Food to Microorganism Ratio

The relationship between the food and the microorganisms is the relationship between the organic loading on the aeration basin (influent BOD) and the quantity of mixed liquor (MLSS). This relationship is called the **F/M ratio**[51]. F/M refers to Food to Microorganism ratio.

MLSS or MLVSS

One of the assumptions in calculating F/M ratio is that the concentration of the mixed liquor is a representation of the quantity of microorganisms in the basin. In order to have a more valid representation

50 **Sludge age** - A measure of the length of time a particle of suspended solids has been undergoing aeration in the activated sludge process.

51 **F/M Ratio** - Food to microorganism ratio. A measure of food provided to bacteria in an aeration tank.

of the microorganisms, most operators use the mixed liquor volatile suspended solids measurement (**MLVSS**[52]) to reflect the microorganism quantity. This value is obtained by placing the filter from the MLSS test into a special oven called a muffle furnace. Here temperatures are raised to 600 °C. At this temperature, all of the organic (volatile) material will be burnt away. The quantity that volatilizes at this temperature is considered to be organic material and is assumed to represent the microorganisms in the basin.

Calculating F/M Ratio

The food-to-microorganism ratio (F/M) is a way of expressing BOD loading with regard to the microbial mass in the system.

$$F/M = \frac{Q \text{ X } BOD}{V \text{ X } MLVSS}$$

Where:

F/M = Food to microorganism ratio, pounds of BOD per day per pound of MLVSS

Q = wastewater flow, MGD

BOD = wastewater BOD, mg/L

V = liquid volume of aeration tank, MG

MLVSS = mixed liquor volatile suspended solids in aeration basin, mg/L

Typical F/M Ranges

Conventional activated sludge systems have a recommended F/M ratio of 0.2 - 0.5 and **extended aeration**[53] facilities range from 0.05 - 0.2.

MLSS and Settleability

The concentration of MLSS maintained in an aeration tank varies with the kind of process and the method of operation. In general, a MLSS of less than 1000 mg/L does not provide a low enough F/M for good sludge settleability and a MLSS over 4000 mg/L results in loss of suspended solids in the clarifier overflow. The common range for MLSS concentration is 2500 mg/L to 3500 mg/L. The best MLSS concentration for a plant is usually determined through experience.

Sludge Age

As was mentioned above, the two major considerations to a good quality sludge are proper balance between food and microorganisms and proper sludge age. While there are many methods of measuring the age of the sludge, one of the more popular is to calculate the average age of the sludge. This is called mean cell residence time or MCRT.

52 **MLVSS** - Mixed liquor volatile suspended solids - The organic or volatile suspended solids in the mixed liquor of an aeration tank.

53 **Extended aeration** - A modification of the activated sludge process that provides for aerobic sludge digestion within the aeration system. The process includes the stabilization of organic matter under aerobic conditions and disposal of the gaseous end products into the air.

MCRT Described

MCRT expresses the average time that a microorganism will spend in the activated sludge process. MCRT is expressed in days and is calculated by dividing the total solids inventory (pounds) in the aeration basin by the pounds of microorganisms that are intentionally wasted *and* the pounds of microorganisms discharged in the effluent.

Typical MCRT Values

The MCRT value should be selected to provide the best effluent quality. This value should correspond to the F/M loading for which the process is designed. For conventional activated sludge plants, a MCRT of 5 to 10 days is considered normal.

Summary

The time the sludge is under aeration (called aeration period), BOD loading per unit volume, food-to-microorganism ratio, and MCRT define an activated sludge process. Aeration period is calculated in the same manner as detention time. BOD loading is usually expressed in terms of pounds of BOD applied per day per 1000 cu ft of liquid volume in the aeration tank.

Controlling the ActivateD Sludge Process

Operator Controls

There are only three things an operator has control over in an activated sludge plant:

- Concentration of sludge (MLSS)
- Rate of return sludge
- Dissolved oxygen (DO) in the aeration basin

DO Control

In small domestic sewage plants there is little need to control the DO and in fact, most small plants are designed with little or no control on the dissolved oxygen. The operational consideration is to make sure the DO never drops below 1 mg/L.

Control of MLSS

The concentration of mixed liquor is controlled by the rate of wasting in the plant. Ideally, one pound of old sludge should be removed from the system for each pound of new sludge produced. The best wasting control is daily removal of small amounts of sludge. If the MLSS is reduced to too low a level, the microorganisms will go into logarithmic growth and produce poor settling sludge.

Return Sludge Control

Return sludge is basically used to control the level of sludge in the clarifier. The rate of return sludge from the final clarifier to the aeration basin is expressed as a percentage of the raw wastewater influent. For example, if the return activated sludge rate is 30 percent and the raw wastewater flow into the plant is 10 MGD, the recirculated flow equals 3.0 MGD.

Improper Return Flows

If the return sludge flow is too high, the excessive hydraulic loading on the aeration basin will push the sludge out of the basin and into the clarifier. This will increase the volume of sludge in the clarifier and reduce the MLSS in the aeration basin. The results will be increased bacterial growth and a poor settling sludge. If the return rate is too low, the majority of the organisms will end up in the secondary clarifier reducing the growth rate and producing an old appearing and poor settling sludge.

Variations of Activated Sludge

Introduction

There are several variations to the activated sludge process. These variations can be defined around physical design considerations, flow patterns, hydraulic and organic loading and operational parameters. However, there are only four popular variations to small activated sludge plants:

- Conventional plants
- Extended air plants
- Contact Stabilization plants
- Package plants

Conventional Activated Sludge

General Description

The term conventional activated sludge plant is defined around operational parameters of MCRT and F/M ratios. For a typical domestic wastewater at about 20 degrees centigrade the conventional process operates between MCRT values of 5 to 15 days and F/M ratios of 0.2 to 0.5 lbs BOD applied/lb MLVSS/day.

Effluent Quality - Center Range

Plants operating in the middle of this range produce an excellent effluent quality and do not **nitrify**[54]**.**

Effluent Quality - Low End of Range

At the lower end of this loading range, an even better effluent is sometime produced. Operational problems such as rising sludge in clarifiers, the appearance of filaments in the sludge, and the formation of a brown, greasy-appearing foam occur when the plant slips slightly or goes completely into nitrification.

Extended Aeration

Typical of Small Plants

One of the basic operational variations for small plants that do not receive 24 hour operator supervision is the extended air process. Extended aeration occurs when a plant is operated at the lowest successful range of process loading.

Operational Criteria

Such plants are very conservative in design and generally operate with an MCRT of 20 to 40 days and an F/M ratio of 0.05 to 0.15 lbs BOD applied/lb MLVSS/day based on typical domestic wastewater at a temperature of 42°F.

Wasting

Some manufacturers claim that no wasting is necessary for an extended aeration design. In fact, after extremely long periods of aeration, suspended matter

54 **Nitrification** - A process in which bacteria change the ammonia and organic nitrogen in wastewater into oxidized nitrogen (usually nitrate). The second-stage BOD is sometimes referred to as the “nitrification stage”.

remains in the effluent. Although sludge wasting need not be conducted on a daily basis in plants operating in the extended aeration range, occasional wasting will provide the best quality effluent.

Contact Stabilization

Typical Doughnut Plants

One of the popular doughnut plant designs is the contact stabilization plant. This plant utilizes two aeration basins. One basin is twice the size of the other. The smaller basin is called the contact chamber and the larger basin the reaeration basin. In addition this facility utilizes a larger than normal final clarifier.

Process Description First Step

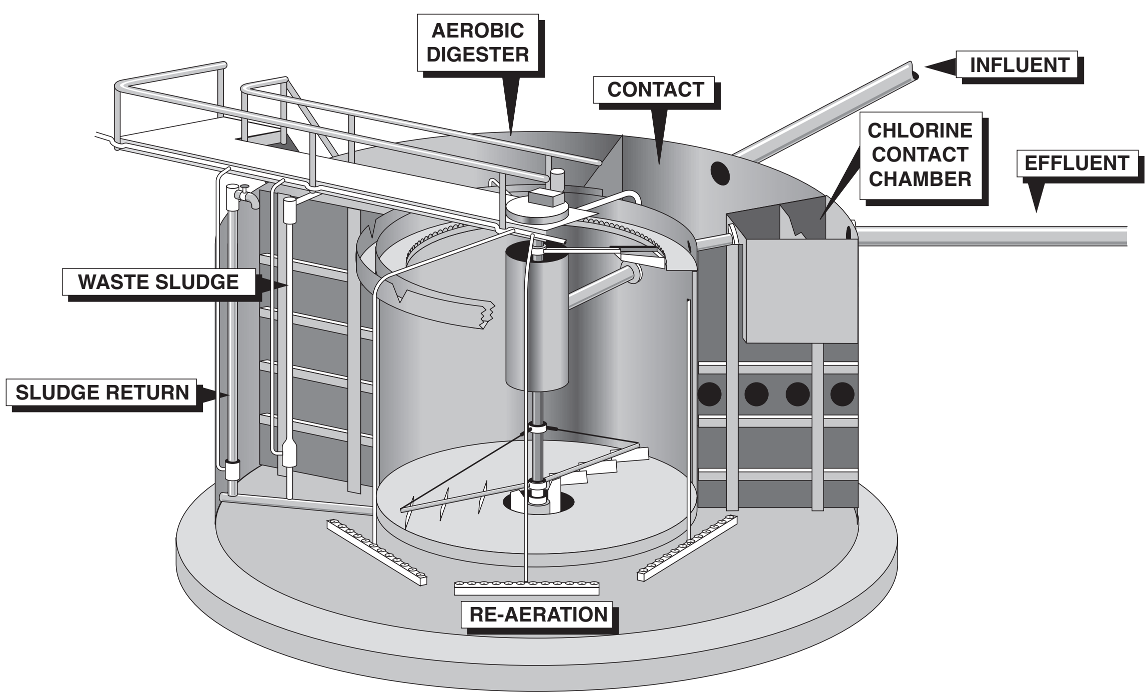
In the contact stabilization plant, raw or primary sewage is mixed with mixed liquor for 20 minutes to 1 hour in the contact tank. During this short period, the bacteria pick up the food in their slime layers. The mixed liquor is then sent to the clarifier for compaction.

Step Two

The sludge is removed from the clarifier and sent to the reaeration tank for two hours where the bacteria and other organisms complete the treatment process. The mixed liquor from the reaeration tank is then mixed with raw sewage at the influent of the plant and the cycle starts over again. The mixed liquor from the reaeration tank is mixed with raw sewage at a rate of 3 to 5 gallons of mixed liquor for every 10 gallons of raw sewage (30% to 50%).

Advantages

The advantage of the contact stabilization process is the ability to hold larger than normal volumes of sludge in reserve in the reaeration basin. This allows to operator to deal with shock loads. Treatment plants in communities where the weekend population is



significantly larger then the week day population benefit from this type of facility.

Disadvantage

The major disadvantage is the amount and quality of process control and operator time the system requires.

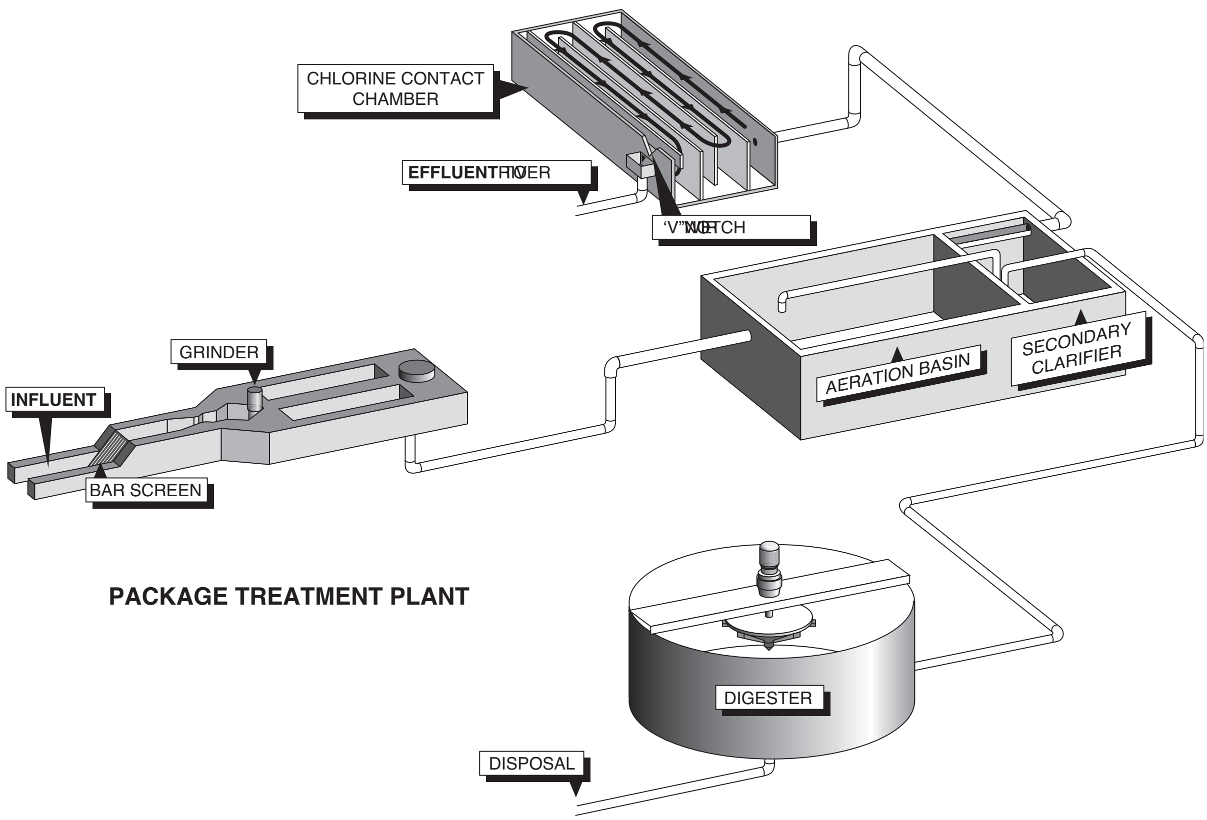
Package plants

General Description

The term “package plant” refers to the configuration of an “all in one” unit. Package plants generally do not have primary clarifiers. The remaining process units are typically contained in a single large rectangular or circular tank.

Rectangular Plants

Rectangular plants may have a separate headworks and digester. The secondary clarifier is fastened directly onto the end of the aeration basin.



PACKAGE TREATMENT PLANT

Circular Plants

The more popular package plant is the circular plant also called a doughnut plant. With this facility the aeration basins, digester and chlorine contact chambers are built around a circular clarifier. The clarifier is the center or hole in the doughnut. Many times flexibility has been built into the package plant so it can be operated as conventional or extended aeration.

Activated Sludge Settling Problems

Introduction

One of the most common problems with activated sludge plants is poor settling. Remember, poor settling can occur with young or old sludge. Determining the cause of poor settleability of an activated sludge involves investigating biological, chemical, and physical factors.

Biological Considerations

Calculations

First the F/M, BOD loadings, MLSS concentration, and sludge age should be calculated and compared to the recommended values for the particular aeration process.

Visual Observation

Microscopic examination and visual observation of the settling characteristics of the MLSS can reveal filamentous growth and poor floc quality. Nitrification-**denitrification**[55] is evidenced by rising sludge in the final clarifier.

Chemical Concerns

Chemical Factors

Chemical factors that can cause poor biological growth are insufficient dissolved oxygen, lack of nutrients, presence of toxins, and low temperature.

Laboratory Test

Laboratory tests must be used to establish the adequacy of dissolved oxygen in the system. Since lowering the temperature of the mixed liquor decreases the rate of biological activity, cold temperature has an effect similar to increasing the BOD loading.

Low DO

The DO in the aeration basin can be reduced due to excessively high organic loading or from a reduction in the capacity of the aeration equipment.

Physical Considerations

Visual Observation Aeration

Finally, the physical characteristics of the aeration system and final clarifier should be considered. Excessive agitation, due to long detention times or overly aggressive mechanical mixing, can cause shearing of biological floc into tiny particles with reduced settleability.

Plugged Diffusers

If a portion of the aeration diffusers become plugged, mixing is reduced along with oxygen transfer. This could result in excessive settling of grit in the aeration basin. Excessive grit can cause more diffusers to become plugged, aggravating the problem. In addition the grit could contain organic material that will go anaerobic producing high DO demand and deteriorating the sludge quality. As if that were not enough of a problem, a reduction of oxygen transfer can cause the sludge to become stressed and thus respond as an old sludge, not settling properly.

55 **Denitrification** - A condition that occurs when nitrite or nitrate ions are reduced to nitrogen gas and bubbles are formed as a result of this process. The bubbles attach to the biological flocs and float the flocs to the surface of the secondary clarifiers. This condition is often the cause of rising sludge observed in secondary clarifiers or gravity thickeners.

Visual Observations Clarifier

Ineffective final clarification can result from an inadequate rate of returning sludge, excessive overflow rate, hydraulic turbulence, or a faulty sludge collector mechanism.

High Flow Problem

When the flow is excessive through an activated sludge plant the solids in the aeration basin can be pushed into the clarifier and washed out over the weirs thus depleting the MLSS. The result is a reduction of sludge age. The reduction in age could be sufficient to produce a young sludge which will not settle properly and a large volume of white foam will form on the aeration basin.

Filamentous Organisms

Introduction

One of the problems that can be difficult to control is the development of filamentous microorganisms. Filamentous organisms grow as long, thread-like organisms having an increased surface area. This increased surface area makes it possible for the filamentous organisms to grow in conditions of low dissolved oxygen or low nutrient concentrations. Unfortunately, filamentous organisms hinder settling by causing excessive bridging and matting of the individual particles of activated sludge floc.

System Conditions

If the conditions in the aeration system deteriorate, low DO and low nutrient levels, the growth of undesirable filamentous microorganisms can result.

Conclusion

Process control balance is generally related to process loading and is expressed by the food to microorganism (F/M) ratio. Inability to settle the mixed liquor can result in a high concentration of suspended solids in the clarifier effluent. Proper control of the activated sludge process will produce a mixed liquor with good settleability.

Desirable Operating Parameters

A properly operated activated sludge plant should have:

- MLSS around 2500 mg/L,
- Dissolved oxygen of 1.0 - 2.0 mg/L in the aeration basin,
- Settleometer that settles to approximately 1/3 of its volume in 60 minutes,
- Return rates of 30 - 100% of influent flow,
- A light brown color in the aeration basin,
- No objectionable odors,
- A clean, crisp appearing effluent.

Secondary Clarifiers

Introduction

Secondary clarifiers are an integral part of a biological treatment plant. Secondary clarifiers are similar to primary clarifiers only larger and with a few specific piping and physical changes.

Physical Difference

In order to reduce weir loading and thus avoid short circuiting, the weirs may be located in the center of the clarifier. Instead of a single weir, a rectangular trough is used, allowing water to enter on both sides of the trough. A second method of making the weirs longer is to just make the clarifier larger in diameter. Depending on the type of treatment process, RBC, tricking filter or activated sludge, the sludge collection mechanism may be different than a primary clarifier. These differences are discussed below.

Tricking Filter and RBC - Secondary Clarifiers

Design Criteria

Common design criteria for secondary clarifiers after trickling filters and RBC plants are surface overflow rates not exceeding 800 gpd/ft^2, minimum side water depth of 7 feet, and maximum weir loading less that 10,000 gpd/ft for small plants and not over 20,000 gpd/ft for larger plants.

Detention Time

The typical detention time for secondary clarifiers used for RBCs and trickling filters is 1 to 2 hours. The detention time is controlled by the hydraulic loading. From an operational standpoint, surface overflow rates and weir overflow rates are more important than detention time.

Sludge Collection Mechanism

The purpose of gravity settling following trickling filters or RBCs is to collect biological growth, or sloughings, flushed from filter media. These sloughed solids are generally well-oxidized particles that settle readily. Therefore, a collector arm that slowly scrapes the accumulated solids toward a hopper for continuous or periodic discharge gives satisfactory performance. This is the same type of sludge collection mechanism that is used in a primary clarifier.

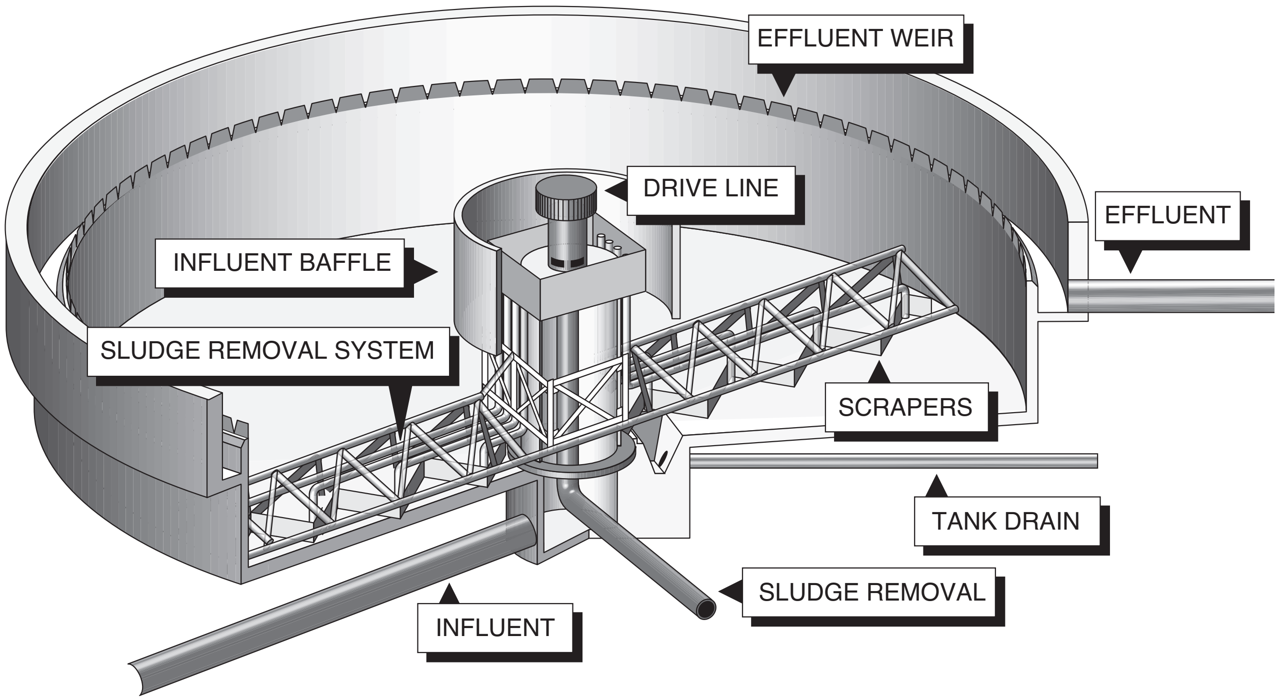
Sludge Depth

Depth of accumulated sludge in a trickling filter secondary clarifier is normally a few inches if recirculation flow is drawn from the tank bottom. Even if sludge is drained only twice a day, the blanket of settled solids rarely exceeds 1 foot.

Activated Sludge - Secondary Clarifiers

Introduction

Gravity separation of biological growths suspended in the mixed liquor of activated sludge systems is more difficult to achieve. The more active microorganisms in the activated sludge results in a lighter, more buoyant sludge with reduced settling velocities. In part, this is the result of bubbles suspended in the floc that float the tiny biological floc particles to the surface. The specific gravity of activated sludge is less than other biological sludge.



SECONDARY CLARIFIER FOR ACTIVATED SLUDGE

Design Criteria

Design parameters for final clarifiers in activated sludge processes take into account the reduced settleability of a biological floc. Compared to other wastewater sedimentation tanks, activated sludge clarifiers are deeper to accommodate the greater depth of settled solids, have a lower surface overflow rate to reduce carry over of light biological floc, and can have longer weir lengths. Typical overflow rates are 600 gpd/ft^2 for plants smaller than 1 MGD and 800 gpd/ft^2 for larger plants. During the peak hydraulic flow of the day, the overflow rate should not exceed 1200 gpd/ft^2 and 1600 gpd/ft^2. The maximum recommended weir loading is 10,000 to 20,000 gpd/ft.

Detention Time

Typical detention time for secondary clarifiers in an activated sludge facility is 2 to 3 hours for the liquid portion and 45 minutes to 1.5 hours for the sludge.

Sludge Depth

The accumulated sludge in a final settling basin for an activated sludge process may be 1 to 2 feet thick in a well operating plant. During peak loading periods, this sludge blanket may expand further to incorporate one third to one half of the tank volume.

Sludge Collection Mechanism

The wastewater flow pattern for a clarifier used in an activated sludge system is the same as other secondary systems discussed in this text except for the sludge collection mechanisms. A draft tube arrangement is often used to facilitate rapid removal of sludge from the clarifier.

Draft Tubes

Draft tubes are hydraulic devices that use a series of "V" shaped scrapers attached to the bottom of the rake arm. As the rake arm rotates sludge is funneled into the "V" and picked up by the siphon tube. There is a difference in hydraulic head between the top of the water in the clarifier and the upper end of the siphon tube. It is this difference in head that is used to force the sludge off the bottom of the clarifier and up through the tube.

Advantage of Draft Tubes

Rapid uniform withdrawal of sludge across the entire bottom of an activated sludge final clarifier has distinct advantages. The retention time of solids that settle near the tank's periphery is not greater than those that land near the center, thus aging of the biological floc and subsequent floating solids due to gas production are eliminated. With a scraper collector used in the trickling filter and RBC clarifiers, the residence time of the sludge depend directly on the radial distance from the sludge hopper.

Ponds or Lagoons

Introduction

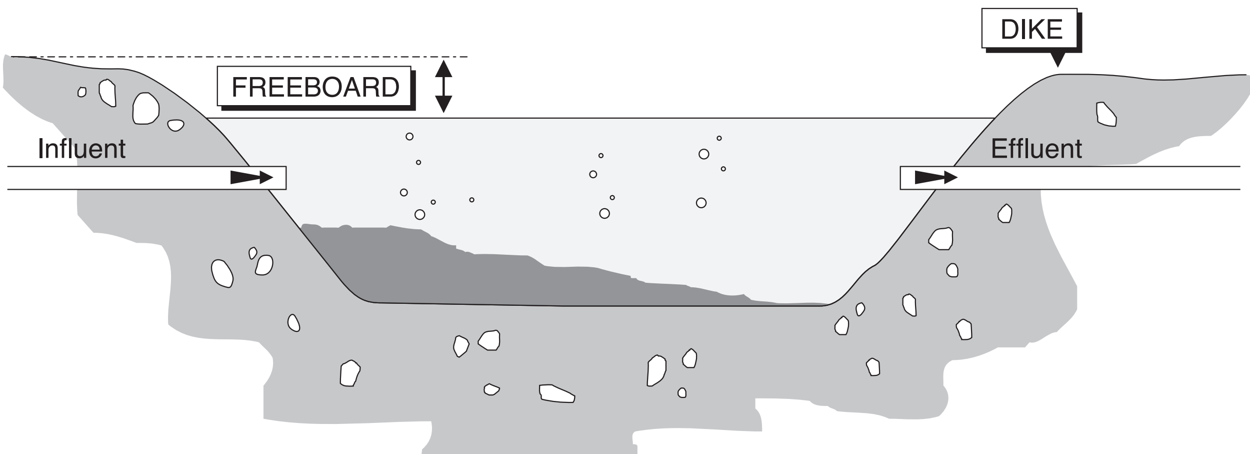
Wastewater lagoons, also called stabilization ponds or just ponds, are classified as secondary treatment systems.

Advantages

The major advantage to the community using ponds for wastewater treatment is the reduction in operation and maintenance cost as compared with mechanical plants.

Disadvantage

The major disadvantage of using ponds is the lack of control over effluent quality. Most ponds are designed with little or no processes control built into the system. The other major disadvantage is quality of the effluent. Ponds normally produce a higher total suspended solids in the effluent than mechanical plants. However, most of these TSS are composed of algae.



CROSS SECTION OF WASTEWATER LAGOON

Tundra Ponds

In the Arctic, naturally occurring tundra ponds and engineered lagoon systems are used for community wastewater disposal. Shallow tundra ponds allow for natural biological treatment, providing waste loading does not overcome nature's ability to maintain adequate oxygen levels. Engineered lagoons or ponds can be designed using the principles established for natural or artificial aeration. These systems need to take into account the wastewater characteristics of the community they serve.

Lagoons for Honey Buckets

Honey bucket lagoons, which are common in rural Alaska, provide for a sanitary means of disposal of honey bucket wastes by providing a site away from the village for waste disposal. However, they provide only a marginal treatment of the contents of the lagoon.

Physical Equipment

Major Components

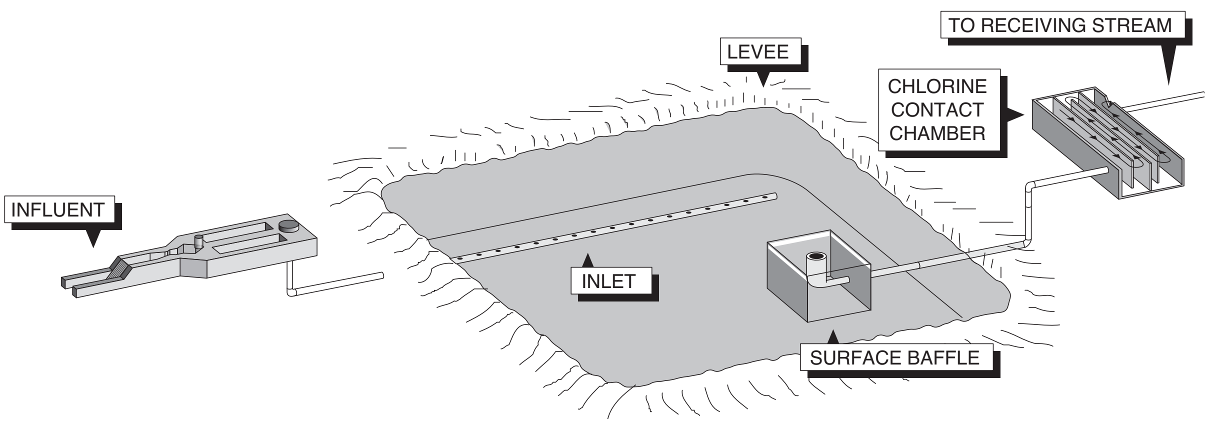
A wastewater lagoon consists of four components. The dike or levee, the lagoon bottom or liner, the piping and the cell dividing walls (for multicell lagoons only). The dike should have a three-foot **freeboard**[56], be impermeable, and be sloped with a 3:1 ratio (i.e., 3 ft horizontal to 1 ft vertical). It may be necessary to drive on the dike, if so, the dike should be at least eight feet wide. The lagoon floor is generally lined to eliminate any seepage.

Piping

Besides the structure, there is the inlet and outlet piping. The inlet piping may be a single pipe exiting above or below the surface or a pipe used to distribute the flow along one side or end of the lagoon. The inlet to the outlet piping may be a fixed elevation elbow, a movable weir plate or some type of flexible pipe or joint. The weir plate and flexible joint allow the operator to control the depth of water in the lagoon and thus provide some process control capabilities.

Other Items

Commonly, a lagoon will be preceded by a preliminary treatment stage. In some facilities, a chlorine contact chamber is included on the lagoon effluent. Flow measurement is provided on either the influent or effluent piping system. In large facilities flow measurement is provided in both the influent and effluent piping.



Lagoons Sizes

Single cell lagoons are usually less than one acre in size. Anything larger requires two or more cells to achieve adequate treatment. The projected flows and loading rates are the determining factors for lagoon size and design. Multicellular lagoons are divided in one of two ways. The most common type is to have two ponds side by side with an earth dike between them. Other dividers, such as cement walls and plastic liners, allow one lagoon to be divided into individual cells. These designs usually offer more flow control and offer a wider variety of operational alternatives than a single cell.

56 **Freeboard** - The vertical distance from the normal water surface to the top of the confining wall.

Treatment Process

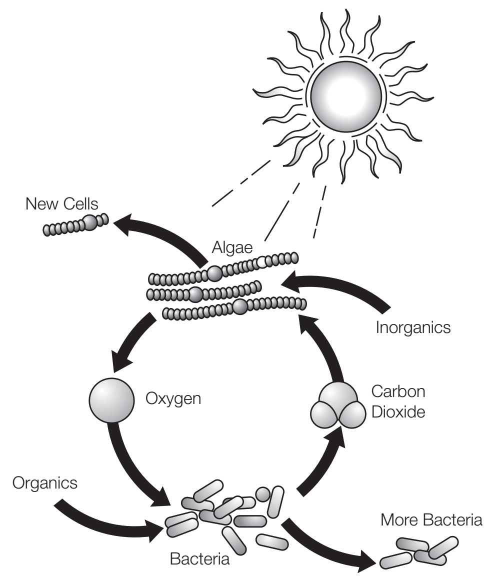
Microbial Relationships

Natural Cycle

The microbial interactions in a pond or lagoon involves a natural cycle which relies upon the relationship between algae and bacteria. This relationship is called a **symbiotic**[57] relationship and is the key to what makes ponds work.

The Relationship

The algae/bacteria symbiosis is a process by which algae and bacteria give and take from each other. Algae, in the presence of sunlight, uses the carbon dioxide, ammonia, and phosphate released from the bacteria (aerobic and anaerobic) to form new algae cells and, in the process, give off oxygen. This process is called **photosynthesis**[58]. The oxygen produced by the algae is in turn used by the bacteria in their reduction and stabilization of the incoming waste.



Night Time Reaction

At night, the algae use the dissolved oxygen they produced during the day and give off carbon dioxide as a by-product. This is the reason why, at night, lagoons can have lower DO levels and lower pH's due to the buildup of CO_2 than they have during the day. It is very important to have oxygen available to all of the bacteria at all times. Because the algae and the bacteria use the available D.O. during the night, a check for D.O. in the hours before daylight can be beneficial indicator of the health of the pond. If the DO is low, supplemental air may be required to maintain treatment. This usually becomes an issue during warmer weather or high organic loading events.

57 **Symbiosis -** The living together or close association of two dissimilar organisms with mutual benefit.

58 **Photosynthesis** - (foto-SIN-the-sis) - A process in which organisms with the aid of chlorophyll (green plant enzyme) convert carbon dioxide and inorganic substances to oxygen and additional plant material, utilizing sunlight for energy.

Wind & DO

Wind is important because it creates surface mixing which will affect DO concentrations. The wind aids in increasing aeration by adding DO to the pond and permits surface DO to penetrate deeper into the ponds.

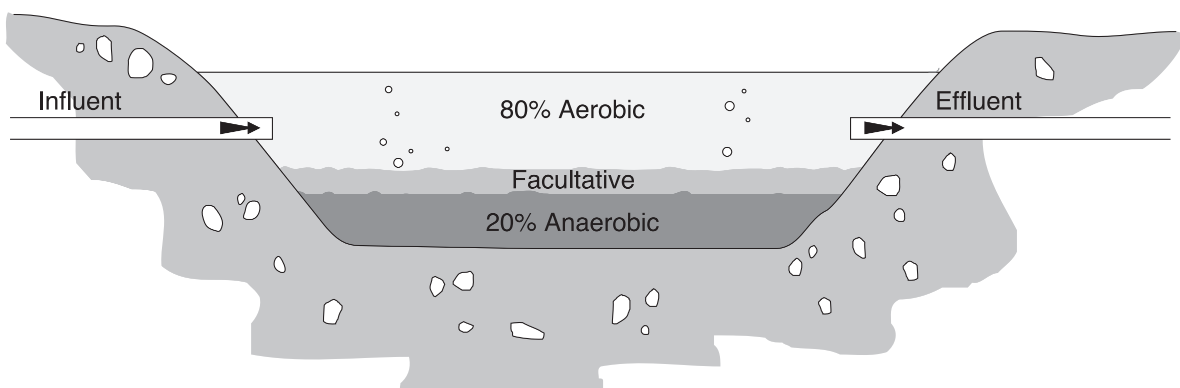
Impact of Temperature

Temperature of the lagoon water is also important since the microorganisms are very sensitive to changes in temperature. Activity doubles with every 10˚C increase and decreases by half with every 10˚C drop in temperature. Therefore, during the cold winters, biological activity is significantly decreased.

Operating Zones

Modes and Zones

Lagoons can be operated as anaerobic, aerobic or facultative treatment facilities. This terminology is in reference to the type of bacteria used to stabilize the waste. The most common and desirable operating modes are aerobic and facultative. These provide the best treatment with the least odors. Aerobic and facultative lagoons have three operating zones that identify the three groups of bacteria that are active in the lagoon.



The Three Zones

The three zones of a aerobic or facultative lagoon are; aerobic, facultative, and anaerobic. These zones are established by separate environments for microbial activity related to waste stabilization. For our purposes, the facultative zone will be included in the aerobic zone discussion, since organisms in this zone usually metabolize aerobically thus utilizing available dissolved oxygen.

Aerobic Zone

Upper 80%

The aerobic zone is found in approximately the upper 80% of the lagoon but will vary according to the sludge level in the pond. *All the zones are measured from above the sludge level.* It is here that the aerobic microorganisms use the soluble BOD and dissolved oxygen in their metabolic process. The required oxygen is supplied from two sources: algae photosynthesis and surface aeration. Surface aeration is accomplished by the penetration of atmospheric oxygen into the liquid and is aided by winds and wave action and from oxygen equilibrium between the water and air.

Biological Action

The microbial synthesis which takes place in this zone promotes new cell formation and leads to an increased biomass. As new cells are formed, older ones die off. This results in the release of nutrients from the dead cells. These nutrients are composed of ammonia nitrogen, phosphate, carbon dioxide, and water. These released nutrients are, in turn, used by other bacteria and algae, or are discharged with the effluent.

Anaerobic Zone

Lower 20%

The anaerobic zone, located in the lower twenty percent of the lagoon, contain only anaerobic bacteria that use the settled wastes (BOD) and chemically bound oxygen for metabolism. Within this anaerobic zone a complex group of bacteria work together to further stabilize the wastes into stable compounds very much like an anaerobic digester.

Microbiological Action

Methane, hydrogen sulfide, carbon dioxide and ammonia are produced as metabolic end products of the anaerobic activity. As these anaerobic microbes metabolize the wastes, they also produce new cells and in turn some die off, releasing nutrients in the same way aerobic microorganisms release nutrients. Some of these nutrients are utilized by algae and other bacteria in the aerobic zone. This aerobic/anaerobic interrelationship helps to minimize overall sludge buildup in the lagoon system. In a properly designed and operated lagoon system, sludge can be expected to accumulate in the bottom of lagoons. Sludge will require removal on a periodic basis.

Classification of Ponds

Many Variations

There are many variations in the classification of ponds. They may be classified according to detention time, size, use and type of organisms used. The most popular classification is by type of organism and the method used to supply air.

Classification by Organism

The three classifications by organisms are:

- Aerobic
- Anaerobic
- Facultative

Aerobic Ponds

Aerobic lagoons are shallow, less than 4 feet in depth. They are characterized by having dissolved oxygen present throughout the depth of the pond. In most instances aerobic ponds will require additional air. This additional air is supplied by a surface aerator or by bubbling air up through the pond from tubes laid on the floor. Aerobic ponds that are supplied additional air from a mechanical device are called aerated lagoons.

Facultative Ponds

Facultative ponds are typically four to six feet deep. These are the most common of the ponds. The facultative pond contains the classic aerobic and anaerobic layers that were described above. The majority of the oxygen needed in these ponds is supplied by the algae and wind. They are called facultative ponds, because it is nearly impossible to maintain clear and distinct anaerobic and aerobic layers on a continuous basis.

Aerated Facultative Ponds

When the land area is small or the organic loading is large, the efficiency of these ponds can be increased dramatically with the addition of surface aerators. These reduce stabilization time from 8 to 12 weeks for standard ponds and 1 to 3 weeks for aerated ponds. In addition, the organic loading can be increased by ten times.

Anaerobic Ponds

Anaerobic ponds are commonly twelve feet deep or deeper. They usually have a small (less than 10% of depth) aerobic layer at the top. However, the majority of the depth of the pond is devoid of oxygen. While they are quite odorous, they are very effective in treating some types of industrial waste as well as domestic waste.

Frozen Ponds

When a facultative pond is frozen for several months the treatment process will switch from aerobic to anaerobic. Treatment continues, but at a slower pace than in the aerobic condition. The major negative impact of this process is the odor that is present when the ice melts.

Operation of Ponds

Overview

Soluble wastes are the food source for the aerobic population. Insoluble and floatables, on the other hand, can pose significant problems. Insoluble organics settle to the bottom and are stabilized anaerobically. This is normal and acceptable. However, insoluble inert material, such as grit and sand, often build up on the bottom and can create **short circuiting**[59] and shorter detention times in the lagoon. A large percent of this inert material will settle out near the influent structure and may cause a plugged or partially plugged influent line. Floatables composed of plastics, grease, or sludge mats can create offensive odors and be an eyesore. If present in excess, these offensive solids need to be manually removed and disposed of properly. Many facilities are utilizing preliminary treatment, including the use of microscreens to prevent these materials from entering the pond.

59 **Short circuiting** - A condition that occurs in tanks or ponds when some of the wastewater travels faster than the rest of the flowing wastewater.

Operational Processes

Four Modes

There are four common operational modes used with lagoons in small communities. They are:

- Total retention
- Intermittent
- Continuous flow
- Series or parallel operation

These four processes can be used in conjunction with any of the bacterial operational considerations (aerobic, facultative, aerated or anaerobic).

Total Retention

In the total retention mode, the effluent is shut off and treated water is evaporated into the atmosphere. Obviously this process works best in climates with significant amounts of daylight and warm days.

Intermittent Operation

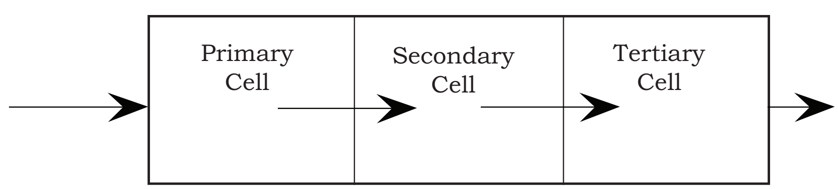
There are several places where the receiving stream flow and quality are marginal during specific portions of the year. In these conditions, the effluent may be shut down during a portion of the year and open during other times of the year. In addition effluent disposal may be accomplished by spray irrigation during that portion of the year when no discharge is allowed.

Continuous Flow

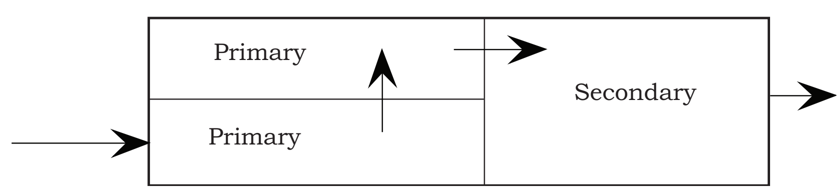
The most common method of lagoon operation is continuous flow. In this mode of operation, the effluent is open throughout the year. However, in some cases, the effluent may utilize some type of control mechanism that allows the operator to control the level of water in the pond and thus provide a limited amount of process control.

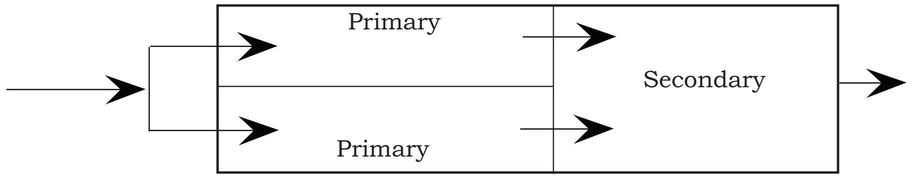
Series and Parallel

If the system has only one cell, then there is no possibility to change the process modes. However, if the system contains two or more cells, the piping system may have been designed to allow series or parallel operation of the cells.

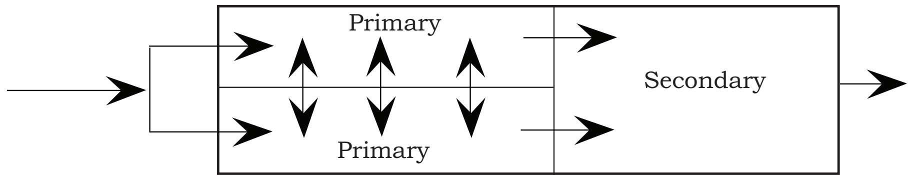


Three Cell Lagoon – Series Operation





Three Cell Lagoon – Parallel Operation



When To Use What

Series operation is best under low hydraulic and organic loading. Parallel operation is best for high hydraulic and organic loading and for cold weather operation.

Operation and Maintenance

Routine Data

As with all treatment facilities, influent and effluent pH, BOD, TSS and temperature should be measured and recorded on a routine basis. The effluent test requirements are described in the discharge permit.

Weeds

Weeds and aquatic plants that grow on and near the levees should be removed at lease twice a year, fall and spring. Some of these plants can permanently damage the levy and all will contribute to odor problems.

Floatables

Floating plastic and paper products should be removed and disposed of in the landfill or incinerator. They contribute to odor and are unsightly.

Ice Related Problems

Prolonged periods of warm or cold temperatures also have an impact on lagoon treatment. Cold temperatures combined with shorter daylight hours slow microbial and algae metabolism and therefore treatment is diminished. A longer detention time may be needed to achieve the same degree of treatment, so “holding” the wastewater (letting the level rise) will improve treatment. Ice covers, which are always a possibility, will temporarily stop sunlight penetration, stop algae oxygen production, and achieve little to no treatment, resulting in poor effluent quality.

Flow Measurements

Why Measure Flow?

There are at least five reasons for accurately measuring the flow through a wastewater treatment plant. They are:

- Compliance with discharge permit requirements
- Determine the hydraulic loading on the plant
- Determine the organic loading on the plant
- Determine wasting quantities
- Determine return sludge flow rates

Who Needs the Data?

While the operator can do little to control the hydraulic and organic loading in the influent of the plant, this data can be very valuable in determining why a plant is not performing properly. In addition, the data is extremely valuable to the design engineers when it is time to upgrade the plant.

Process Control Data

Determining the wasting and return sludge flow rates are valuable operational tools. When activated sludge plants are designed without flow measuring equipment at these locations, the ability of the operator to control the process is severely hampered.

Flow Measurement Location - Plant

Flow measuring equipment can be located in the plant headworks or at the beginning or end of the chlorine contact chamber. With large facilities, it is desirable to measure the flow at the influent and effluent.

Process Control Flow Locations

For the best process control, it is desirable to have flow measurement devices installed in each sidestream and in the return and wasting lines.

Flow Measurement Devices

Three Devices

There are three flow measuring devices commonly used in small wastewater treatment facilities. They are the:

- Weirs
- Flumes
- Magnetic flow meters

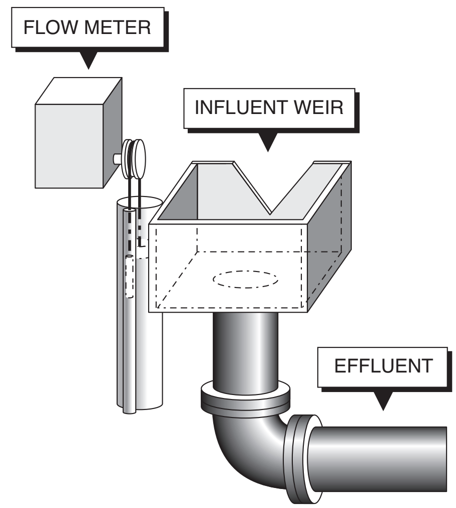
Weirs

Primary Device

Weirs and flumes are called primary measuring devices. Weirs are the least accurate but most used of the primary devices. They are used because of their simplicity. The weirs used in wastewater treatment plants are called sharp crested weirs.

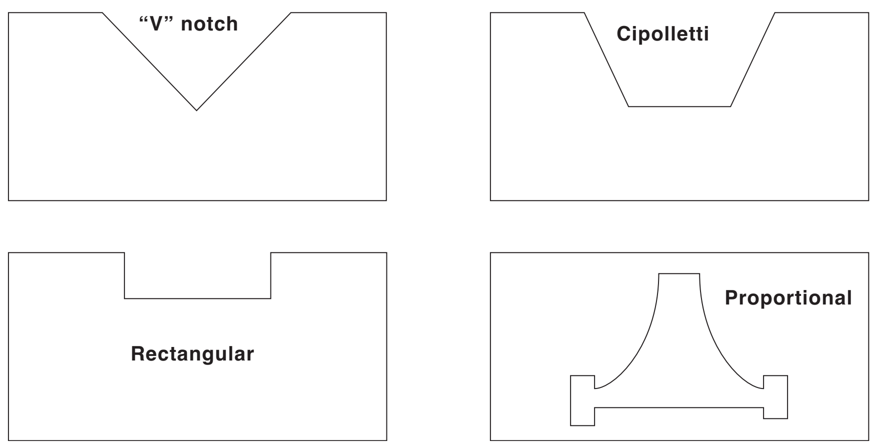
Weir Components

A sharp crested weir is simply a vertically mounted plate with a slot of a specific size and shape cut into the plate. The bottom of this slot is called the crest of the weir. To be a sharp crested weir, the top of this crest must not be wider than 3/16 of an inch.



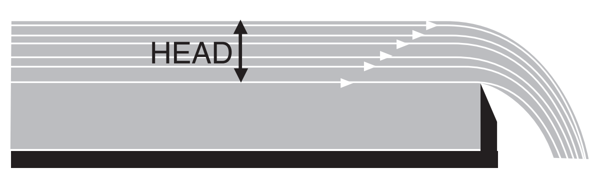
Types of Weirs

Weirs are identified by the shape of the slot cut into the plate. The two most common weirs are rectangular and “V” notch. A special type of rectangular weir with sloped sides is called a cipolletti weir. “V” notch weirs are classified by the shape of the notch. They range from 22.5° for very low flows to 90° for higher flows.



How to Determine Flow

The flow through a weir is determined by reading the height of water above the crest, called the head, and either entering this data into an equation or using a chart designed specifically for that type of weir.



Problems with Weirs

If order for a weir to be accurate, the water behind the weir must be still. As a result, grit, rags and floating material can accumulate behind the weir, causing an increase in maintenance time.

Flumes

Primary Device

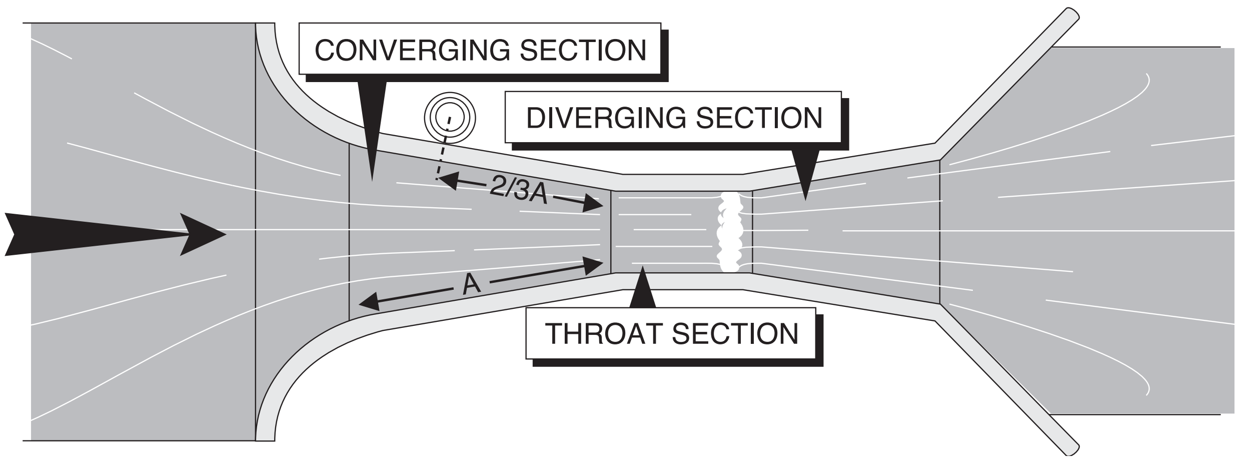
Flumes are one of the most accurate of the primary measuring devices. In addition, they do not stop the flow of water and therefore do not cause a buildup of material behind the flume.

Parshall Flume

There are a wide variety of flumes used to measure flow. However, the Parshall flume is almost exclusively used in small treatment plants.

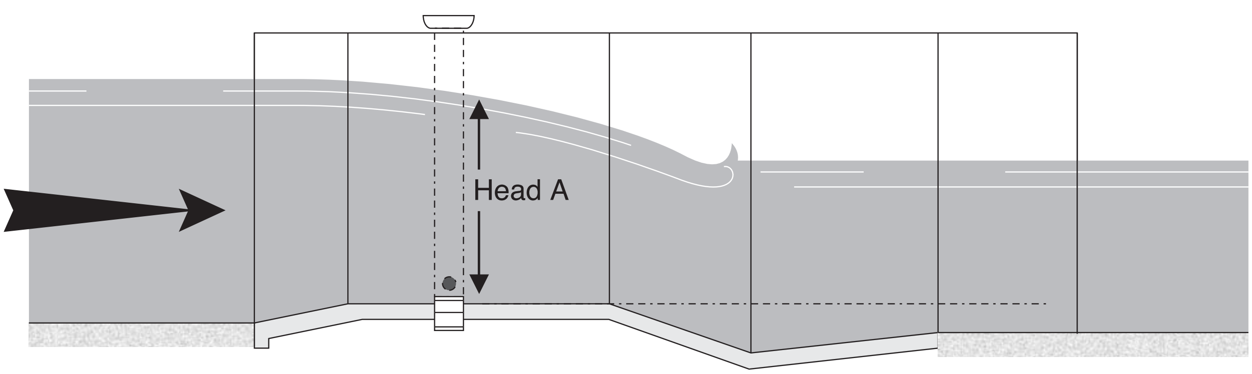
Flume Components

The Parshall flume is composed of three major sections. The entrance area is called the converging section, the center is called the throat and the downstream section is called the diverging section. The size of a Parshall is identified by the width of the throat.



Stilling Well & Measurement

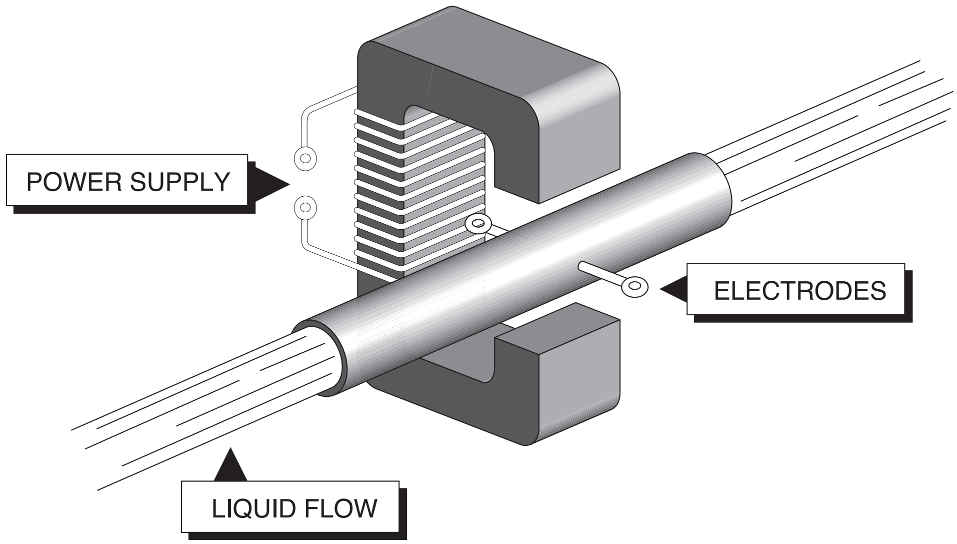
A stilling well is attached to the converging section of the flume 2/3 of the distance from the throat. The flow of water is restricted through the throat. The height of the water in the stilling well is directly proportional to the velocity of water through the throat and the width of the throat. The higher the flow the higher the velocity through the throat. Therefore the height of water in the stilling well, head, directly represents the flow through the flume. The head is then entered into an equation or a flow chart to determine flow.



Magnetic Flow Meters

Operating Principle

The magnetic flow meter works on the electrical principle of induction. In this principle, when a conductor is passed through a magnetic field, a current and thus a voltage will be induced (created) in the conductor. The greater the velocity of the conductor, the greater the voltage that is induced in the conductor.



Application to Flow Meter

A large electromagnet is placed around a nonmetallic pipe that will carry the wastewater flow. Electrodes are attached to the pipe at right angles to the magnetic field that will be produced by the electromagnet. The wastewater becomes the conductor. When it passes through the magnetic field a voltage is induced in the wastewater and can be measured with a volt meter attached to the electrodes.

Velocity and Flow

The velocity of the wastewater is directly proportional to the flow. Using the formula Q = VA, where "Q" is the flow, "V" is the velocity and "A" is the area of the pipe, the flow can be computed. Since this is an electronic device, this calculation is performed electronically providing a digital or graphed readout.

Wastewater Treatment Techniques

Worksheet

1. Coarse screens found in the headworks of a sewage treatment plant are called ____________ screens or trash ___________.

2. Another name for a fine screen used in preliminary treatment is a _________- screen.

3. What are the four processes that make up preliminary treatment and what is their function?

   a. ____________________________

   b. ____________________________

   c. ____________________________

   d. ____________________________

4. List examples of material that are normally removed by the screens found in the headworks of a wastewater treatment plant.

   a. ____________________________

   b. ____________________________

5. The two most common methods of disposal of screenings are:

   a. ____________________________

   b. ____________________________

6. Two common grinding devices are:

   a. ____________________________

   b. ____________________________

7. The following materials are found in wastewater grit.

   a. ____________________________

   b. ____________________________

   c. ____________________________

   d. ____________________________

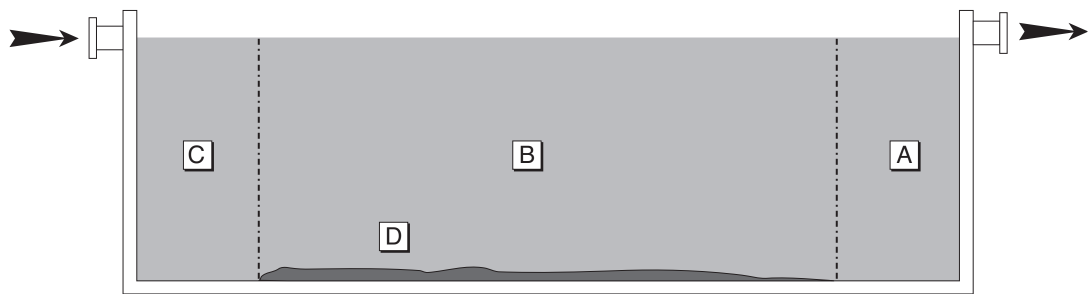
8. What is the purpose of grit removal?

9. Grit removal channels are designed with a velocity of ____________.

10. What is the most common grit disposal process?

11. Primary clarifiers are used to remove those solids that will _________ or ________ out of solution within ________ to ________ minutes.

12. Identify the clarifier zones identified below.



a. ______________________________________

b. _________________________________

c.

d. ______________________________________

13. The treatment provided by a primary clarifier is called _______________ or _________________.

14. Another name for a primary clarifier is a ____________________ basin.

15. Influent baffles are placed in a primary clarifier in order to dissipate the influent ________________.

16. Primary sludge from a primary clarifier will commonly have a concentration of ______ to _______% solids.

17. What are the primary clarifier removal ranges for the following items?

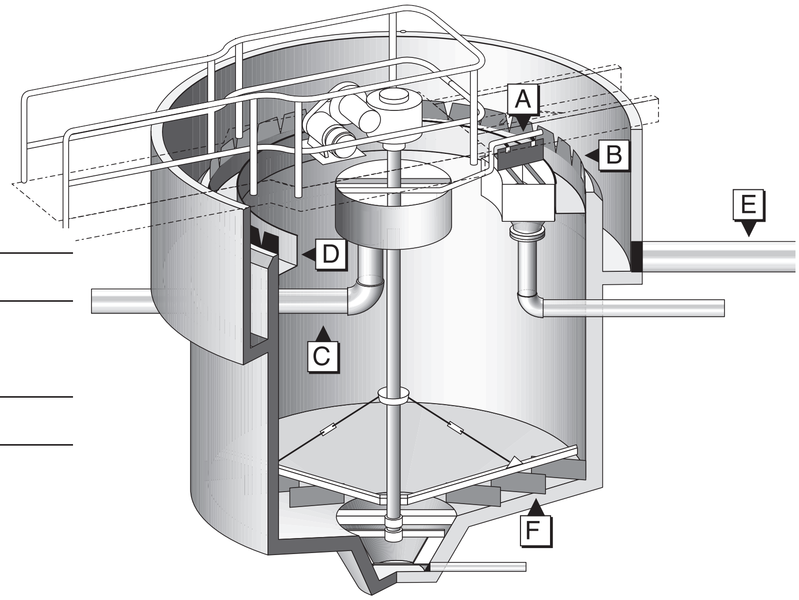
a. TSS _________ to ________

b. BOD _________ to ________

c. SS __________ to ________

18. What is the major operational problem associated with primary clarifier inlet channels and weirs?

19. Identify the items indicated on the drawing below. Show the sludge and water flow paths.



a. ___________________________________
b. ___________________________________
c.
d. ___________________________________
e. ___________________________________
f.

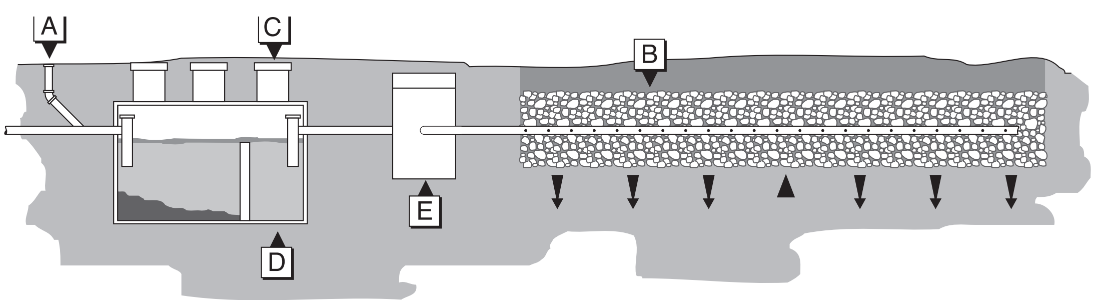
20. A septic tank provides what type of treatment?

21. A septic tank should be pumped in accordance with the discharge __________. However, more frequent pumping may be required if the scum blanket is within ______ inches of the outlet pipe or the sludge level is within _______ of the outlet.

22. A septic tank is classified as a _______________ space, and thus a special permit is required before entry.

23. List the materials that should not be flushed into a septic tank.

24. Identify the components indicated on the septic system below.



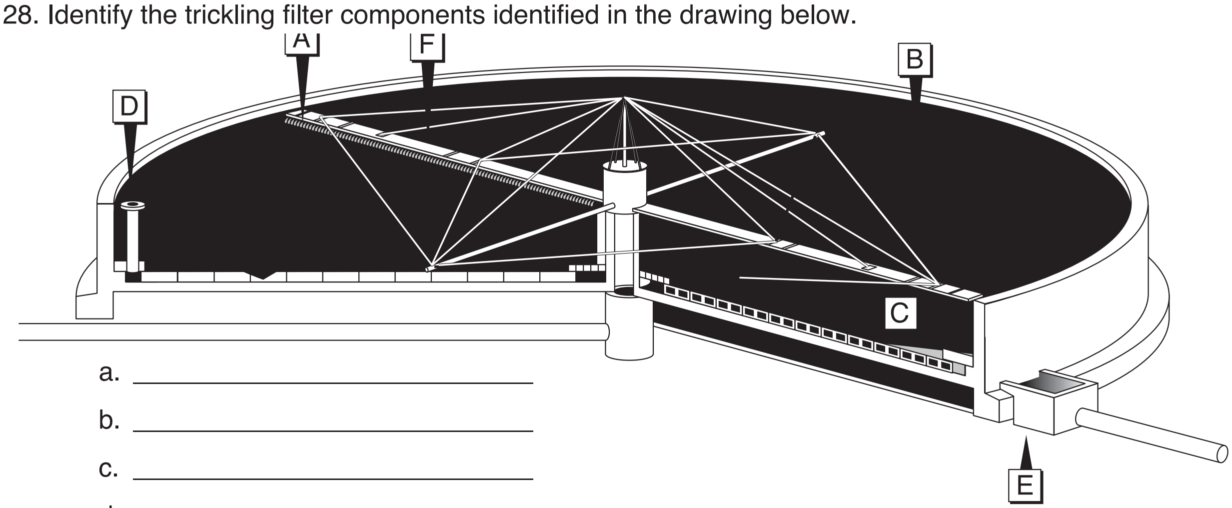
a. ___________________________________
b. ___________________________________
c. ___________________________________
d. ___________________________________
e. ___________________________________

25. A trickling filter is classified as a _________________ treatment process.

26. Bacteria and protozoa that provide the treatment in a trickling filter live in a slime called a _______________________ film.

27. How is oxygen supplied to the biological film in a trickling filter?

28. Identify the trickling filter components identified in the drawing below.



a. ___________________________

b. ___________________________

c. ___________________________

d. ___________________________

e. ___________________________

f. ___________________________

29. What are the two purposes of recirculation in a trickling filter system?

a. ___________________________________

b. ___________________________________

30. What is the one process control change that an operator can make with a trickling filter?

31. Other than rocks what can be used for media in a trickling filter?

32. Describe two common operational problems with trickling filters.

a. ___________________________________

b. ___________________________________

33.The biomass that falls off of the media of a trickling filter or RBC is called ____________________.

34. RBC is the initials for a ____________________ ____________________ ___________________.

35. An RBC treatment plant is what type of treatment plant?

36. With an RBC plant describe one cause of loping and one cure.

37. In an activated sludge plant the liquid in the aeration basin is called ______________ ___________ and is measured as ___ ___ ___ ___ .

38. The relationship between the concentration in the aeration basin and the BOD in the influent to the aeration basin is called what?

39. What is the function of the aeration system in an activated sludge plant?

40. Aeration devices located near the bottom of an aeration basin are called ___________________.

41. In an activated sludge plant the sludge that is piped from the bottom of the secondary clarifier to the aeration basin is called ________________ _______________ _______________.

42. Sludge that is removed from the secondary clarifier to the digester is called _______________ _______________ _________________.

43. Describe how normal settling sludge would appear in a settleometer.

44. Describe the response of bacteria to a situation where there is more food than bacteria.

45. For young sludge in an aeration basin describe the following:
    a. Color
    b. Foam - color and amount
    c. Settleability

46. For old sludge in an aeration basin describe the following:
    a. Color
    b. Foam - color and amount
    c. Settleability

47. Pin floc is the result of ❑ young sludge or ❑ old sludge.

48. Straggler floc is the result of ❑ young sludge or ❑ old sludge.

49. What causes mixed liquor to agglomerate?

50. The MLSS in an aeration basin is controlled by __________________.

51. The depth of the sludge blanket is controlled by __________________.

52. When the return sludge flow is excessive, what will be the impact on the MLSS?

53. How will high flow through an activated sludge plant impact MLSS in the aeration basin?

54. An activated sludge facility that uses brush aerators is called an _____________ __________.

55. Describe the impact that plugged diffusers will have on an activated sludge plant.

56. What is activated sludge?

57. Mixed liquor is a mixture of what?

58. What is the function of return sludge in an activated sludge plant?

59. In an activated sludge plant an operator can only control three things. They are:

    a. ____________________

    b. ____________________

    c. ____________________

60. What is the physical difference between a conventional activated sludge plant and a packaged plant?

61. What are two causes of low DO in the aeration basin of an activated sludge plant?

    a. ____________________

    b. ____________________

62. Identify the components indicated on the activated sludge plant below.

    a. ____________________

    b. ____________________

    c.

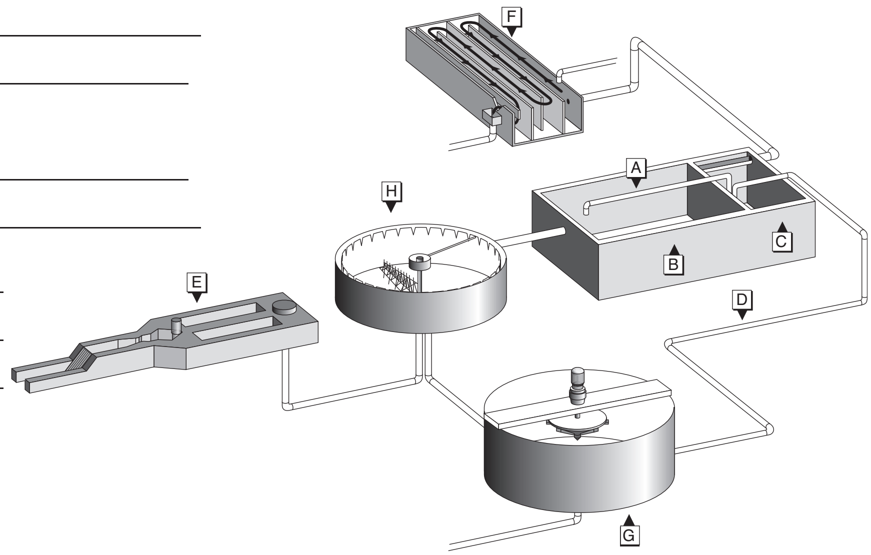
    d. ____________________

    e. ____________________

    f. ____________________

    g. ____________________

    h. ____________________



63. Activated sludge is a ________________ biological system and is classified as ________________ treatment.

64. When an activated sludge plant is designed to work with very old sludge ages and little or no wasting, the process is called ________________ ________________.

65. What is the name of the activated sludge plant that has two aeration basins, one called the contact basin and the second the reaeration basin.

66. There are two common types of package plants. Name them.

    a. ____________________

    b. ____________________

67. The following are found in activated sludge plants. Rank them as in order of when they would appear in large numbers, in reference to sludge age.

    ______ a. Rotifers

    ______ b. Stalked ciliates

    ______ c. Free swimming ciliates

68. Long chain-like microorganisms that are undesirable and inhibit settling in an activated sludge plant are called ______________________________.

69. In a conventional activated sludge plant, what is the normal operating value or range for each of the following?

    a. MLSS ________________

    b. DO in the aeration basin _________ mg/L to _________ mg/L

    c. Settleometer reaches __________ of height after 60 minutes

    d. Aeration basin is ____________________________ in color

70. Secondary clarifiers are designed to settle _____________ ___________ from an activated sludge plant and/or _________________ from a trickling filter.

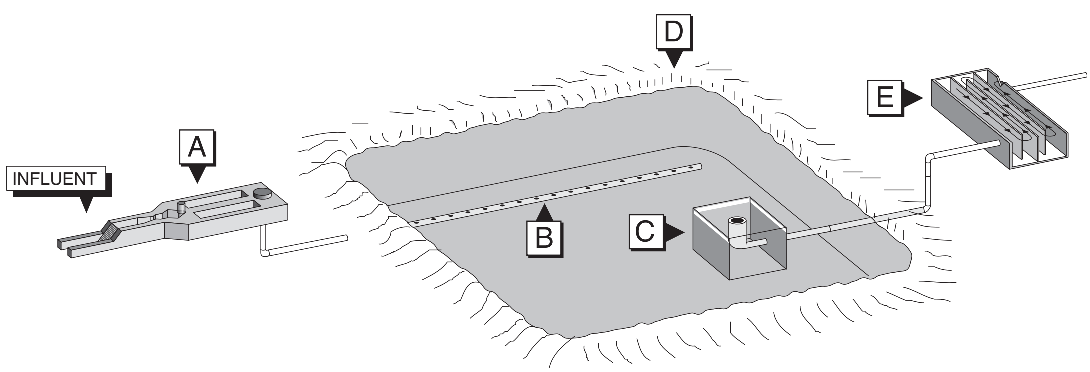
71. What would cause sludge to rise in a secondary clarifier?

72. Typical detention time for secondary clarifiers are:

    Trickling filter ______ to ______ hours

    Activated sludge liquid portion ______ to ______ hours, sludge is _______ to _______ hours.

73. Identify the items indicated on the wastewater lagoon below.



a. _____________________________

b. _____________________________

c. _____________________________

d. _____________________________

e. _____________________________

74. What is the average water depth for each of the following ponds.
    a. Aerobic
    b. Anaerobic
    c. Facultative

75. In a waste stabilization pond the required oxygen comes from two natural sources. They are:
    a. ____
    b. ____

76. In a wastewater stabilization pond bacteria stabilize ________________ matter and give off the gas __________________________. This gas is consumed by algae, which in turn give off the gas ____________________ which is used by the bacteria. What is this process called?

77. The term used to describe the process of utilizing sunlight to produce oxygen is called what?

78. In a facultative lagoon the anaerobic zone is found where?

79. What is the major change that takes place in a lagoon that is frozen over for several months?

80. What is the advantage of aerating a lagoon?

81. What are two reasons for accurately measuring the flow through a wastewater treatment plant?
    a. ________________________________
    b. ________________________________

82. The height of water behind a weir is called _________________.

83. The height of water through a parshall flume is measured _______ of the distance back of the throat.

84. Identify the flow measuring devices shown below.

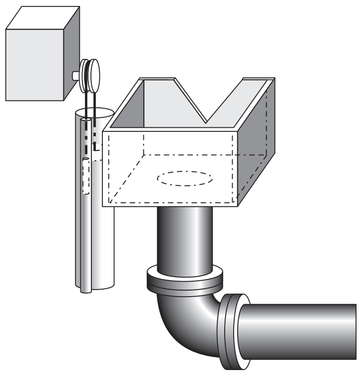
a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________



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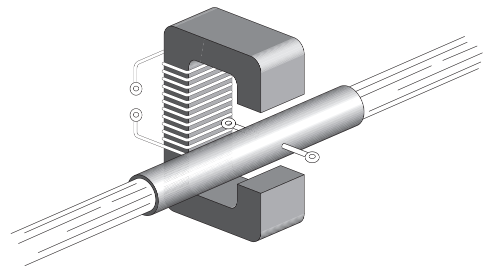

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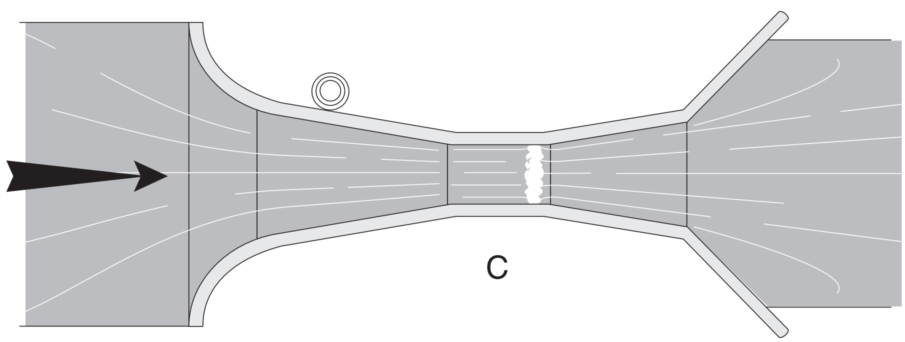

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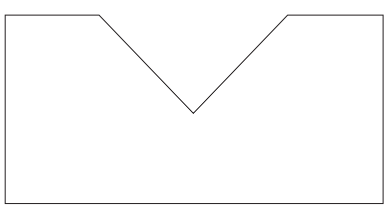

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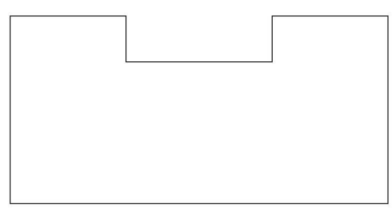

E

Sludge Treatment and Disposal

What is in the Lesson?

1. The required concentration of sewage sludge prior to disposal at a landfill.
2. The processes used in drying beds to remove water.
3. The proper control of feed to an anaerobic digester.
4. The sequence used to dry sludge in a drying bed.
5. Common dewatering processes.
6. The unit that is used to collect waste sludge.
7. The reason for sludge digestion.
8. The two sludge digestion processes.
9. The detention time in a aerobic digester.
10. The by-products of anaerobic decomposition.
11. The major health and safety concerns associated with sludge disposal.
12. Four sludge disposal processes.
13. The three sources of sludge in a wastewater treatment plant.
14. The primary reason for heating and mixing an anaerobic digester.
15. The major equipment found in digesters, Imhoff tanks and sludge dewatering equipment.

Key Words

- Aerobic Digestion
- Anaerobic Digestion
- Biosolids
- Decant
- Digester
- Evaporate
- Inorganic
- Land Application
- Organic
- Pathogenic
- Percolation
- Screening
- Scum
- Sludge
- Stabilization
- Supernatant
- Vector

Sludge Treatment and Disposal

Introduction

Removal of Solids

One of the functions of a wastewater treatment plant is to remove solids from the influent. The primary portion of the treatment process removes those solids that will easily float or sink. The secondary portion of the treatment plant converts dissolved and suspended solids to solids that will settle in the secondary clarifier. These solids that are removed as a result of primary and/or secondary treatment are called **sludge**[1].

Sludge or Biosolids

The EPA has encouraged changing the name of sludge to **biosolids**[2]. This name change encourages people to think of sludge as a less objectionable product. This text will use the words sludge and biosolids interchangeably.

The Problem with Biosolids

When this sludge is removed from the main treatment process full **stabilization**[3] of the **organic**[4] content of the sludge has not been completed. As a result the sludge contain a significant quantity of **pathogenic organisms**[5]. If this sludge is disposed of on the land without any further treatment, anaerobic decomposition will proceed producing foul odors as well as providing a source of contamination to surface and groundwater supplies.

Two Reasons for treating sludge
Reduce pathogens and reduce odor

Water Content

In addition to the problems with odor and pathogenic organisms, the sludge produced by a treatment plant contains only 0.5% to 10% solids. The major portion of the sludge is water. One of the goals of solids handling is to reduce the water content and thus reduce handling cost.

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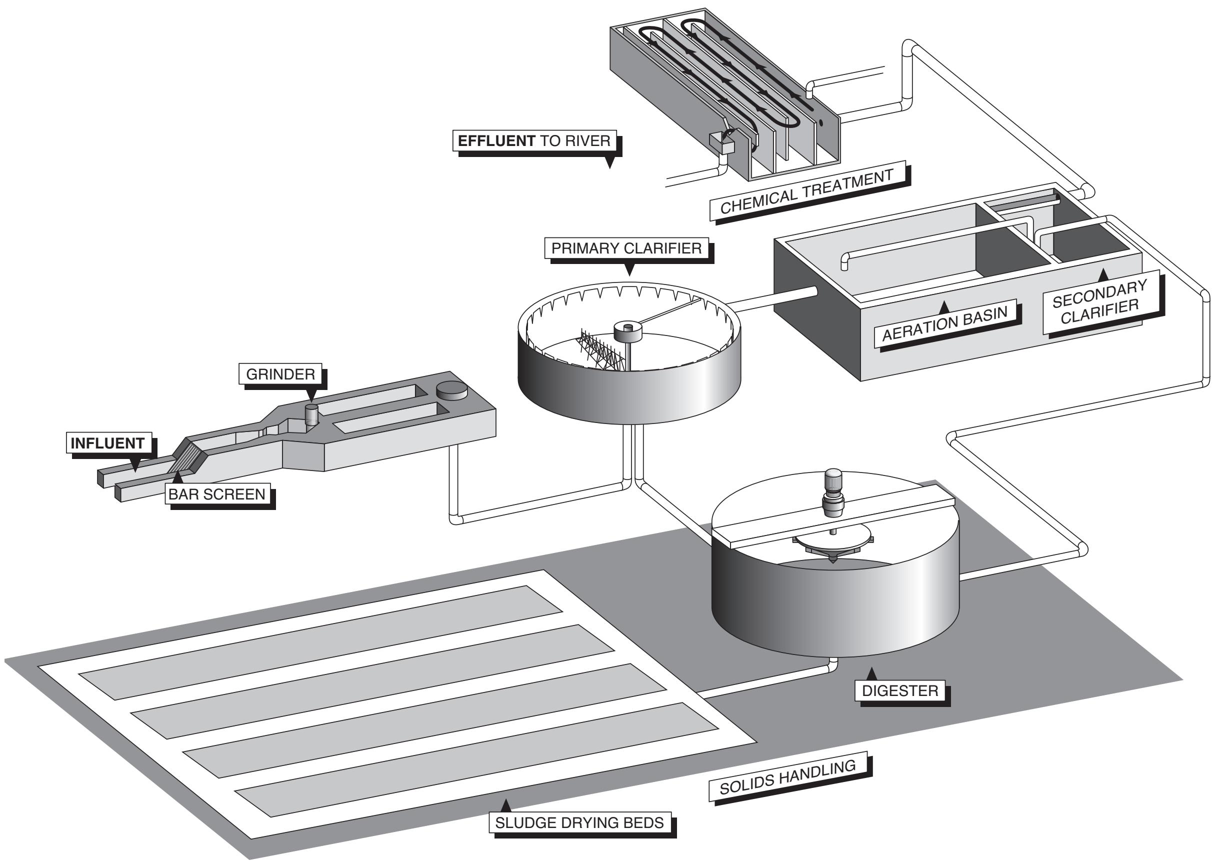
1 **Sludge** - (SLUJ) - The accumulated settled solids deposited from sewage or industrial wastes, raw or treated, in tanks or basins, and containing more or less water to form a semi-liquid mass.
2 **Biosolids** - A formal name for stabilized sludge from a wastewater treatment plant.
3 **Stabilization -** The process of converting a material to a form that resists change. Organic material is stabilized by bacteria which converts the material to gases and other relatively inert substances. Stabilized organic material generally will not give off obnoxious odors.
4 **Organic -** Chemical substances of animal or vegetable origin, made basically of carbon structure.
5 **Pathogenic Organisms -** Bacteria, virus and protozoa which can cause disease.

Solving the Problem

To prevent or reduce these potential problems the sludge must be treated and disposed of properly. The process of treating and disposing of sludge is called solids handling. Typical solids handling is accomplished in three steps:

- Stabilization - to reduce pathogenic organisms and the organic content of the sludge.
- Condition & Dewatering - to reduce the volume
- Disposal - to prevent contamination



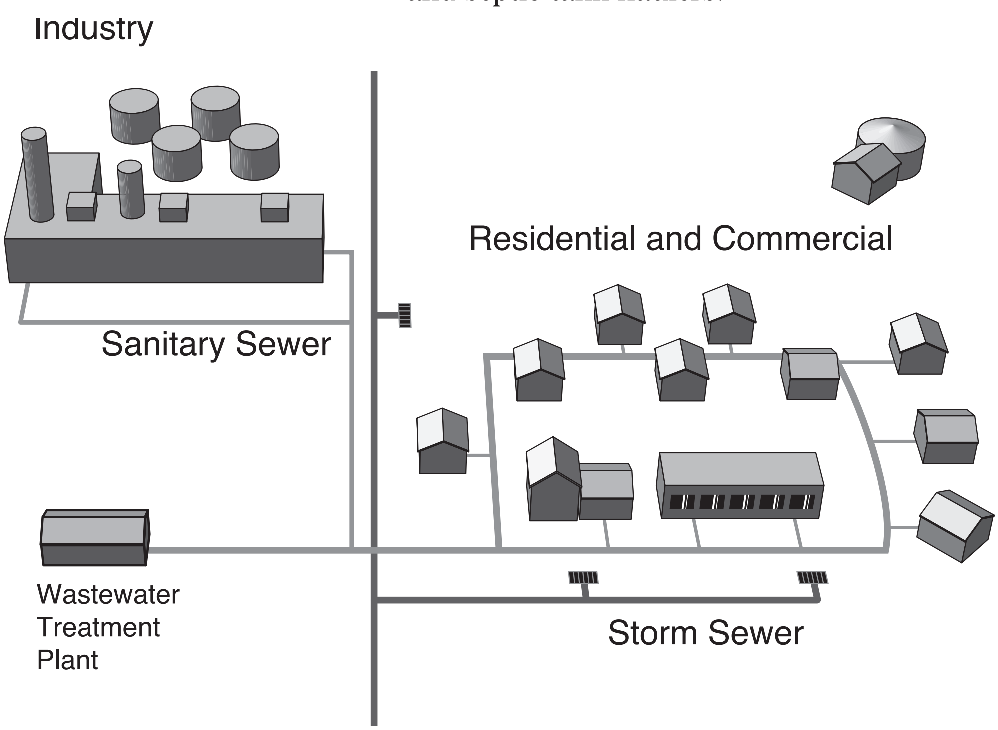
Lesson Content

This will provide information on the sludge produced by primary and secondary biological wastewater treatment of domestic wastewater. Included in the section is the review of the sources of sludge, the treatment process used to stabilize sludge and reduce its volume, and disposal or reuse techniques.

Sources of Sludge

Basic Sources

The end product, or sludge, from a treatment plant comes from many sources. These sources include households, commercial users, industrial dischargers, and septic tank haulers.



Content of Wastewater - Solids

As wastewater is carried from households, the water carries food products, human waste, and some **inorganic**[6] material such as plastics and grit. Wastewater from commercial users contains such materials as food and grease from restaurants and rest room waste. Industrial users discharge many materials including food and cannery waste, metal filings, oils, etc.

Quantity of Sludge

Function of Treatment

The function of primary and secondary treatment is to remove suspended solids and BOD. Once removed this material becomes sludge. The quantity of sludge produced by a treatment plant is dependent upon the removal capabilities of the plant, the strength of the raw sewage, the sources of the raw sewage and the ability of the solids treatment system to remove water.

Quantity

As a general rule, for every pound of BOD entering a wastewater treatment plant, the wastewater operator will "handle" about 1/2 pound of dry solids.

[6] **Inorganic -** Chemical substances of mineral origin.

Types of Sludge

Once the sewage reaches the treatment plant, different types of sludge are produced depending on the type of treatment process. The type of treatment required varies with the type of sludge. The types of sludge produced will include:

- Primary or raw sludge
- Waste activated sludge
- Sloughings from a trickling filter or RBC plant
- Other solids including skimmings and **scum**[7].
- Sludges from lagoons

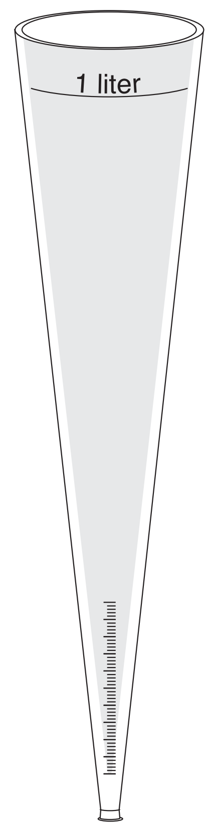
Four Basic Groups

Because of the availability of sludge treatment processes these various types of sludge are typically placed in one of five groups. The groups are:

- Primary sludge
- Biological sludges
- Scum
- **Screenings**[8]
- Lagoon sludge

Primary Sludge

Primary sludge (sometimes called raw sludge because no treatment has been applied) is sludge removed from a primary clarifier. Primary sludge has a solids concentration of 0.5 - 5.0%. If a treatment plant does not have primary clarification, the primary sludge becomes additional food to the biological process.

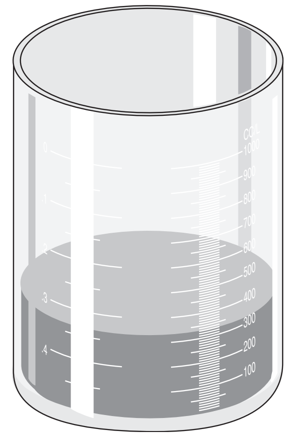


7 **Scum -** A mass of sewage matter which floats on the surface of sewage.

8 **Screenings -** Relatively coarse floating and suspended solids removed from wastewater by straining through racks or screens.

Biological Sludge - WAS

Waste activated sludge and other secondary biological sludges will vary in concentration from 0.4 - 4.0% solids. Waste activated sludge is the biological sludge material that is removed from the activated sludge system. This waste activated sludge is primarily bacteria and other organisms that require further treatment before they can be disposed of safely.

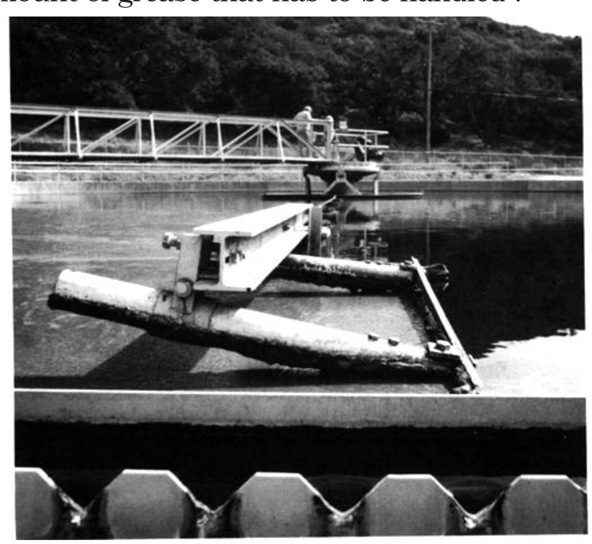


Other Biological Sludges

Trickling filters, RBCs and ABF biological systems also produce a biological sludge. This sludge, sometimes referred to as sloughings, is harder to treat than waste activated sludge as it does not settle or concentrate well.

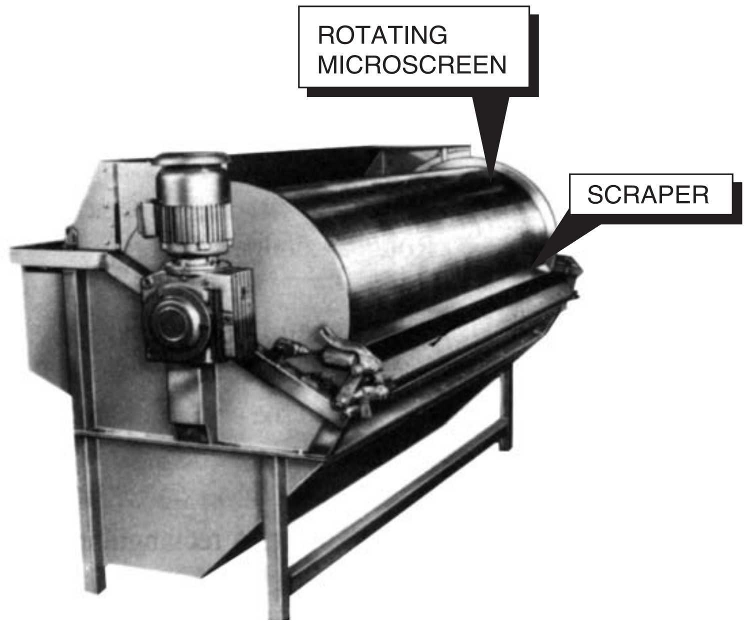
Scum

The “other” solids component added to the sludge treatment processes can include skimmings from primary clarifiers which contain plastics and grease and biological foam from the secondary clarifier. These materials are easily treated by typical sludge treatment processes. It would be ideal to remove grease from wastewater systems before it can create problems at the plant and in the collection system. A grease trap program at the grease generation sites (restaurants are an example) can greatly reduce the amount of grease that has to be handled .



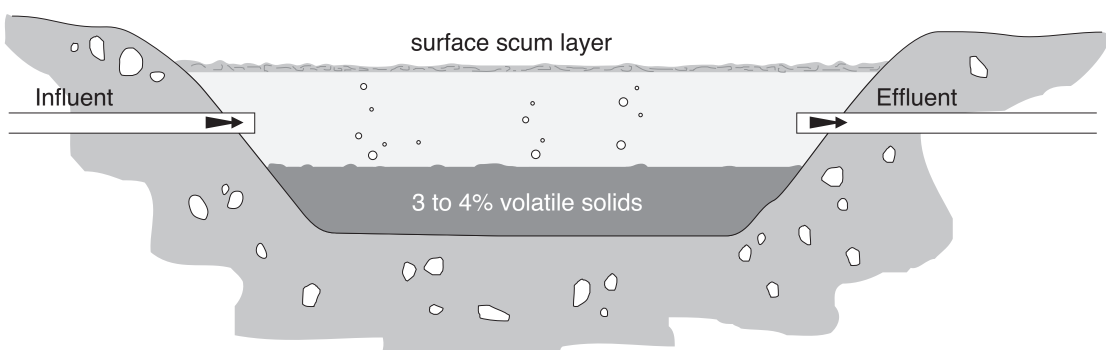
Screenings

Screenings include material removed by bar screens as well as the material removed by microscreen. Screenings require special solids handling techniques that will not be covered in this lesson. Treating with lime and burial of this material, if applicable, is desirable.



Lagoon Sludge

The sludge that accumulates in the bottom of a properly operated lagoon system is generally considered stabilized and can usually be applied directly to the land, providing it meets sludge quality standards* for **land application**[9]. The sludge must be tested in order to determine an appropriate disposal plan.



[9] **Land Application** - The disposal of stabilized sludge onto or under the surface of the land. Commonly, this process requires placing the sludge a few inches below the surface with specially designed trucks.

* Sludge quality standards are established by EPA and individual state agencies..

Sludge Stabilization

What is Stabilization?

The stabilization process reduces the number of pathogenic organisms while reducing the odor of the sludge and conditioning the sludge so that it can be dewatered more efficiently.

Stabilization Processes

The two most common stabilization processes are lime treatment and digestion. There are two common digestion processes: **aerobic digestion**[10] and **anaerobic digestion**[11]. When properly controlled either of these processes can produce a sludge that is low in pathogenic organisms and does not produce an overly objectionable odor. In addition the two digestion processes produce a sludge that can effectively be dewatered.

Aerobic Digestion

General Description

In the aerobic digestion process, sludge is placed in a open tank called a **digester**[12], where air is applied using the same type of equipment used in an activated sludge aeration basin. Stabilization is accomplished by aerobic microorganisms. This process is considered to be an extension of the activated sludge process and is commonly utilized with activated sludge plants. Stabilization of domestic wastewater by a aerobic digester can be accomplished in approximately 30 days. Then properly operated aerobic digestion will:

- Effectively stabilize the sludge
- Reduce the water content of the sludge
- Condition the sludge so that it can be treated effectively by sludge dewatering equipment.

Sludge Types

Aerobic digesters provide the most ideal stabilization when used to stabilized aerobic biological sludges produced by secondary treatment processes.

Solids Concentration

After thirty (30) days of digestion, and with proper settling, aerobic digesters can produce sludge with a 1 to 3% solids content.

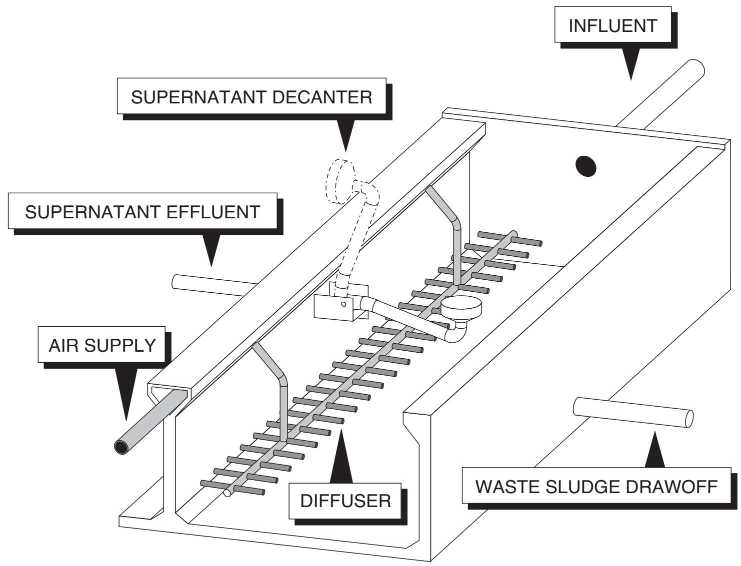
[10] **Aerobic Digestion** - (air-OH-bic) - The process in which wastewater solids, primarily waste activated sludge, are placed in an open tank, and aerobic bacteria and other aerobic microorganisms decompose the solids into water, gases and solids.

[11] **Anaerobic Digestion** - (AN-air-OH-bik) - Wastewater solids and water (about 5% solids) are placed in a large tank where bacteria decompose the solids in the absence of oxygen. At least two general groups of bacteria act in balance; Saprophytic (acid-forming) bacteria break down complex solids to volatile acids and methane-Fermenters breakdown the acids to methane, carbon dioxide and water.

[12] **Digester** - (dy-JES-tur) - A tank in which sludge is placed to allow sludge digestion to occur. Digestion may occur under anaerobic or aerobic conditions.

Equipment

The main component of an aerobic digester is a round, square or rectangular tank. Air is supplied to the liquid in the tank utilizing a blower and diffusers placed on the bottom of the tank or by a surface aerator. Valves and piping are required in order to control the flow of liquid and sludge through the tank. One of the most important portions of the piping system is the **decant**[13] piping. This system is used to remove clear water from the top of the digested sludge. In the drawing below the decant pipe has a flexible joint. This allows the operator to change its position.



Process Description

Biological Action

Sludge entering an aerobic digester contains inorganic solids, organic solids, microorganisms and water. During the digestion process microorganisms (mainly bacteria) continue to stabilize the organic material. This stabilization process releases water from the solids. In addition, as the food supply is reduced the microorganisms die causing their bodies to break open releasing more water. Finally, as the sludge is stabilized, the water that is entrapped in the sludge is released.

Solids Separation

Once a majority of the water is released the liquid under digestion would be allowed to sit idle until the sludge settled. The relatively clear fluid on the top, called **supernatant**[14], could be drawn off and returned to the influent of the plant. The concentrated, digested sludge on the bottom could be withdrawn for dewatering and disposal.

[13] **Supernatant** - (SEW-pur-NAYT-unt) - The liquid in a digester that lies between the sludge at the bottom and the top of the scum on the top of the tank.

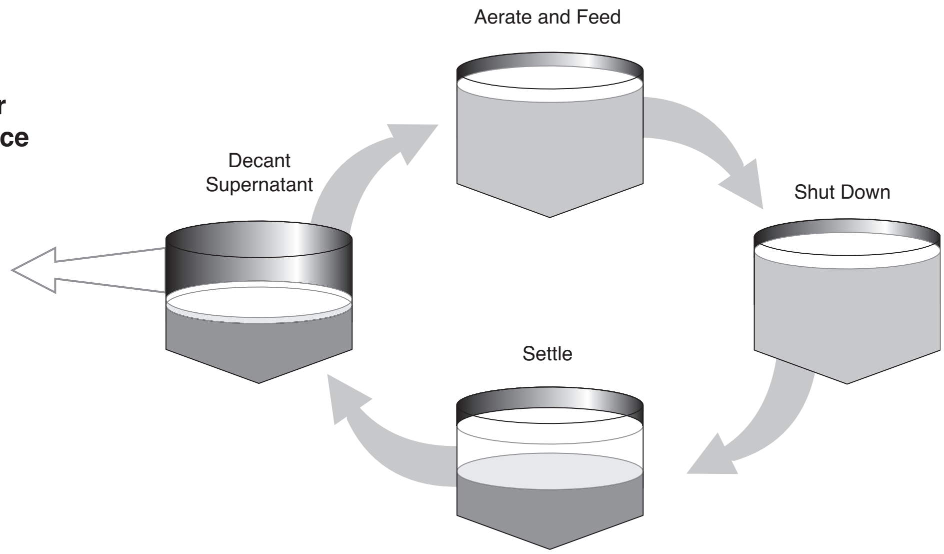
[14] **Decant** - The removal by pouring or drawing off the liquid from a vessel in such a way as to not disturb the sediment on the bottom of the container.

Normal Operation

Two Operation Sequences

There are two operational strategies used for aerobic digesters, batch operation and continuous operation. The process just described is called a batch treatment process, that is, one batch of sludge is treated at a time. The most common process is continuous operation. With the continuous operation sludge is wasted to the digester every day and withdrawn when digestion is complete or the digester is too full to hold any more sludge.

Aerobic Digester Operation Sequence



Continuous Operation

Seed

At the start of a continuous digestion cycle the digester contains between one-fourth to one-half digested sludge. This digested sludge is called seed.

Feed

In the most successfully operated plants, some sludge is fed to the digester throughout the day. In others, sludge is fed once a day. Process control limitations built into the plant may not allow continuous feed. This sludge is aerated continuously.

Decanting

Once every day or two the air is shut off on the digester allowing the sludge to settle for one to two hours. The sludge will settle to the bottom of the digester leaving a clear supernatant near the top. This supernatant is decanted back to the treatment plant.

Repeat the Cycle

The cycle of feeding sludge, aerating, settling and decanting is repeated on a set interval. During this process the concentration of the sludge in the digester gradually increases and the percent of the volume that is supernatant is gradually reduced.

Disposal

Once the volume and concentration of the sludge has reached a point where there is little room remaining in the digester, the sludge must be removed for conditioning, dewatering and/or disposal.

Anaerobic Digestion

General Description

In the anaerobic digestion process sludge is placed into an airtight tank called a digester where it is heated and mixed. Stabilization is accomplished by anaerobic bacteria. Stabilization of domestic wastewater by an anaerobic digester can be accomplished in approximately 20 to 25 days. When properly operated anaerobic digestion will:

- Effectively stabilize the sludge
- Reduce the water content of the sludge
- Produce methane gas, which can be used for heating the digester or the production of electricity.

Anaerobic digestion is a process that reduces sludge volume and destroys pathogens in an anaerobic environment. The process produces sludge that can be disposed of safely.

Sludge Types

Anaerobic digestion can be effective in stabilizing sludge from primary and secondary clarifiers as well as clarifier scum pits. They are more effective than aerobic digesters in stabilizing primary or raw sludge.

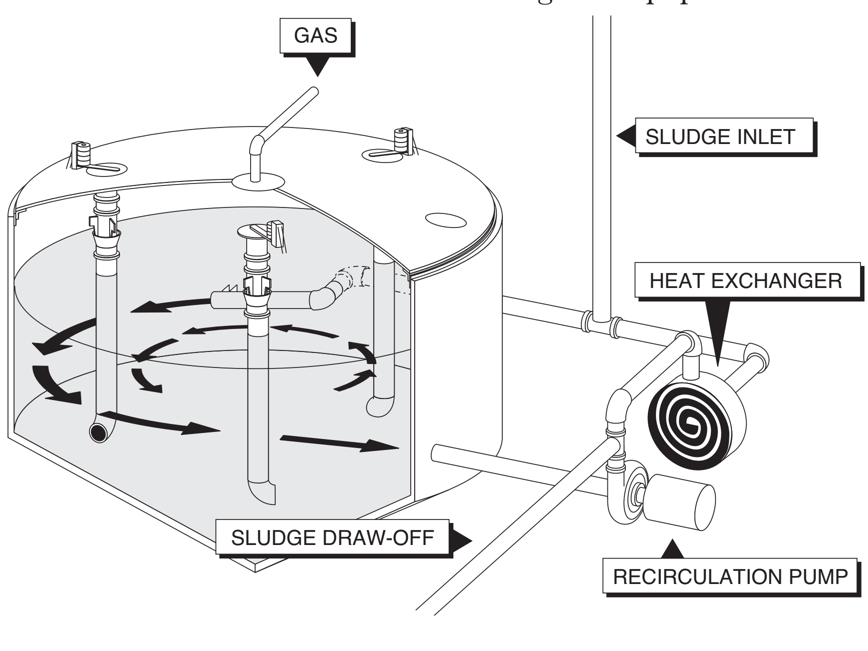
Solids Concentration

After thirty days of digestion, and with proper settling, anaerobic digesters can produce sludge with a 3% to 4% solids content.

Basic Equipment

The main component of an anaerobic digester is an airtight tank. The tank may be round or egg shaped. Heat is usually supplied by an external heat exchanger and a low pressure boiler. Mixing is provided by internal mechanical mixers or by utilizing the gas produced by the digester and diffusers mounted on the floor of the tank. In addition, various valves, piping, and gas handling equipment make up the remainder of the basic digester equipment.

Fixed lid, single stage anaerobic digester with mechanical mixer and external heat exchanger



Digestion Process

Digestion - General Discussion

Anaerobic digestion is accomplished by the combined activities of two groups of bacteria. One group called acid-formers, decompose the organic material and produce special acids. These acids are used by the second group for food. This second group are called methane-producers, because they produce methane gas (CH_4) and carbon dioxide (CO_2) gas. In addition both groups of bacteria release water from the sludge and from their own bodies when they die.

Mixing and Heating

In order to reduce the amount of time required to stabilize sludge, these digesters are heated to a temperature of 94° to 98° F and continuously mixed. The mixing increases the contact between the food supply and the microorganisms and thus reduces digestion time.

Summary

In summary, an anaerobic digester produces three products:

- Methane gas that can be used to heat and mix the digester as well as produce electricity.
- Carbon dioxide
- Water

Operation Sequence

Seed

At the start of a continuous digestion cycle, the digester contains between one-fourth or less digested sludge. This digested sludge is called seed.

Feed

In the most successfully operated plants, sludge is fed to the digester continuously throughout the day. In others the sludge may be fed to the digester two to three times a day. This sludge is mixed and heated continuously.

Decanting

The fluid in an anaerobic digester stratifies in the digester tank to form a scum layer on the top, then a supernatant layer followed by a digestion layer. On the bottom is commonly a layer of grit. (Some high rate digester are mixed so effectively that there is no stratification). The operator must adjust the feed rate and the decanting piping so that supernatant is removed at the same rate as sludge is feed to the digester. This supernatant is returned to the influent of the plant.

Repeat the Cycle

The cycle of feeding sludge, heating & mixing, and decanting is repeated on a set interval. During this process the concentration of the sludge in the digester gradually increases and the percent of the volume that is supernatant is gradually reduced.

Disposal

Once the volume and concentration of the sludge has reached a point where there is little room remaining in the digester, the sludge must be removed for conditioning, dewatering and/or disposal.

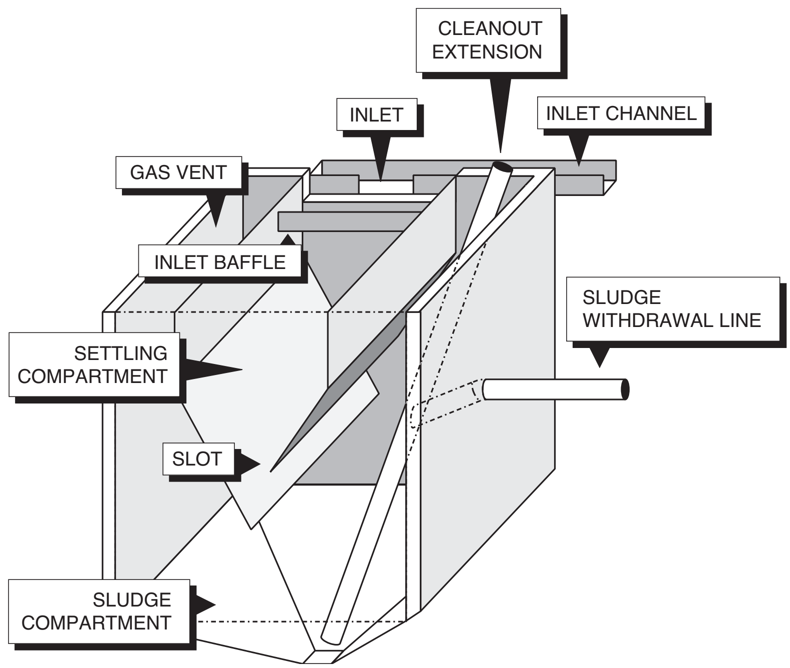
Operational Considerations

Because anaerobic digestion is carried out in an atmosphere with no oxygen and at elevated temperatures, special anaerobic bacteria do the work. Indications of a poorly operating digester include: high or low pH, a change in methane gas production, and a change in odor. Anaerobically digested sludge does not have an offensive odor.

Imhoff Tanks

Description

An older wastewater treatment method used in many small communities is a two-story primary treatment plant called an Imhoff tank. The units are a combination of a primary clarifier, the top tank, an anaerobic digester, and the bottom tank. While the digester utilizes anaerobic bacteria for stabilization, it is neither heated or mixed.



Process

Sludge settles in the primary clarifier and enters the digester through the slot at the bottom of the clarifier. In the digester section anaerobic bacteria stabilize the sludge. This process produces a stable sludge that can be disposed of directly in a land application process and methane gas. Because the gas production is low and the gas of poor quality it is released into the atmosphere rather than being utilized.

Operational Considerations

Operation of this type of digester is simple. The sludge level should be checked frequently and not allowed to rise more than 18 inches below the clarifier slots. In order to prevent large volumes of foam on the surface, the amount of sludge withdrawn from the tank should not exceed 40% to 50% of the tank volume.

Lime Stabilization

Honey Buckets

One of the common methods of stabilizing honey bucket waste is with lime. The most effective lime application is obtained by mixing 1 part of lime to four parts water. This mixture is called “milk of lime.”

Application Rate

Fill the bucket 1/2 full of “milk of lime” then fill the remainder with the contents from a honey bucket. Mix completely and allow to stand for 30 minutes to 1 hour before disposing.

Sludge Stabilization

Dewatered sludge can be stabilized with dry lime by mixing sufficient quantities of lime to raise the pH to 12.

Caution

Hydrated Lime

The preferred lime for this treatment is $Ca(OH)_2$ calcium hydroxide, also called hydrated lime. This material is a very strong base and will burn the skin or mucous membranes of the nose and mouth. When added to water heat is generated. If the quantity of lime is too high for the volume of water an explosion can occur.

Honey Bucket Caution

If dry lime is mixed directly with honey bucket waste containing urine, an extremely violent explosion can occur.

Handling

The operator should wear a dust respirator, chemical goggles, rubber gloves and rubber apron when handing the dry material. In addition gloves, goggles and an apron are recommended for handling the liquid.

Solids Conditioning & Dewatering

Conditioning

It may be necessary or desirable to condition a sludge before disposal or before digestion. The purpose of such conditioning would be to aid in the further reduction of the volume of sludge to be handled.

Common Conditioning Processes

The most common conditioning process used in small wastewater treatment plants is the addition of polymers prior to dewatering. Polymers help to hold the sludge together and thus reduce the amount that is returned to the influent of the treatment plant.

Why Dewater?

The largest portion of sludge is water. The cost of handling sludge can be drastically reduced by reducing its water content. The most common methods used to remove water from sludge include:

- Drying beds
- Vacuum filtration
- Centrifuges
- Screw Presses
- Belt filters

Drying Beds

Advantages

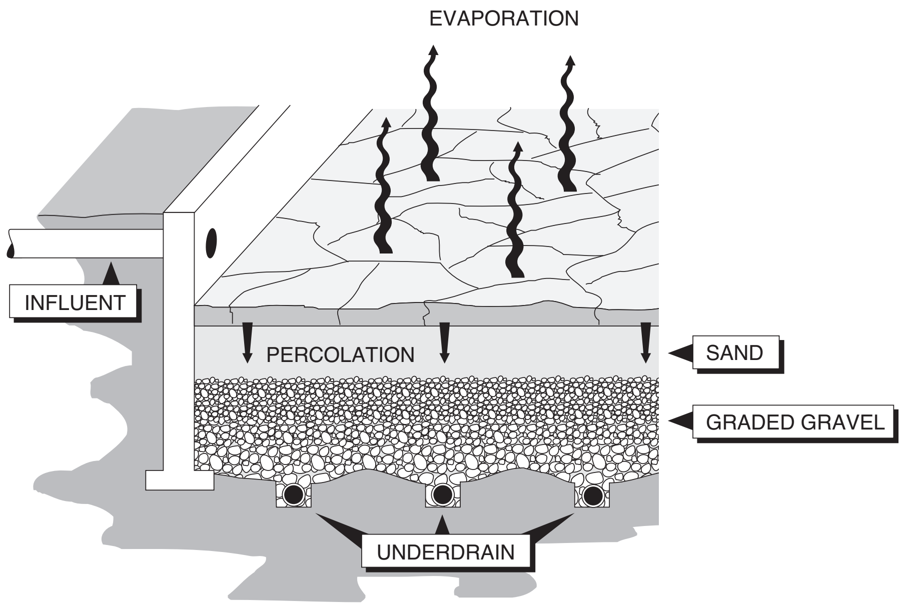
The least expensive and possibly easiest method for dewatering a sludge is to allow nature to take its course. The construction of drying beds will reduce the volume of sludge to be ultimately handled, and reduce pathogens and **vectors**[15].

Equipment

A drying bed is a cell that is constructed to hold anywhere from 10,000 to 50,000 gallons of digested sludge at a depth no greater than 18 inches. Each cell is equipped with a porous bottom, usually sand, and a drainage collection system installed to remove the water that **percolates**[16] downward through the sand.

Operation

Operation of a drying bed is accomplished by simply "charging" the bed by filling to the 18 inch mark with digested sludge. This charging should be completed in one filling. The sludge is then allowed to dry. In addition to percolation, some of the water will **evaporate**[17] from the sludge.



Use with Primary Sludge

Drying beds perform best with aerobically and anaerobically digested sludges. Because of odor problems they are not recommended for primary or septic sludge.

Solids Production

If the weather conditions are right, drying beds can produce sludge that contains up to 25% solids.

Weather Consideration

Because sludge cannot dry in a reasonable length of time if it is exposed to rain or snow, drying beds are of limited use.

15 **Vector -** An agent who transmits pathogenic organisms from one organism to another. In a sewer this includes birds, mice, rats, flies and other insects.
16 **Percolation** - (PUR-cuh-LAY-shun) - Movement of water into and through the ground.
17 **Evaporate** - (ee-VAP-o-rate) - The process of conversion of liquid water to water vapor.

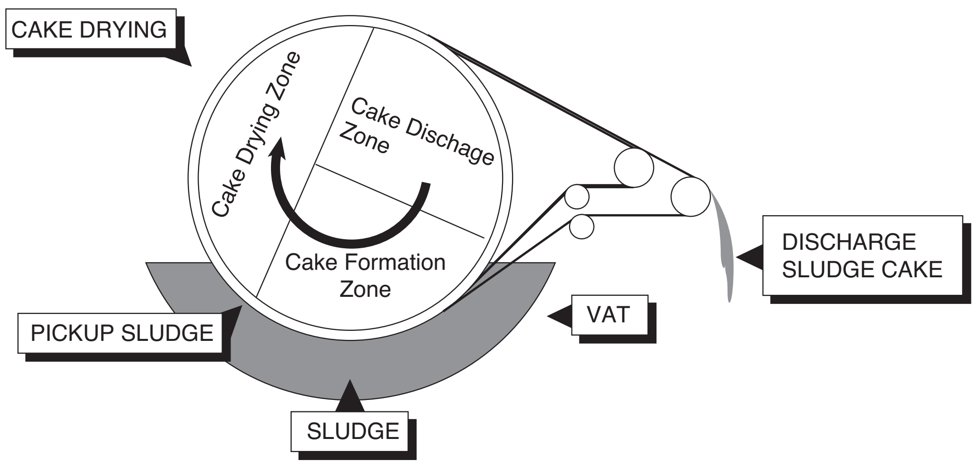
Vacuum Filtration

General Description

The vacuum filtration method is a mechanical method of dewatering sludge. This method utilizes polymers to condition the sludge and a vacuum machine to remove the water from sludges.

Equipment

Equipment consists of a sealed cylindrical drum covered with a porous fabric, a tank and a vacuum source. The drum is partially submerged in a large tank. This drum is divided into three sections; cake formation zone, cake drying zone and cake discharge zone. The internal piping and special arrangements allow the unit to apply different amounts of vacuum to specific sections of the drum as it rotates.



Operation

The sludge is conditioned with a polymer just prior to its addition to the tank. The drum is then rolled through the sludge. A vacuum on the inside of the drum draws water through the fabric and holds the sludge on the surface in the cake formation zone. As the drum turns the vacuum removes more of the water from the sludge (cake drying zone). Vacuum is then released in the cake discharge zone and a scraper is used to remove the partially dried sludge from the drum.

Filtrate & Solids

The water that is removed from the sludge is called filtrate and is piped back to the influent of the plant. Solids concentration can be expected to run from 12 - 25% solids.

Operational Considerations

This method is energy intensive, chemical dependent and operator challenging.

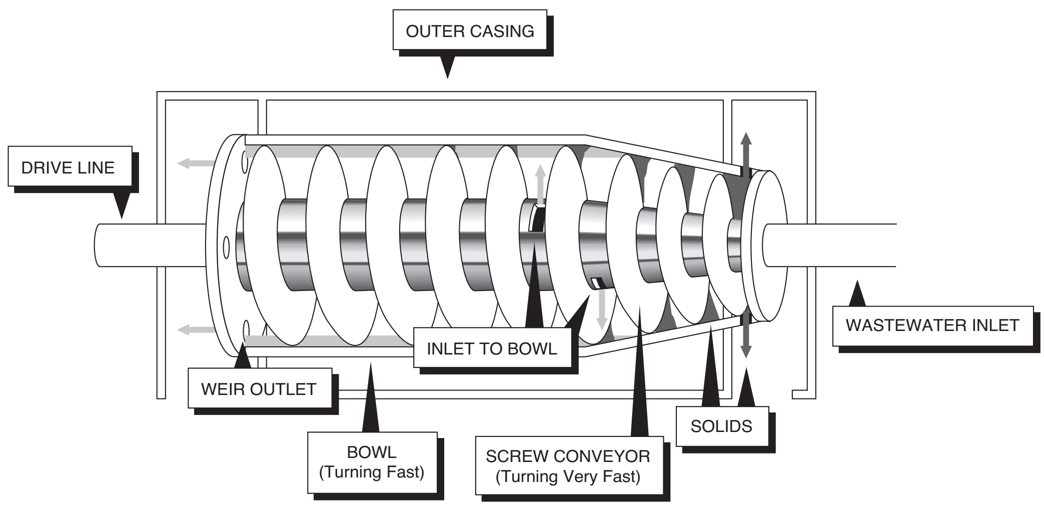
Centrifuge

General Description

The centrifuge is a mechanical method of sludge dewatering that utilizes centrifugal force to remove water from the sludge. As with other dewatering devices the centrifuge requires the sludge to be conditioned, usually with polymers, prior to dewatering.

Three Types

There are three types of centrifuges used in dewatering wastewater sludge; the basket centrifuge, disk centrifuge and the solid bowl centrifuge. The most successful has been the solid bowl which is discussed here.



Equipment

The main components of the solid bowl centrifuge are the rotating bowl and rotating screw or conveyer. The level of sludge in the centrifuge is controlled by weirs which are placed on the end of the bowl. The entire unit is rotated by an electric motor and gear drive.

Operation

Solids are fed into the end of the screw and flow out inside of the bowl. Centrifugal force throws the solids against the sides of the bowl. The screw moves the solids up a slight incline and out the discharge openings. The key to the operation of this device is the difference in the speed of the screw and the bowl.

Operational Considerations

This method uses chemicals and electricity to dewater the sludge and is quite expensive in both on-going operation and initial purchase cost.

Solids Concentration

Solids concentration from the centrifuge can be expected to run from 12 - 25% solids.

Screw Press

General Description

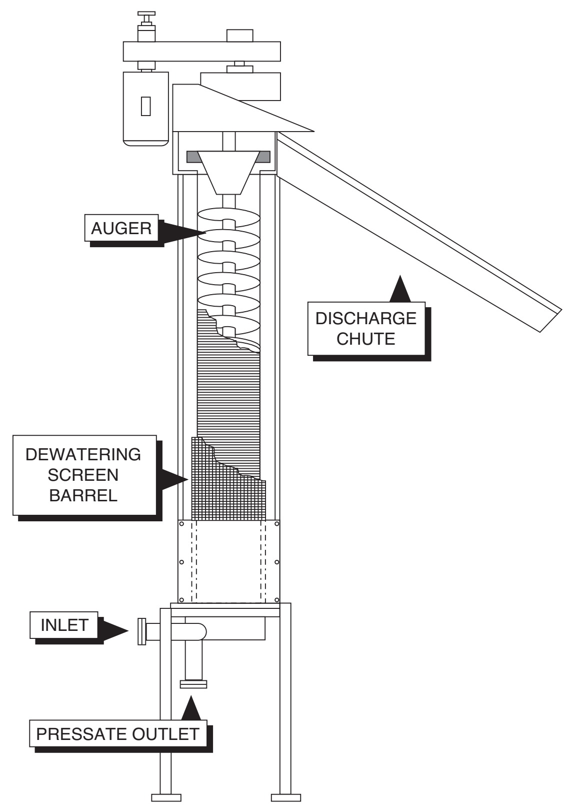
A mechanical method for dewatering sludge that requires minimal physical space is a vertical screw press. This unit requires the sludge to be conditioned by a polymer to achieve reasonable solids dewatering.

Sludge Flow

An auger carries sludge up through the unit and the water that is removed from the sludge is squeezed through the screen. A brush attached to the auger helps to keep the screen clean.

Operational Control

Thickened, dewatered sludge is carried up and out the discharge chute and into an awaiting container. Operator adjustment of polymer feed rates, polymer concentration and polymer type, each effect the end product and the cost to prepare. Operator adjustment of feed sludge rates and auger speeds also affect sludge moisture concentration and polymer costs.



Process Control

Sludge feed rates, polymer feed rates, polymer concentrations and auger speed can all be adjusted by the operator.

Performance

Theoretical performance for aerobically digested sludge reported by manufacturers range from 12 to 15 percent solids with 6-15 pounds of polymer used per ton of solids applied to the press. Anaerobically digested sludge performance reports the same solids results with slightly higher polymer usage.

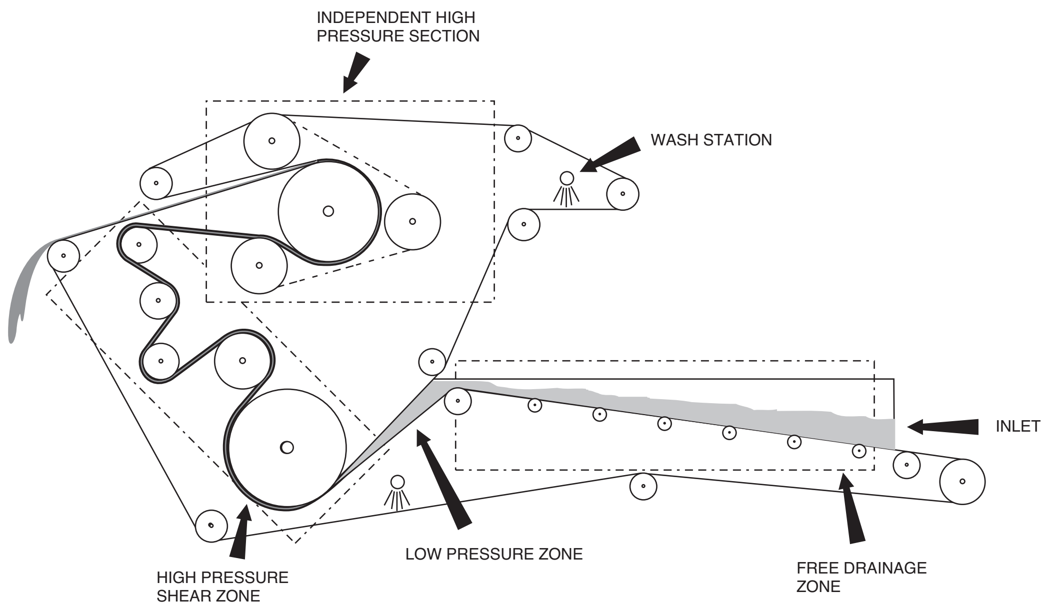
Belt Filter Press

General Description

A belt press utilizes gravity and pressure to reduce the water content of sludge. Sludge is sandwiched between two porous belts and pressure applied to each.

Operation - Initial Stages

The sludge is conditioned with polymer and then fed evenly over a porous belt. It then passes through three zones for water removal. As the belt moves forward, some water is removed by gravity in the free drainage zone. The belt and sludge then move into the low pressure zone. Here the sludge is slowly squeezed between two belts. From the low pressure zone the sludge moves to the high pressure zone. As the roller size is reduced through the high pressure zone, pressure and shear forces are applied to the sludge, thus squeezing water out.



Operation - Final Stages

After the water has been removed, pressure is released and the sludge cake is scraped off of the lower belt. This lower belt returns to the start of the press to pick up more sludge. The upper belt is cleaned with a clear water rinse and then returned to service. The water that is removed is called filtrate and is recycled to the influent of the treatment plant.

Performance Parameters

Key performance parameters are solids recovery, cake dryness, wash-water consumption and wastewater discharge. A solids concentration of 3% is expected at the end of the free drainage zone and a final concentration of 10% to 13%.

Sludge Disposal

Third Step

The third step in solids handling is the disposal of the sludge. It is common practice to refer to this as sludge reuse or biosolids utilization. In these days of recycling, the terms sludge reuse or biosolids utilization is more politically correct than sludge disposal.

Regulations

In most states the reuse or disposal of sludge is regulated by EPA and the state.

Common Methods

There are three methods of disposal; land application, landfills and incineration. This section of the lesson provides information on these three methods and the use of sludge lagoons.

Land Application

Process

Land application of digested and dewatered sludge includes:

- Direct application on top of the land
- Use of the sludge as fertilizer for specific non-human consumption crops.
- Application of the sludge in a liquid form just below the land surface.

EPA Regulations

The current EPA regulations for the disposal of sewage sludge on the land is called the 503 Regulations for Sludge Disposal (biosolids utilization). These regulations classify sludge and outline the required treatment processes and testing criteria for land disposal of wastewater sludge. The following is a brief review of these regulations.

The 503 regulations

Overview

These regulations provide information on:

- Required stabilization techniques for the control of pathogenic microorganisms, including anaerobic digestion, aerobic digestion, lime stabilization and thermophilic (high temperature) stabilization.
- Treatment techniques required to reduce vector attraction and prevent odors and other nuisances. These methods include drying, lime stabilization, heat treatment, and composting.

Classification of Sludges

The 503 regulations encourage land application for disposal or reuse of sewage sludges. The sludge is classified into three categories: Type A, Type B, and Type C sludges. The classification determines the measures that need to be taken in order to apply sludges to the land.

Type A Sludge

Type A sludges pose virtually no health threat to humans and can be land applied with minimal reporting or testing. Type A sludge includes anaerobically digested sludge that has been tested for viruses or composted sludge processed according to documented time and temperature levels.

Type B Sludge

Type B sludge, such as aerobically digested sludge with lime stabilization (for vector control) can be land applied providing there is sufficient separation between adjacent crop lands and only the specified crops growing on the land. Type B sludge requires more reporting and tracking than type A.

Type C Sludge

Type C sludge, such as septic tank sludge needs to be covered within 8 hours of application or injected into the soil immediately upon application. The truck in the photo on the previous page is the type of equipment required for this type of application.

Option to Land Application

An option to land application would be to develop a dedicated land disposal site. This dedicated land site would be set aside specifically for the disposal of sewage sludge and would have to be fenced to prevent access by the public. Dedicated land disposal sites are not required to meet the regulations for use of crops or special management techniques that apply to common land application processes. However, monitoring for possible surface or groundwater contamination is still required.

Summary

The above is an overview of the new regulations and requirements and are not meant to list sludge treatment pathogen or vector reduction requirements completely.

Disposal in Landfills

Landfills

While the EPA encourages reuse of sludge - or application to land, the environmental conditions do not always make this possible. The basic disposal technique used in most small communities is to place the sludge in the landfill. Landfilling of sludges require coordination among landfill owners and treatment plant operators.

State Regulations

In most states, the solid waste regulations stipulate that sewage sludges must contain a minimum of 10% solids before they can be disposed of in a landfill. The solid waste regulations further stipulate that the sludge, "placed in landfills be covered at once or otherwise managed to prevent health hazards and odor nuisances".

Other Disposal Methods

Sludge Lagoons

Partially digested or undigested sludges are sometimes transferred to sludge lagoons for further treatment. While this allows for further stabilization it does not remove the need for disposal. Eventually the sludge in the lagoon will need to be removed and disposed of safely.

Incinerators

Incinerators are used to burn sludge. Disposal of the ash from an incinerator becomes the challenge as burning sludge tends to accumulate the metals found in sludge. EPA is discouraging the use of incinerators because of air quality standards and requirements. Incineration is very energy intensive and expensive, but may be an option where land area is limited or other environmental conditions make land application and landfill impractical.

Composting

Composting sewage sludge can create a usable product that can be used to enrich poor soils or can be disposed of in a landfill. However, the composting process must be carefully controlled and monitored while requiring ambient conditions not normally found in many northern locations.

Conclusion

Overview

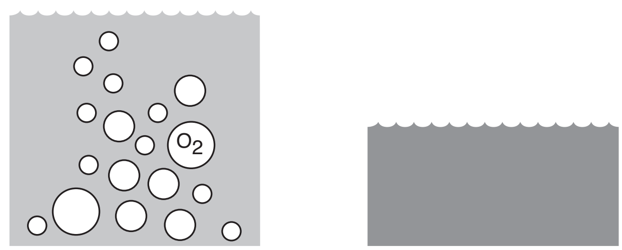
This lesson has provided information on the handling of sludges from domestic wastewater process. Handling includes, stabilization, conditioning, dewatering and disposal.

Disposal Regulated

Current regulations governing the disposal, or reuse of sludge are in place to regulate the application rates and outline reuse practices.

1 lbs of BOD = 0.5 lbs Sludge

Ultimately, sludge is the tail that wags the dog in the wastewater business. For every pound of BOD entering a wastewater treatment plant, the wastewater operator will “handle” about 1/2 pound of dry sludge. This handling leads to disposal outside the treatment plant boundaries.



1 lb. BOD = 0.5 lbs. sludge

Disposal Problem

While land disposal of sludge is a viable alternative from an environmental standpoint it often is not a reasonable political alternative. Very few people want sewage sludge disposed of in the vicinity of their home. For instance, the closest land disposal site found by the City of Fairbanks, was so far away that the hauling costs made land disposal economically undesirable.

Solids Handling

Worksheet

1. Describe the following types of sludge.

   a. Primary sludge ____

   b. Biological sludge ____

   c. Scum ____

   d. Screenings ____

2. What are two major health and safety concerns associated with sludge disposal?

   a. ______________________

   b. ______________________

3. The process unit used to collect and stabilize waste sludge is a ____________________.

4. The two reasons for sludge digestion are:

   a. Reduction in __________________ and

   b. _________________ stabilization.

5. When the air is shut off to an aerobic digester the sludge will settle leaving a clear liquid at the top. This liquid is called the ____________________. The process of removing this liquid is called ______________.

6. A sludge stabilization process that uses an open tank is ______________ ______________ and requires approximately __________ days to complete.

7. _________________ ______________ is accomplished in the absence of oxygen and one of the by products is methane gas.

8. Anaerobic decomposition will produce what by-products?

   a. ______________________

   b. ______________________

   c. ______________________

9. The primary reason for heating and mixing an anaerobic digester is to ______________ the __________ of digestion.

10. In an Imhoff tank sludge digestion takes place in which tank?

11. Before sewage sludge can be placed in a landfill for disposal the solids content must be at least _____%

12. In a sludge drying bed, water is removed from the sludge through two processes. These processes are:

    a. ______________________________

    b. ______________________________

13. A dewatering process that uses vacuum and a large drum is called: ________________________

14. A dewatering process that uses centrifugal force is called: ______________________________

15. List four sludge disposal processes:

    a. ______________________________

    b. ______________________________

    c. ______________________________

    d. ______________________________

16. Milk of lime is a mixture of ________ parts lime and ________ parts water.

Wastewater Disinfection

What is in this Lesson?

1. The function of disinfection in wastewater treatment
2. The name of the tank used for disinfection
3. Three methods of disinfecting wastewater
4. The most common method of disinfection used in the U.S.
5. The color and weight to air relationship of chlorine gas to air
6. The OSHA and medical classifications of chlorine gas
7. The relationship between a volume of liquid chlorine and concentrated gas
8. The items that affect the germicidal effectiveness of chlorine
9. Typical detention time in a chlorine contact basin
10. Description of a good chlorine cylinder storage area
11. The components of a chlorine gas room and their functions
12. Proper temperature for storage of chlorine cylinders
13. The proper method of securing a chlorine cylinder
14. The tool used to operate a chlorine cylinder valve
15. How to find a chlorine leak
16. Proper and safe handling process for 150 pound cylinders
17. The cause of frosting of a chlorine cylinder
18. The function of fusible plugs in chlorine cylinders
19. The net weight of the three common gas chlorine containers
20. The temperature that fusible plugs release
21. The type of gasket used to make a connection to a chlorine cylinder
22. The function of a hypochlorinator
23. The proper handling, storage and mixing of sodium and calcium hypochlorites
24. The components of a hypochlorination system
25. The application point of chlorine in order to reduce odors in a collection system
26. Use of chlorine to disinfect digested sludge
27. Two methods of dechlorination
28. Two reasons that dechlorination may be required
29. The application process used to disinfect sludge and sewage with lime

Key Words

- Calcium Hypochlorite
- Coliform Bacteria
- Demand
- Dosage
- Enzymes
- Feces
- Hypochlorite
- Hypochlorous Acid
- Residual
- Sodium Hypochlorite
- Tertiary Treatment
- Turbidity
- Chloramines
- Combined Chlorine Residual
- Disinfection
- Element
- Free Chlorine Residual
- Germicide
- Hypochlorite Ion
- pH
- Short Circuiting
- Soluble
- Total Chlorine Residual

Wastewater Disinfection

Introduction

Lesson Content

In this lesson on the introduction to wastewater disinfection the focus will be on the reasons for disinfection, the basic theory associated with disinfection with chlorine and the mechanical components of chlorine systems found in small wastewater facilities.

Small System

While most of the concepts and mechanical equipment discussed in this lesson are used in small and large systems the focus of the lesson will be on small systems; primarily those systems with a population of less than 3,300.

Simple Systems

Many small system operators may be operating very simple systems or no disinfection systems at all. It is still important for these operators to understand the basic concepts and theories behind typical disinfection systems

Not in This Lesson

The routine processes associated with operation, management and maintenance of chlorination systems, along with calculations and techniques on chemical mixing will not be discussed. These are found in the next level of training. While some mention of routine testing and data collection is given, the details are found in other materials.

Disinfection

Definition

Disinfection[1] is defined as the process used to control pathogenic organisms found in wastewater effluent, digested sludges and honey bucket dump sites. Disinfection prevents the spread of waterborne disease and diseases associated with contact with human waste or **feces**[2].

Goal

The goal of proper disinfection in a wastewater system is to destroy all disease causing organisms in order to protect downstream users of the water.

How Do we Measure Effectiveness

The effectiveness of disinfection in a wastewater system is measured by testing for the presence of **fecal coliform bacteria**[3]. Fecal coliform bacteria that are found in wastewater are generally not pathogenic. They are indicators of contamination and the potential presence of pathogenic organisms. When they are present in low numbers it is considered that the potential for pathogenic bacteria is low.

Why Fecal Coliform?

Fecal coliform bacteria have been selected as the indicator of bacteriological water quality for several reasons:

[1] **Disinfection** - The process used to control pathogenic organisms.
[2] **Feces -** (Fee-seez) - Dung, excrement of man or animal.
[3] **Fecal Coliform Bacteria** - The Fecal coliform group of bacteria is a bacterial indicator of contamination. This group has as one of its primary habitats the intestinal tract of human beings. Coliforms also may be found in the intestinal tract of other warm-blooded animals. Also called E. Coli or Escherichia Coli.

- First, they survive longer than most pathogenic organisms in the water environment.
- Second, they are easy to test for. That is, the testing process has been perfected and it is not excessively expensive or difficult.
- Thirdly, they are less sensitive to disinfection than many of the pathogens found in wastewater.
- Fourth, they only exist in the intestinal tract of warm blooded animals.

Why Fecals and not just Coliform

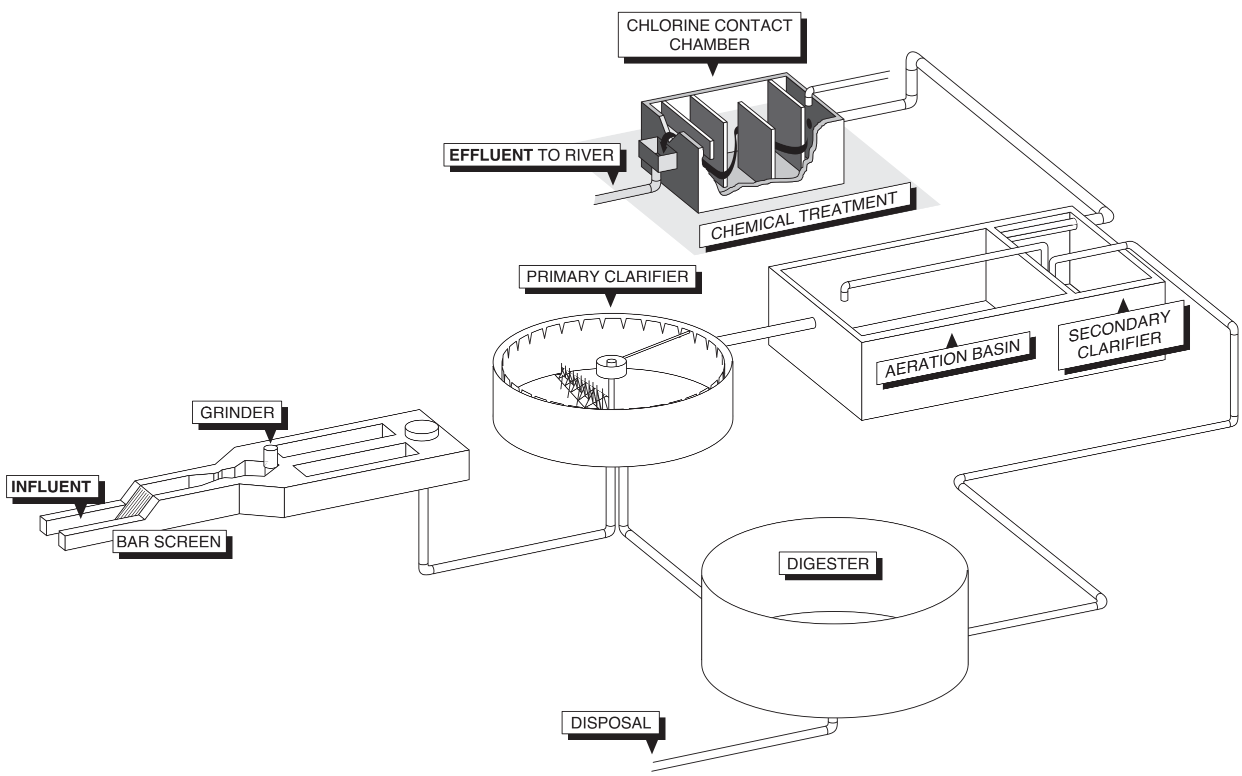
Fecal coliform is a sub-group of the general group of bacteria called **Coliforms**[4]. Unlike coliform, which is found in plants, soil, air, the aquatic environment and in warm blooded animals, fecal coliform are found only in the intestinal tract of warm blooded animals.

Testing

To differentiate between the fecal coliform and the rest of the coliform group, microbiological testing is conducted at higher temperatures than the standard coliform test.

Disinfection Methods

While chlorine is the most common disinfectant used in wastewater treatment other processes such as ozone, ultraviolet light and lime are also used for disinfection. The following is a brief discussion of each of these processes.



[4] **Coliform Bacteria** - The coliform group of bacteria is a bacterial indicator of contamination. This group has as one of its primary habitats the intestinal tract of human beings. Coliforms also may be found in the intestinal tract of warm-blooded animals, and in plants, soil, air and the aquatic environment.

Methods of Disinfection

Ozone - O_3

Description

Ozone is composed of three oxygen atoms. It is extremely unstable and cannot be stored successfully. Consequently, it must be produced on site; it cannot be purchased in cylinders like chlorine gas.

Using Ozone

Ozone has been successfully used in Europe for a number of years as a means of disinfecting drinking water and wastewater effluent. Ozone costs more than chlorine to produce, it is much more effective than chlorine and it produces fewer objectionable by-products. One of the primary problems with using ozone as a disinfectant is the lack of a measurable residual. However, since it may be desirable to limit the amount of chlorine being discharged, ozone my be a suitable alternative.

Ultraviolet Light

Description

Ultraviolet light is a form of radiation that can destroy some microorganisms. Ultraviolet treatment does not produce any chemical changes. However, in order to kill, the ultraviolet rays must actually penetrate the organism. Solids drastically interfere with UV disinfection, so its use in wastewater is limited. It has more applicability when used on the final effluent of a **tertiary treatment**[5] plant (a plant that filters the effluent prior to disinfection).

Lime

Background

Lime has proved to be a successful disinfectant of water, sludge and raw sewage. It is effective in the destruction of bacteria, viruses and protozoa. The destruction is obtained by raising the **pH**[6] of the material to above 11.5. Past studies have indicated that a pH of 11.5 to 12 is effective in inactivating microorganisms at temperatures down to 1°C. Naturally, when a fluid or sludge is frozen, lime and other disinfectants can not kill microorganisms.

Using Lime

Lime does not leave a residual. If there is a requirement for a residual in the final effluent lime application may need to be followed by the addition of chlorine. The most common use of lime is in the treatment of digested sludges and raw sewage in pit toilets, honey bucket dumps and in treating spills from honey buckets and honey bucket haulers.

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5 **Tertiary Treatment** - (TER-she-AIR-ee) - Any process of water renovation that upgrades treated wastewater to meet specific reuse requirements. May include general cleanup of water or removal of specific parts of wastes insufficiently removed by conventional treatment processes. Typical processes include chemical treatment and pressure filtration.

6 **pH** - An expression of the intensity of the basic or acidic strength of a water. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion concentration. pH may range from 0 to 14, where 0 is the most acid, 14 most alkaline, and 7 neutral.

Chlorine

Background

Chlorine is the most common method used in the United States for disinfection of water, wastewater and swimming pools. Chlorine is produced as a gas, a liquid and a powder (the liquid and powdered chlorine are called **hypochlorites**[7]).The addition of chlorine to wastewater effluent kills bacteria, viruses and protozoa.

Chlorine Problems

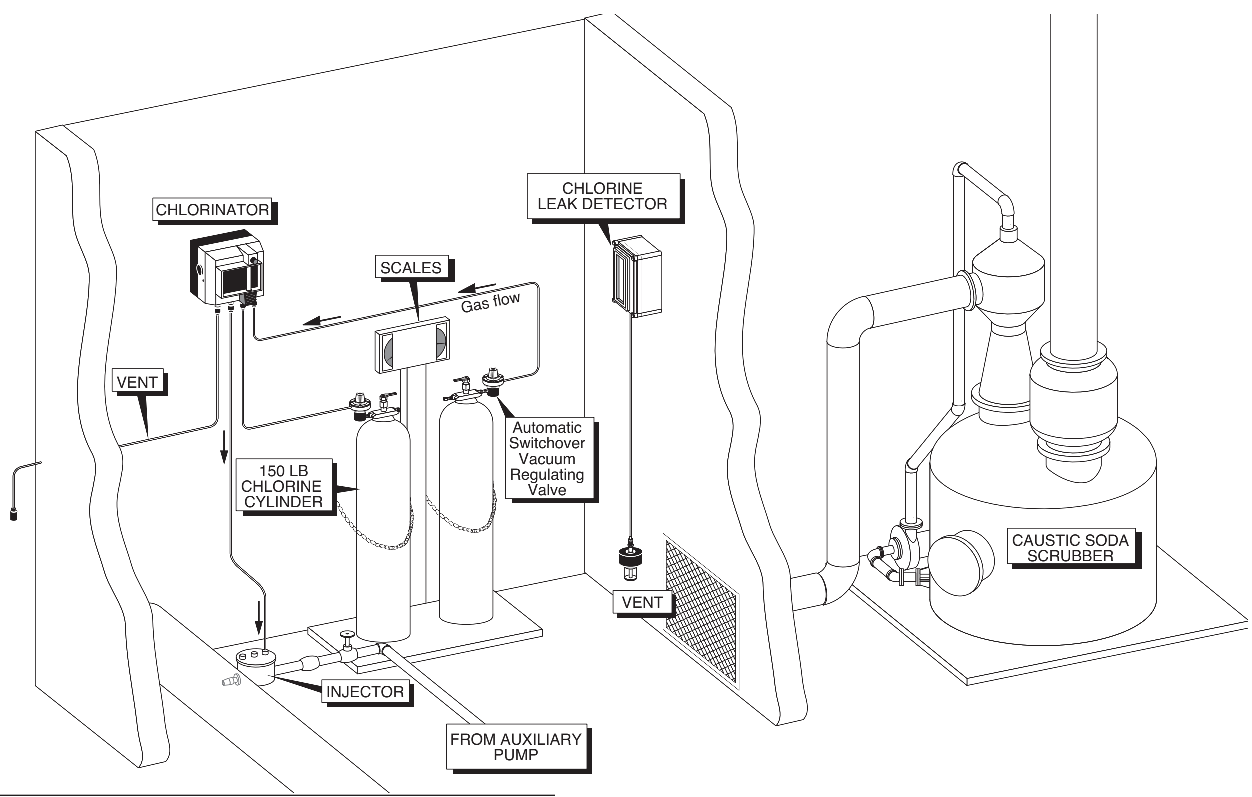
Chlorine gas is classified as a poison and an inhalation hazard, making transportation and handling difficult and dangerous. In addition, excessive chlorine residuals that enter a stream from the wastewater effluent can destroy fish and aquatic plants.

Why Use Chlorine

Despite problems, chlorine remains the most common method of disinfection because, 1) it costs less than most of the other methods and 2), we have more knowledge about chlorine than any of the other methods.

Equipment- Gas

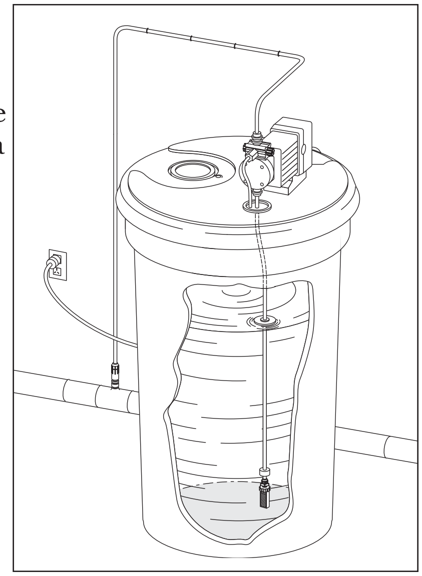
Chlorine gas is supplied in a pressurized tank. It is fed to the system using a vacuum device called a chlorinator. This device provides safety for the operator and allows precise control of the rate of application. The most common gas chlorinators found in small systems are either mounted directly onto the chlorine cylinder or mounted onto the wall. In the diagram below, the chlorinator is mounted on the wall.



[7] **Hypochlorite** (HY-po-KLOR-yt) - Compounds containing chlorine that are used for disinfection. They are available as liquids or solids, in barrels, drums and cans.

Equipment - Hypochlorination

In order to use powdered or liquid chlorine products (hypochlorites) they are commonly mixed into a tank and then fed into the system using a chemical feed pump.



Chlorine Properties & Chemistry

Chlorine Products

Chlorine for disinfection can be purchased as a solid, liquid or gas. Chlorine in its solid form is called **calcium hypochlorite**[8]. It is available in powder or tablet form. HTH™ is a brand name for one of the common calcium hypochlorite products. Liquid chlorine or **sodium hypochlorite**[9] is commonly known as bleach.

Chlorine Gas

Basic Properties

Chlorine (Cl) is an **element**[10], but is never found uncombined in nature. In the gaseous form two atoms of Cl combine to form the gas Cl_2. This gas is approximately 2.5 times heavier than air. At room temperature chlorine gas is greenish-yellow in color and only slightly **soluble**[11] in water. When released into the atmosphere one volume of liquid chlorine will evaporate to form 450 volumes chlorine gas.

A Poison

Chlorine is classified by OSHA, EPA and DOT as a poison and an inhalation hazard. Medically, chlorine is classified as an irritant because it does not build up in the human body.

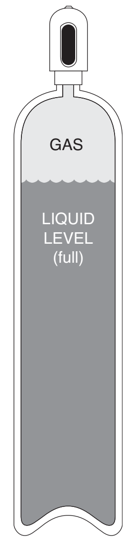
Threshold of Odor

Chlorine gas has an extremely pungent odor. The level of concentration that can be detected by smell is between 0.08 and 0.4 ppm depending on the capabilities of the individual. When the level of chlorine reaches 30 ppm, it will cause severe coughing. At concentrations of 1000 ppm it kills quickly.

[8] **Sodium Hypochlorite** - A water solution of sodium hydroxide and chlorine, in which sodium hypochlorite is the essential ingredient.
[9] **Calcium Hypochlorite** - A dry powder consisting of lime and chlorine combined in such a way that when dissolved in water, it releases active chlorine.
[10] **Element** - Any of the more than 132 fundamental substances that consist of atoms of only one kind and that singly or in combinations constitute all matter.
[11] **Soluble** - Capable of being dissolved.

Gas Chlorine Cylinders

Gas chlorine is provided in 100 lb, 150 lb or 1-ton steel containers (This is the weight of the chlorine in the container). Chlorine is placed in the container as a liquid. The liquid boils at room temperature producing a gas and pressurizing the cylinder. At a temperature of 70°F, a chlorine cylinder will have a pressure of 85 psi. Chlorine gas is 100% chlorine.



150 pound chlorine cylinder

Hypochlorites

Two Hypochlorites

There are two hypochlorites used for the disinfection of wastewater, calcium hypochlorite and sodium hypochlorite.

Calcium Hypochlorites

Hypochlorites are produced by combining chlorine with either calcium or sodium. Calcium hypochlorites are either a powder or a tablet and can contain chlorine concentrations up to 67%. The powder or tablets must be dissolved in water.

Sodium Hypochlorite

Sodium hypochlorite is a liquid bleach. Sodium hypochlorite is found in concentrations up to 12.5%. Chlorine concentrations of household bleach range from 4.75% to 5.25%.

Chlorine Terms

Introduction

One of the major difficulties new operators have with the chlorination process is understanding the terms used to describe the various reactions and processes used in chlorination. The following is a brief description of the common terms used in chlorination.

Dosage

Dosage is the amount of chlorine added to the system. The units used to describe dosage can be either milligrams per liter (**mg/L**[12]), pounds per day or ppm (parts per million). The most common is mg/L.

Demand

Demand is the amount of chlorine that is used by substances like nitrogen compounds, iron, manganese, algae and microorganisms in the water. As chlorine reacts with these substances, the quantity of chlorine available for disinfection drops. The quantity used by these substances is called demand. Demand, like dosage is expressed in mg/L.

Residual

Residual is the amount of chlorine remaining after the demand is satisfied. Residual, like dosage and demand, is expressed in mg/L. There are three types of residual; free, combined and total.

[12] **mg/L** - milligrams per Liter. A unit of the concentration of a constituent in water. It is 0.001g of the constituent in 1,000 ml of water. mg/L has replaced the PPM (parts per million) in reporting results in water.

Free Residual

Free chlorine residual[13] is the amount of chlorine as Cl_2, **hypochlorous acid**[14] (HOCl) and the **hypochlorite ion**[15] (OCl^-) in the water. Free chlorine is a stronger disinfectant than combined chlorine. In wastewater free residual is seldom detected and chlorine is usually in the combined residual form.

Combined Residual

Combined residual is the result of combining free chlorine with nitrogen compounds such as ammonia. With typical chlorine residual test instruments we can not test directly for **combined chlorine residuals**[16].

Total Residual

Total chlorine residual[17] is the combination of free and combined residuals. Total residual can be determined directly with standard chlorine residual test kits. Total residual is the normal test required at wastewater treatment facilities.

Pre-Chlorination

Pre-chlorination is the addition of chlorine prior to a process unit.

Post-chlorination

Post-chlorination is the addition of chlorine after a process unit.

Dechlorination

Dechlorination is the reduction of the residual to an acceptable level. Dechlorination can be accomplished with the use of activated carbon or with chemicals such as sulfur dioxide and sodium bisulfite.

Chlorine Chemistry - Briefly

Introduction

In order to explain the chlorination process it is necessary to have a basic understanding of the reactions of chlorine in water. The basic reaction is a two step process.

Hypochlorous Acid

When chlorine gas is added to pure water, the first reaction is the production of hypochlorous acid (HOCl), hydrogen and the chloride ions. Hypochlorous acid is measured as free chlorine residual.

$$Cl_2 + H_2O \Leftrightarrow HOCl + H^+ + Cl^-$$

Hypochlorite Ion

In the second part of the reaction a portion of the hypochlorous acid disassociates (breaks apart) to form the hypochlorite ion (OCl^-), and hydrogen. The hypochlorite ion is also measured as free chlorine residual. When the pH of the water is at 7.5 one half of the residual will be HOCl and one half will be OCl^-.

$$HOCl \Leftrightarrow H^+ + OCl^-$$

---

13 **Free Chlorine Residual** - The amount of chlorine available as dissolved gas, hypochlorous acid or hypochlorite ion that is not combined with ammonia or other organic compounds. It is 25 times more powerful than the combined chlorine residual.

14 **Hypochlorous Acid** - An umstable, strongly oxidizing but weak acid (HOCl) obtained in solution along with hydrochloric acid by reaction of chlorine with water.

15 **Hypochlorite Ion** - An ion that results from the reaction of chlorine gas and water. Hypochlorite ion (OCl^-) along with hypochlorous acid are called free chlorine residual. However, the hypochlorite ion is not as powerful a disinfectant as hypochlorous acid.

16 **Combined Chlorine Residual** - The amount of chlorine available as a combination of chlorine and nitrogen.

17 **Total Chlorine Residual** - The sum of the combined and free chlorine residuals.

Nitrogen Compounds

Nitrogen compounds present in the wastewater combine with hypochlorous acid to form chemical compounds called chloramines. Nitrogen compounds include inorganic nitrogen compounds such as ammonia and organic nitrogen compounds like protein and amino acids.

Free to Combined

In the chemical reactions shown above, free chlorine (HOCl) is the first component produced. Combined chlorine residuals only occur after the free chlorine is produced. However, the reaction between the free chlorine and nitrogen compounds is so quick that we are unable to observe free chlorine in a test sample. Only after the demand (reactions with ammonia, turbidity, iron, manganese, microorganisms and other organic nitrogen compounds) has been satisfied will free chlorine become available. Because of the amount of ammonia in most wastewater effluents, the demand will be so high that free chlorine will not last longer than a few seconds.

Residual Requirements

Because of the quantity of ammonia in wastewater, it is not practical to inject enough chlorine to provide a free chlorine residual. Therefore, combined chlorine residuals are the common disinfection compounds used in the wastewater treatment disinfection process. Combined residuals cannot be tested for directly. Therefore, it is common practice to test for total chlorine residual. In order to maintain an effective line of defense against pathogenic organisms, a total chlorine residual, at the point where the effluent exits the chlorine contact chamber, is usually maintained. Two important criteria for disinfection are contact time and chlorine residual concentration. When the contact time is low it is necessary to increase the residual.

Type of Residual

As we described above, free chlorine residual is the best of the disinfectants. However, due to practical limitations, combined residuals are used in wastewater. A typical wastewater effluent will have between 0.5 and 1.5 mg/L total chlorine residual. However, system limitations may require a higher residual than stated.

Interfering Agents

Minerals, such as iron and manganese, combine with chlorine and increase the demand. Turbidity uses chlorine and provides a place for microorganisms to hide. Organic material, such as leaves, combine with chlorine increasing the demand and reducing the residual.

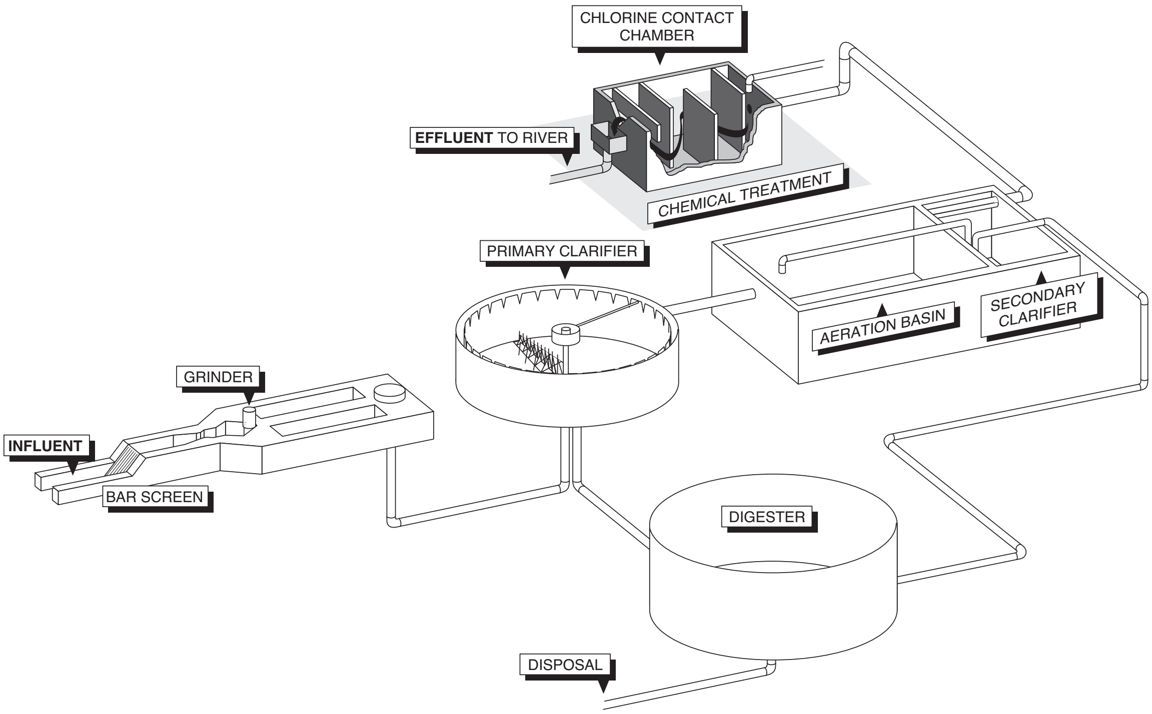
Contact Time

One of the key items in predicting the effectiveness of chlorine on microorganisms is contact time. Typical contact time in a chlorine contact chamber will range between 20 minutes and 30 minutes.

Chlorine Facilities

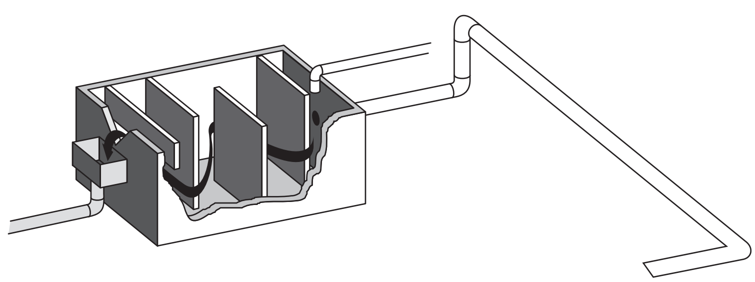
Application Point

Chlorine and other disinfectants that need time to react are introduced in a wastewater treatment plant after all other treatment has been completed. In a typical plant, chlorine would be introduced in a tank called the chlorine contact chamber. This chamber is designed to maximize contact time between the chlorine and the pathogenic organisms.



Contact Chamber Shape

To prevent **short circuiting**[18] in the chamber and to provide the maximum contact time with the least amount of turbulence, chlorine contact chambers are commonly designed so the flow snakes through them. This provides what is called plug flow through the chamber.



Typical chlorine contact chamber with plug flow.

18 **Short Circuiting -** A condition that occurs in tanks or ponds when some of the wastewater travels faster than the rest of the flowing wastewater.

Chlorine gas systems

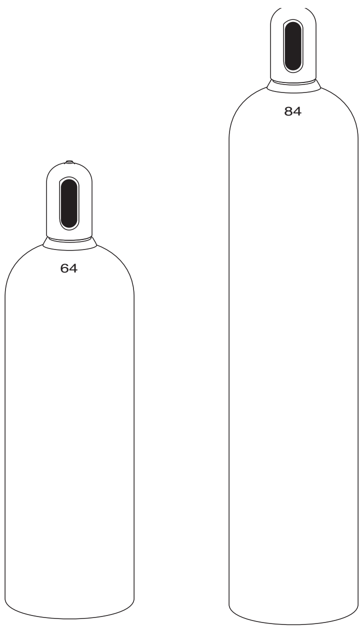
Feeding Gas to the System

The chlorine gas is drawn off the cylinder by a chlorinator and mixed with water to form a concentrated chlorine solution which is then mixed with the flow of the system.

Cylinders

Container Sizes

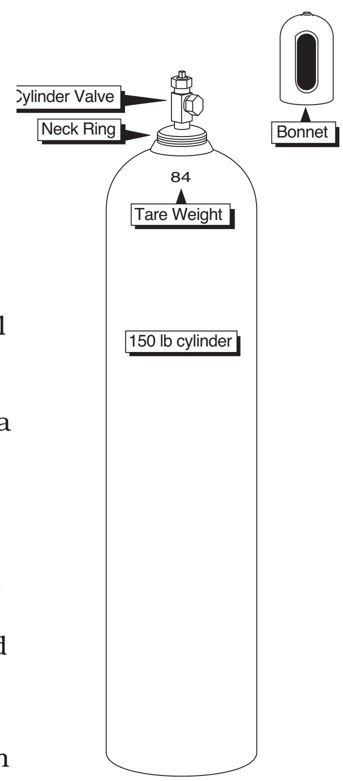
Gas chlorine, which is 100% chlorine, is provided in 100lb, 150lb or 1-ton containers. (this is the next weight of the chlorine in the container.) Chlorine is placed in the container as a liquid. The liquid boils at room temperature producing a gas and pressure in the cylinder. Most small wastewater plants using gas chlorine will use the 100 lb and 150 lb cylinders.



100 pound cylinder **150 pound cylinder**

1 ton container

Cylinder Components



Overview

The cylinder is made of steel and manufactured to DOT regulations. The cylinder is composed of the container, a neck ring, bonnet and cylinder valves. Some containers have a separate foot ring welded to the cylinder. The bonnet should remain on the cylinder whenever it is not connected to the chlorine system.

Tare Weight

Each cylinder has a tare (net) weight stamp placed on the shoulder of the cylinder. By weighing the cylinder and subtracting the tare weight, the weight of the remaining chlorine can be determined. A typical tare weight of a 150 pound cylinder can range from 85 to 140 pounds.

Container Data

Fill Information

Chlorine containers are filled at the factory to 88% of their volume with liquid chlorine. This volume is set at 70°F.

Liquid to Gas

In order for gas chlorine to be produced, the liquid must boil. This happens at any temperature above -29 °F. The gas will evaporate and fill the space above the liquid. At room temperature (70°F), the gas will produce a pressure of 85 psi.

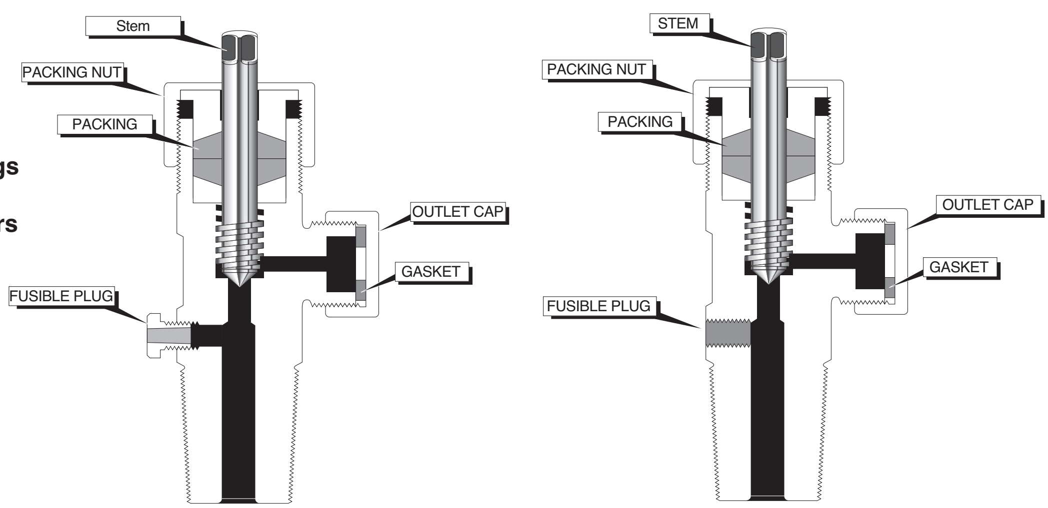
Expansion of Volume

At 70°F the liquid in a full container occupies 88% of the volume and will provide a discharge pressure of 85 psi. If the temperature of the same container were raised to 158°F, the liquid would expand to fill 100 % of the volume of the container and the gas pressure would be 310 psi.

Fusible Plug

To prevent the cylinder from rupturing, a fusible plug is built into the cylinder valve. This plug is designed to melt at between 158°F and 165°F, and allow the gas to escape. This would reduce the cylinder pressure and prevent cylinder rupture.

Cylinder valves with fusible plugs used with 100 and 150 cylinders



Withdrawal Process

In order for chlorine gas to be extracted from a cylinder, the liquid must boil. The heat that is required to produce this boiling must come from the air around the cylinder.

Frost on the Container

When the draw off rate from a chlorine cylinder exceeds the rate of evaporation of the chlorine gas the pressure in the container will drop. If this high withdrawal rate continues, frost will begin to form on the outside of the cylinder.

Changing Containers

When a container is changed the face of the cylinder valve and the connection should be cleaned with steel wool and a new gasket installed. The gaskets supplied for this are made of lead or pressed fiber. The wrench used to open and close the cylinder should be no longer than 8". When suppling gas, the cylinder valve should never be opened more than one full turn.

Handling Cylinders

Introduction

This section is dedicated to the handling of 100 and 150 pound chlorine cylinders in and around the chlorine room. It includes moving of containers from outside of the building into a storage area. It does not include any handling of the containers in conjunction with the transportation of chlorine.

Protective Hood

The protective hood or bonnet must be in place any time the cylinder is being moved.

Hand Truck or Rolled

Anytime a chlorine cylinder is moved inside of a building, a hand truck should be used. A cylinder can also be moved by tipping it back at a slight angle and rolling along the bottom edge.

Chained

The cylinder must be chained up 2/3 of the way from the bottom with a chain sufficient to hold the weight of the container.

Not Acceptable

Under no circumstances should a container be lifted by the bonnet, nor should a magnetic device or straps be used to lift or move the container.

Training Requirements

Under OSHA regulations 29 CFR 1910.1200, hazard awareness training must be provided for all employees who are required to handle chlorine cylinders. This training is a part of the hazard communication training requirement. In addition to the basic training, there must be additional training that is process specific for handling chlorine.

Cylinder Storage

Introduction

This portion of the lesson is unique to the storage of 100 and 150 pound cylinders. There will be no information provided on the storage of 1 ton containers or tank cars.

Assumption

When discussing storage, we are assuming that none of the containers are in any way connected to a chlorinator or other device. That is, they are in storage.

Clean & No Other Chemicals

The storage area should be clean and dry. No other compressed gases or other chemicals can be stored in the same room with chlorine gas. This includes all hydrocarbons such as gas, diesel and floor sweeping compounds that contain light hydrocarbons.

Chained

All cylinders must be stored in a vertical position and chained up 2/3 from the bottom. In an earthquake area, a second fastening device must be placed near the bottom. The chain must be strong enough to hold the weight of the cylinder.

Heat

The room should be heated to 70°F. The heat should be indirect. No direct heat should be applied to a chlorine container. The steel (the container) will ignite and burn if the temperature reaches 483°F.

Empty & Full Cylinders

Empty and full cylinders must be marked and separated. They can be in the same room. However, the full and empty cylinders need to be physically separated so that in an emergency, a responder can easily determine which are full and which are empty.

Chlorine Building

Materials

The building should be constructed so as to contain a chlorine leak. That is, the leak should not pass through the walls. Concrete or sealed concrete block is best. If not concrete or block, the walls and joints should be sealed.

Door

The door must open out, preferably to the outside and have a crash bar. There should be more than one access into the room. All doors must open out.

Windows

To reduce the need to enter the room, there should be a window between the chlorine room and some other portion of the mechanical area. This will allow the operator to observe the chlorinator and read the scales without entry into the room.

Electrical

All lights, plugs, motors and other electrical fixtures inside of the chlorine room should be corrosion proof. This is NEMA Code 4X. This is to prevent the deterioration of the electrical equipment from the occasional release of chlorine.

Exterior Switches

The interior lights and ventilation fan should have a switch outside the entry door. The standard practice would be to turn these devices on 3 to 4 minutes before entry into the room.

Motors and Control Panel

There should be no electric motors or electrical control panels placed in the chlorine room that are not directly related to the chlorination system. Occasional releases of chlorine will quickly deteriorate the motors and control panels.

Ventilation System

Vent

The room must be equipped with a mechanical exhaust ventilation system. The intake to this ventilation system must be near the floor. (Chlorine as a gas is 2.5 times heavier than air.)

Inlet of Fresh Air

The total ventilation system must be designed to allow fresh air to enter the room near the ceiling.

Exhaust Rate

The exhaust system must be able to exchange the air in the room every 3 to 4 minutes.

Vent exhaust

The exhaust air must be treated so that the chlorine concentration exhausted into the atmosphere is below 15 ppm.

Air Treatment System

The most common air treatment system is a caustic soda scrubber.

Containment of Scrubber

When the scrubber system contains caustic soda, a secondary containment system, usually concrete, must be built to contain a spill of the total volume of the caustic soda.

Negative Pressure

The exhaust and fresh air entry system must be designed so that a slight negative pressure is maintained in the room anytime the exhaust ventilation system is on.

Ventilation Without Treatment

If the system is designed without an air treatment system the exhaust of air from the chlorine room must be placed so that there will be of no harm to the plant operator. Normally the vent is placed near the floor and then piped outside and up high enough to avoid being covered by normal snow levels.

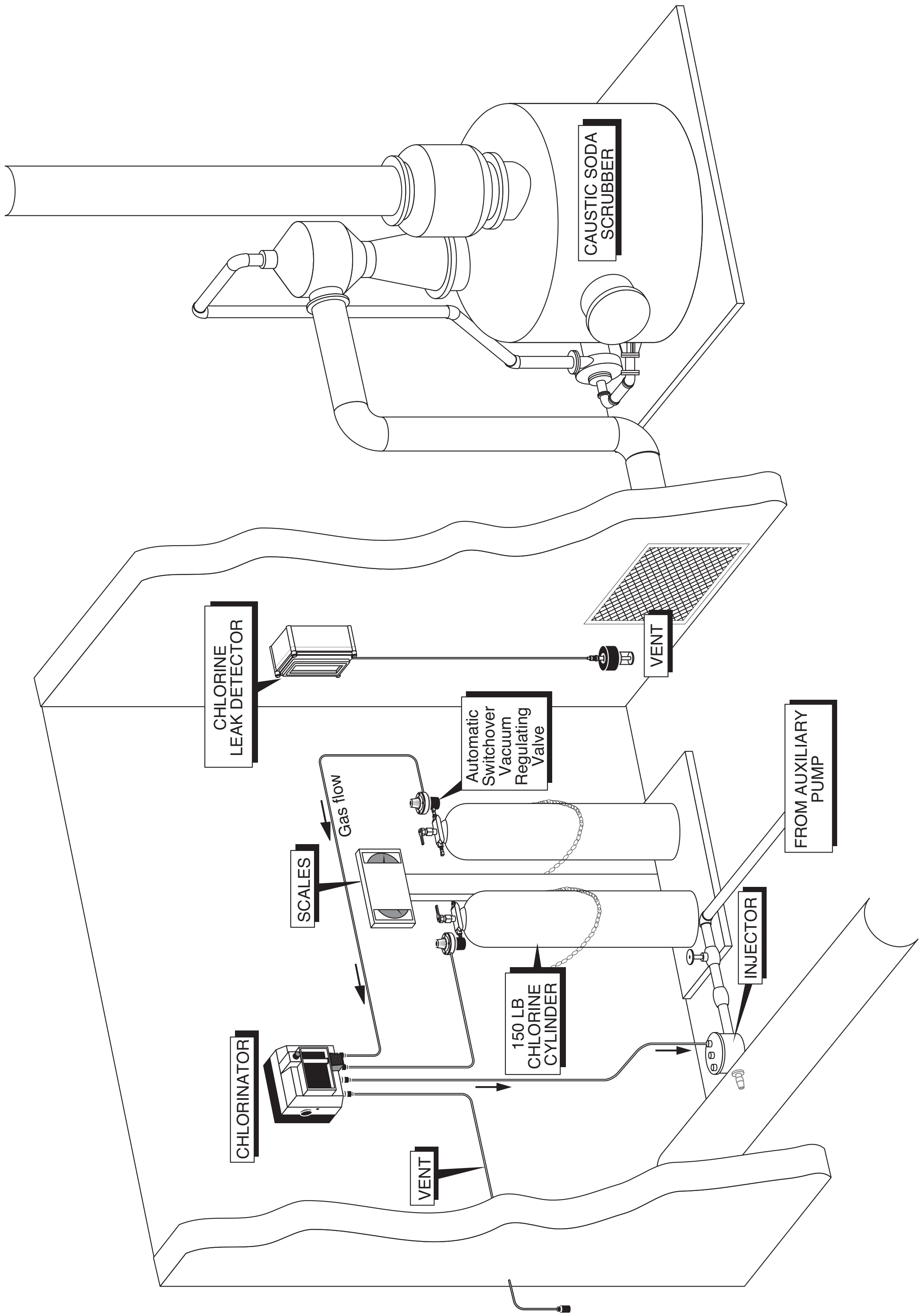
Other Considerations

Eye Wash & Shower

An emergency eye wash and emergency shower must be provided. The eye wash must be rinsed daily. If considering a new design, we recommend that a tepid water design be chosen.

Floor Drains

The floor drains must be isolated so that a release of chlorine in the room cannot enter into another room. If an air treatment system is available the floor drain should be connected to this system.


CAUSTIC SODA SCRUBBER
CHLORINE LEAK DETECTOR
VENT
Automatic Switchover Vacuum Regulating Valve
Gas flow
SCALES
FROM AUXILIARY PUMP
INJECTOR
150 LB CHLORINE CYLINDER
CHLORINATOR
VENT

Sprinkler System

The chlorine room and any secondary chlorine cylinder storage area must have an overhead fire sprinkler system. The system must be designed to produce maximum flow for at least 20 minutes.

Secondary Containment

A secondary containment system, usually made of concrete, must be designed to contain a spill of the maximum amount of chlorine that could be available from all cylinders that are connected and on line, plus the water from the overhead sprinkler system.

Emergency Power

There must be emergency power available to handle the exhaust system, scrubber and if necessary the fire sprinkler system.

Leak Detector

The chlorine room and storage area should be equipped with a chlorine leak detector. This detector should be set to sound an alarm anytime the chlorine level goes above 1 ppm.

Vandals

All attempts must be made to make the chlorine storage and use area vandal resistant. This includes proper locks and signs.

Scales

Scales are used to determine the amount of chlorine fed. The only way to determine the actual chlorine used is to weigh the cylinders on a daily basis. Using this data and the daily flow of the system the chlorine dosage can be calculated. By calculating dosage daily, the operator can separate mechanical chlorine problems from increased demand problems.

Chlorine Gas Feed Equipment

Basic Operating Principles

The gas chlorine feed equipment used in wastewater systems is rated in pounds per day. This is the maximum amount of chlorine that the system can feed in a day. All of the units sold today are vacuum operated. This is a safety feature. If there is a break in one of the components in the chlorinator the vacuum will be lost and the chlorinator will shut down preventing the escape of chlorine gas.

Components

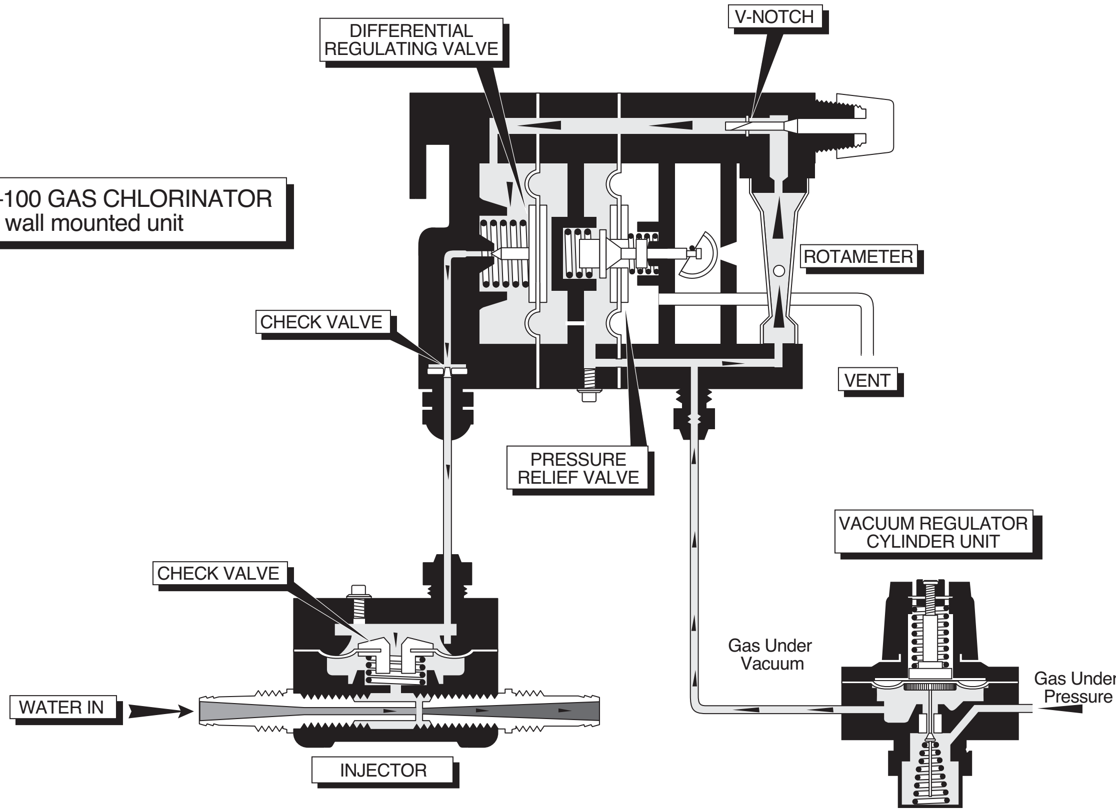
The vacuum is produced by a device called an injector or ejector. The vacuum is used to open one or more valves in the chlorinator allowing gas to enter the chlorinator. Gas flows through the chlorinator to the injector where it is mixed with the feed water. The water leaving the injector has a high concentration of chlorine. Concentrations of 1000 mg/L are common.

Mixed with Flow

The concentrated chlorine solution is mixed with the main system flow. If the flow varies with time then the chlorinator is required to automatically adjust to the flow. This is called a flow proportional chlorinator.

Wall Mounted Chlorinators

A common gas chlorinator used in small communities is the wall mounted unit. The most common wall mounted units are the Wallace and Tiernan V-75, V-100, and V-500.



W&T V–100 GAS CHLORINATOR
wall mounted unit

Cylinder Mounted Chlorinators

Several companies make chlorinators that mount directly on a 100 or 150 pound cylinder. Common brands are Wallace and Tiernan, Capital Controls, Regal, and Fisher & Porter.

Cylinder Mounted Chlorinators
Capital Controls

Diffusers

Diffuser in Line

In order to properly mix the concentrated chlorine with the effluent there are two common processes. One is to use a diffuser placed in the effluent line just prior to the chlorine contact chamber. A typical diffuser is a 1/2" PVC pipe that is placed through a plug valve or gate valve. The diffuser is allowed to extend to 1/3 to 1/2 of the diameter of the effluent pipe. By extending the diffuser inside of the pipe the best possible mixing is assured.

Diffuser in Chamber

The second method is to place a pipe with holes, slots or a nozzle directly into the chlorine contact chamber. This type of diffuser is placed so that the flow into the chamber thoroughly mixes with the flow from the diffuser.

Safety Equipment

Respiratory Protection

Proper respiratory protection must be provided for any person who is handling gas chlorine containers. The most common protection is the self contained breathing apparatus (SCBA) and the canister gas mask. All personnel working with the chlorine system should be equipped with either a 10 minute escape SCBA or a cartridge or canister escape gas mask.

Regulation Requirements

Anytime an employee is expected to use a respiratory protection device, the employer is obligated to implement a respiratory protection program. This program must have at least the following elements:

- An evaluation of the types of potential hazards that require the use of respiratory protection.
- A written policy and written procedures on the proper use of respiratory protection.
- Initial respirator fit test and training of all personnel expected to use the respiratory protection.
- Monthly inspection of the devices.
- Annual retraining on the use of the devices.
- Documentation of the training and the evaluation.

Not in the Regulation

There is no federal regulation that requires the use of a SCBA when changing a chlorine cylinder.

Emergency Response

In order for an individual to respond to a chlorine emergency they must be trained as described in 29 CFR 1910. (The minimum training is the 40 hour hazardous material response training.) The responders must be part of an official emergency response team.

Repair Kits

Another safety item of consideration is the emergency repair kit. There are three different emergency repair kits.

- Kit “A” is for 100 and 150 pound cylinders.
- Kit “B” is for 1 ton containers.
- Kit “C” is for tank cars and tank trucks.

Use of the Kits

The kits must only be used by those individuals who are properly trained and part of an official hazardous material response team.

Finding Leaks

A strong ammonia solution is used to find a chlorine leak. In order to observe the leak the fumes from the ammonia are placed in the vicinity of the leak. When the ammonia fumes mix with the chlorine gas a white vapor or cloud will be formed.

Hypochlorite systems

Hypochlorites

Calcium Hypochlorite

Handling Calcium Hypochlorites

When mixing calcium hypochlorite the operator must wear chemical safety goggles, a cartridge respirator and rubberized gloves. Partially fill the vat with water before you add the powder. Placing powder into the vat first and then adding water could cause an explosion.

Storing Calcium Hypochlorite

Calcium hypochlorites should be stored in a cool, dry room away from oil, gas and other organic material. Calcium hypochlorite will ignite and burn at 350°F. Make sure the lid is closed tightly, check the container for cracks.

Sodium Hypochlorite

Handling Sodium Hypochlorites

When mixing sodium hypochlorites the operator must wear chemical safety goggles and rubberized gloves.

Hypochlorinator Feed Equipment

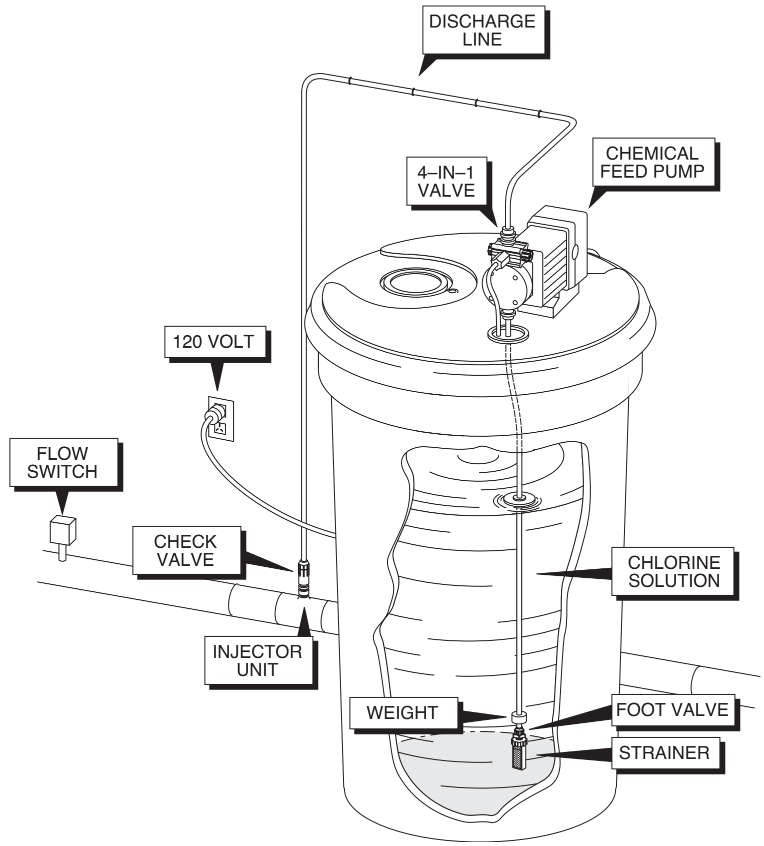
Basic Equipment

The most common hypochlorinator system is composed of a 20 to 50 gallon plastic tank in which a hypochlorite solution is mixed. This solution is pumped into the system using a chemical feed pump. The most common chemical feed pumps used in small wastewater systems are those manufactured by LMI, Wallace and Tiernan, and Pulsafeeder.

Piping System

To protect the pump, a strainer is placed on the end of the suction line. Also on the suction line is a weight and foot valve. The weight keeps the line in the solution and the foot valve helps to maintain the prime on the pump. On the end of the discharge line is another valve. This check valve prevents the water in the system from flowing back into the mixing tank.

Hypochlorite feed system



Routine Operations and Records

1. Check chlorine residual - daily
2. Determine quantity of chlorine used - daily
3. Determine chlorine dosage - daily
4. Clean injector and ball valves - monthly
5. Rebuild pump, clean and replace gaskets - annually
6. Replace foot and diffuser check valves - annually
7. Clean injector and pump check valves as needed.

Operational Considerations

Chlorine Residual

When chlorine is used as a disinfectant, it is desirable to keep the amount of chlorine entering a receiving stream at a minimum and at the same time provide disinfection. Therefore, effective operations would be to maintain as low a residual as possible without exceeding the fecal coliform requirements.

Chlorine and the Environment

Chlorine can be deadly to fish and other aquatic life. For instance salmon fry can be killed with chlorine levels of as little as 6 μg/L (micrograms per liter). Therefore, many treatment plants must either reduce their chlorine residual by dechlorination or use a disinfectant that does not harm the fish.

Other Uses of Chlorine

General Uses

Chlorine can be used in a wastewater collection system and treatment plant to: reduce odor, prevent destruction of pipe and pumping systems from hydrogen sulfide, control certain types of bacteria in the treatment process and prevent sewage from becoming septic.

Digester Sludge

While a few facilities use chlorine in an attempt to disinfect digester sludge the practice is not very effective. In an Arctic environment where the sludge freezes quickly the use of chlorine to disinfect the sludge is of no value.

Odor Control

One of the most common uses of chlorine other than disinfection is odor control. When using chlorine for odor control in a collection system it must be injected into the system upstream of the source of the odor. A common process is to inject the chlorine in the wet well of a lift station that is upstream of the problem. While this can cause damage to the pumps and station electrical system the benefit to resolving a serious customer service problem can often out weigh the repair cost.

Dechlorination

Why Dechlorinate?

One of the major concerns associated with the addition of chlorine to wastewater effluent is the impact the residual chlorine can have on the aquatic environment and more specifically on fisheries.

Do Not Add Chlorine

One obvious solution is to not add chlorine to the final effluent. While this may appear as a choice it also endangers downstream users. The failure to kill pathogenic organisms in wastewater effluent can be the major contributor to disease such as hepatitis in communities and villages downstream.

Dechlorination

When it is desired to prevent chlorine from damaging the aquatic environment a more reasonable approach would be to apply the chlorine at the head of the chlorine contact chamber and remove the chlorine residual as the effluent leaves the contact chamber.

Process Used

There are two common processes of dechlorination used by small communities. Either sulfur dioxide or sodium bisulfite can be fed in the final effluent.

Equipment

Sulfur dioxide is supplied as a compressed gas and is fed using a standard gas chlorine system. Sodium bisulfite is supplied as a liquid and is fed using a standard chemical feed pump system.

Lime Application

Uses

Lime can be effectively used to disinfect raw sewage spills and digested sludge. The best disinfection is obtained when the pH is at 11.5 or above.

Concentrations

Dry lime applied to a dry or frozen surface has little effect. The most effective lime application is obtained by mixing 1 part of lime to four parts water. This mixture is called “milk of lime.” This solution should be liberally applied to the material that you wish to disinfect.

Honey Buckets

One of the common methods of stabilizing honey bucket waste is with the “milk of lime” solution. Fill the bucket 1/2 full of “milk of lime” then fill the remainder with the contents from a honey bucket. Mix completely and allow to stand for 30 minutes to 1 hour before disposing.

Cautions

Hydrated Lime

The preferred lime for this treatment is $Ca(OH)_2$ calcium hydroxide, also called hydrated lime. This material is a very strong base and will burn the skin or mucous membranes of the nose and mouth. When added to water heat is generated. If the quantity of lime is too high for the volume of water, an explosion can occur.

Honey Bucket Caution

If dry lime is mixed directly with honey bucket waste containing urine, an extremely violent explosion can occur. This is a result of the reaction between the lime and ammonia.

Safety

Wear a dust respirator, chemical goggles, rubber gloves and rubber apron when handing the dry material. Gloves, goggles and an apron are recommended for handling the liquid.

Wastewater Disinfection

Worksheet

1. _____________ microorganisms cause disease.

2. Wastewater is disinfected in order to prevent ______________.

3. The tank used to provide contact time for disinfection in a wastewater treatment plant is called the __________________ _________________ chamber.

4. What does mg/L stand for? Is this the same as PPM?

5. The quantity of a chemical added to the water is called the ______________. The quantity of chemical used in a reaction is called the _________________, and the quantity of chemical remaining after the reaction is called the ____________________.

6. ________________ time is the length of time water is kept in a basin.

7. Define disinfection: ____.

8. The ultimate test for disinfection is a bacteriological test for the _______________ _______________ bacteria.

9. Name two methods commonly used to disinfect wastewater other than chlorination.
   a. _____________________________
   b. _____________________________

10. ________________ is the most common disinfection process used in the United States.

11. Gas chlorine is shipped in ___________ lb and __________ lb cylinders and __________ ton containers.

12. Chlorine gas is classified by OSHA as a _______________ and an _____________ hazard. At room temperature this gas is ___________ times heavier than air. A leak of gas can be seen by using ______________ ______________.

13. Chlorine gas is _________________ ________________ in color.

14. One part of pure liquid chlorine will evaporate to form ________ parts pure chlorine gas.

15. List four items that affect the germicidal efficiency of chlorine.

    ____

    ____

    ____

    ____

16. Typical detention time in a chlorine contact chamber ranges between _______ and ________ min.

17. The door to a gas chlorine room should open ❑ in or ❑ out.

18. List four things that you would consider important in a quality gas chlorine storage area:

    ____

    ____

    ____

    ____

19. Chlorine cylinders should be chained up a distance of ____________ from the bottom

20. The wrench used to open a chlorine cylinder should not be longer than _________ inches.

21. What will cause a chlorine cylinder to gather frost on the outside?

22. Fusible plugs on a chlorine cylinder will melt between _________ °F and _________ °F.

23. When changing a chlorine cylinder a gasket is placed against the cylinder valve. These gaskets are supplied by the chlorine vendor and are made of ___________ or ___________ ____________.

24. There are two hypochlorites used to disinfect water: ____________ hypochlorite which is commonly a liquid and _______________ hypochlorite which is commonly a powder.

25. When a chlorine residual is required in wastewater effluent, the type of residual tested for is commonly _____________ chlorine residual

26. The best pH range for disinfection is between _____ and _______.

27. Identify the items indicated on the drawing.

A. ______________________________

B. ______________________________

C. ______________________________

D. ______________________________

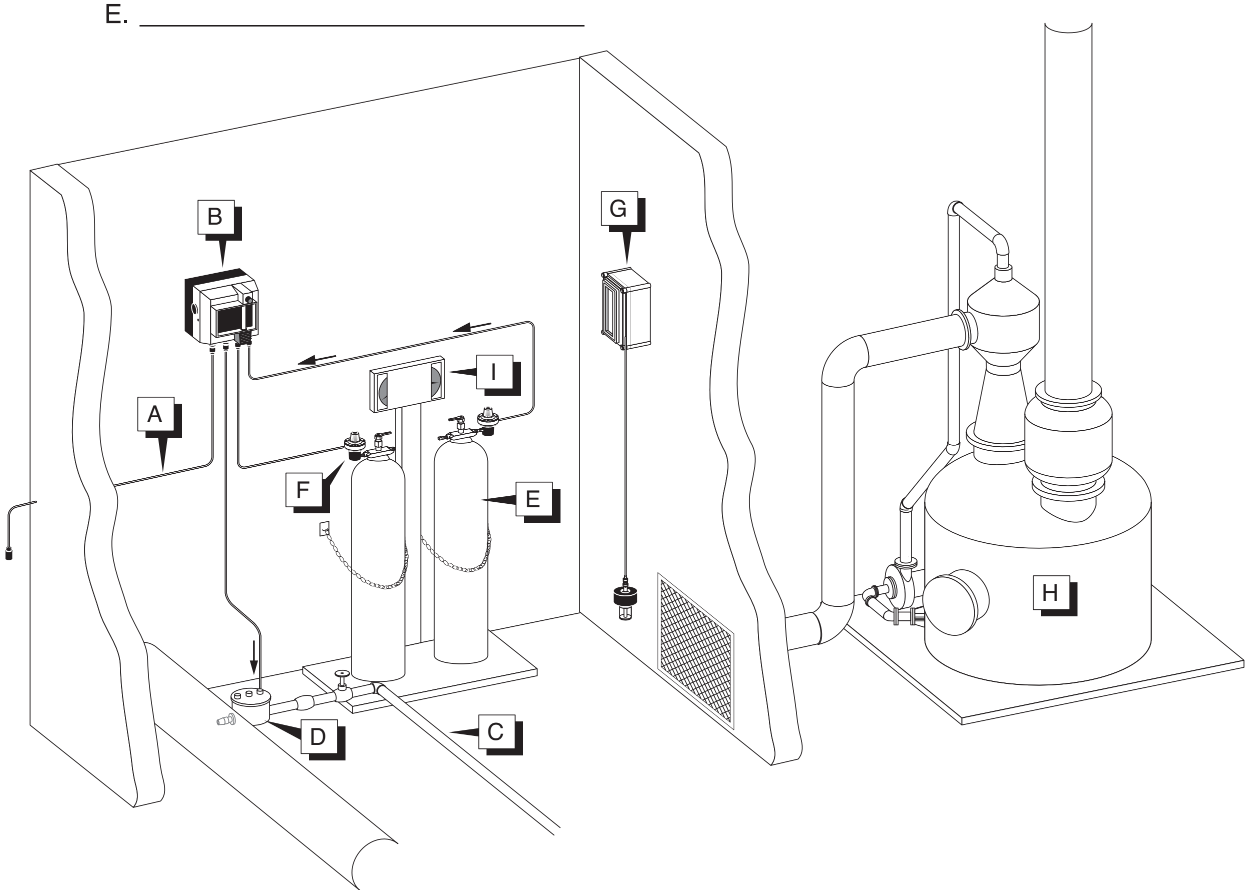
E. ______________________________

F. ______________________________

G. ______________________________

H. ______________________________

I. ______________________________



28. From the drawing to the right, identify the items indicated to the list.

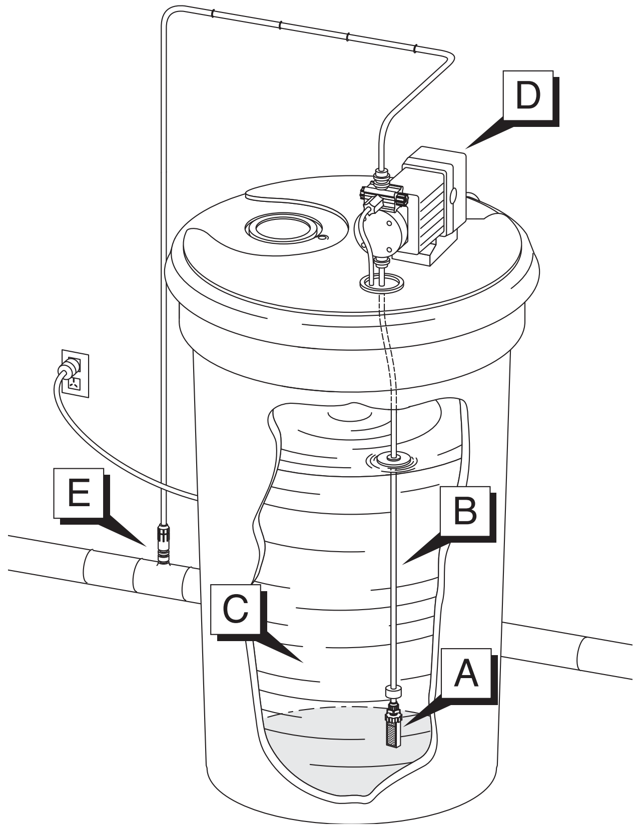
A. ________________________________

B. ________________________________

C. ________________________________

D. ________________________________

E. ________________________________



Wastewater Laboratory

What is in this Lesson?

1. Common equipment used in a wastewater laboratory
2. How to use the meniscus to properly measure a liquid volume
3. The basic laboratory techniques of pipetting and titration
4. Common laboratory safety procedures and techniques
5. The three different types of samples
6. A description of a good sample location
7. Which tests are best determined from grab samples
8. The hold time and temperature for biological samples
9. The three cardinal rules to sampling.
10. When during the flow cycle grab samples should be taken for BOD and TSS
11. When in the daily flow cycle chlorine residuals should be taken
12. The basic procedure for running a BOD, TSS, settleable solids, fecal coliform, pH and chlorine residual
13. The procedure for performing a settleometer test
14. How to measure the sludge blanket in an activated sludge plant final clarifier
15. The difference in settling (SVI) of young and old sludge
16. What “good” sludge will look like in a settleometer
17. The function and use of QA/QC
18. Proper recordkeeping procures

Key Words

- BLT
- BOD
- DMR
- DOB
- Fecal Coliform
- MLSS
- MSDS
- NIST
- NFR
- NPDES
- pH
- QA/QC
- Sludge Blanket
- SVI
- TSS

Wastewater Laboratory

Introduction

Level of Material

The material in this lesson is presented at a beginning level. There has been no assumption that the reader is familiar with wastewater laboratory equipment or procedures. Only a general discussion is provided for routine laboratory testing. There has been no attempt to provide step-by-step procedures for the tests discussed in this lesson. The goal is to provide the user with a general understanding of the common laboratory procedures used in a typical wastewater laboratory in a small treatment plant.

Reference Text

There are numerous reference books available that provide step-by-step procedures for all of the laboratory tests that are normally conducted by an operator. Contact EPA, the Water Enviroment Federation or the local state enviromental agency for information on these books.

Commercial Laboratories

Many small systems prefer to utilize a commercial laboratory to perform the testing that is required by their discharge permit (permit testing). However there are lab tests that help an operator control their treatment processes (process control testing). A basic understanding of both types of testing can be useful for the entry level operator.

Content

This lesson contains the following sections:

- Equipment
- Laboratory Safety
- Sampling Procedures
- Testing
- Process Control Testing
- **QA/QC**[1]
- Record Keeping

[1] **QA/QC - Quality Assurance - Quality Control -** The formal process of assuring the laboratory is performing testing in the most accurate and precise manner possible in order to comply with specified regulations.

Equipment

Limitations

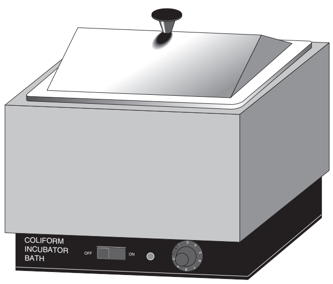
A typical wastewater laboratory could contain a wide variety of special equipment. The following discussion provides information on only that equipment discussed in the test procedures provided in this lesson.

Hardware

BOD Incubator

In order to perform a **BOD**[2] test an incubator capable of maintaining a 20°C temperature must be used. This device usually looks like a refrigerator, with racks for the BOD bottles and a temperature controller. A thermometer is often placed in the door of the incubator.

Water Bath Incubator

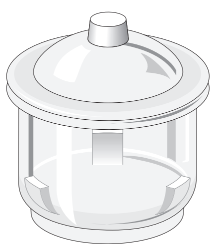


The incubator required to perform the fecal coliform test must be capable of maintaining a temperature of 44.5°C within 0.2°C. A water bath incubator is frequently used. This device looks like a rectangular metal basin. Water is placed inside the basin. The temperature is maintained by a heating element at the bottom of the basin and a lid that keeps the heat from escaping. This type of incubator is capable of maintaining the strict temperature requirement for the fecal coliform test.

Drying Oven

A small oven that looks like a rectangular metal box is used to maintain the proper temperature to dry filters for the suspended solids and mixed liquor suspended solids tests.

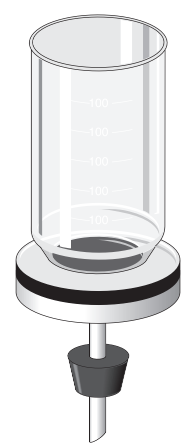
Desiccator



A desiccator is a glass or plastic device that looks similar to a salad bowl with a lid. The device is used to allow heated samples to cool without taking on moisture from the air. To prevent moisture from entering the samples a material called desiccant is placed in the bottom of the desiccator. This material absorbs moisture.

Fecal Filter Apparatus

A special stainless steel or plastic funnel and filter holder are used to run the **fecal coliform**[3] test. The bottom of this device is mounted in a rubber stopper that will fit into a filter flask. The top of the funnel secures to the bottom by a 1/4 turn twist or a magnet.



[2] **BOD** - Biochemical (BY-oh-KEM-ih-kul) Oxygen Demand - The quantity of oxygen required by microorganisms when stabilizing decomposable organic matter under aerobic conditions at 20° C.

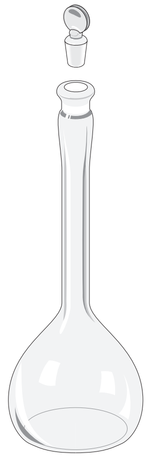
[3] **Fecal Coliform** - The Fecal coliform group of bacteria is a bacterial indicator of contamination. This group has as one of its primary habitats the intestinal tract of human beings. Coliforms also may be found in the intestinal tract of other warm-blooded animals. Also called E. Coli or Escherichia Coli.

Autoclave

In order to sterilize the equipment needed to perform the coliform test an autoclave is needed. This device allows the development of high temperatures and pressures needed to kill all microorganisms. An autoclave is very similar to a pressure cooker.

GlassWare

Volumetric Flasks



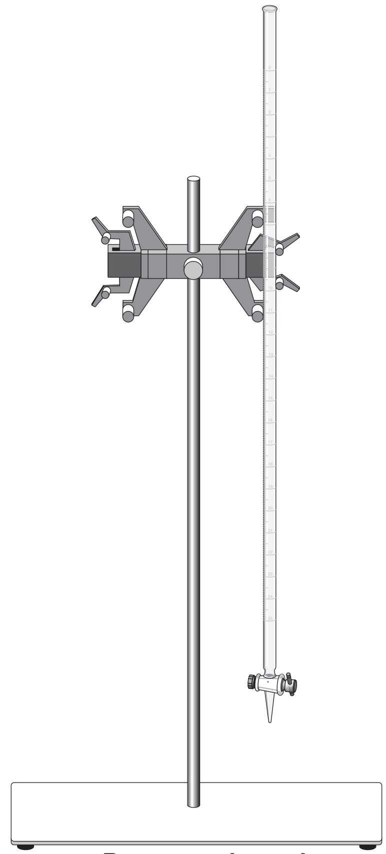
In order to measure large volumes of liquid accurately, a volumetric flask is used. These devices have only one measurement point. This point is a line etched on the neck of the flask. Various sizes are available.

Pipettes

In order to measure small volumes of liquids accurately a pipette is used.

Burettes

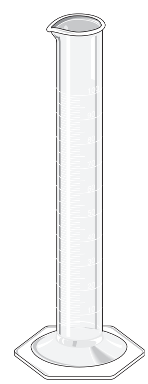
In order to deliver precise volumes of fluid at a controlled rate a long glass tube called a burette is used. This tube is fastened into a stand and filled from the top. The flow is controlled by a small valve on the bottom.



Burette and stand

Graduated Cylinders

Graduated cylinders are glass or plastic cylinders that have a scale marked to the nearest milliliter etched onto their sides. Graduated cylinders are used to measure sample volumes. While fairly accurate, they are not as accurate as volumetric flasks.



Beakers

Beakers are glass or plastic containers used in a laboratory. While they have a scale on the side that indicates their volume they are the least accurate of all of the glassware. They are used to hold samples, mix solutions and other general tasks in the lab.

Erlenmeyer Flasks

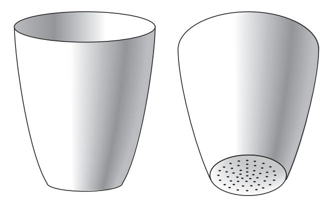
A special flask called an Erlenmeyer flask is used to titrate samples. (See titration discussion). These flasks have a large flat bottom and taper to a narrow top to prevent spilling when the contents are mixed.

Vacuum Flask

Vacuum flask are used in the fecal coliform and suspended solids test. The vacuum flask is made like an Erlenmeyer flask except there is a connection near the top of the flask for a vacuum source.

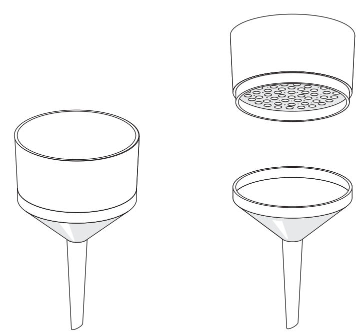
Gooch Crucible

One of the suspended solids test procedures requires the use of a ceramic device called a Gooch Crucible. This device is funnel shaped with small holes in the lower end. The Gooch is placed in a rubber holder in a vacuum flask and a glass fiber filter is placed inside.

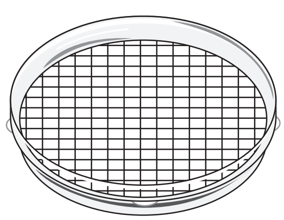


Buchner Funnel

The Gooch crucible is too small to allow filtration of a large volume sample that contains a high concentration of solids, like mixed liquor. To measure the mixed liquor suspended solids a buchner funnel is used. This is a large ceramic or plastic funnel with holes in a plate that has been formed inside the funnel. A glass fiber filter is placed on the plate and the funnel placed in a rubber holder in a vacuum flask.



Petri Dish



A petri dish is a small flat glass or plastic dish with a lid. Media and bacteriological samples are placed in the petri dish which is placed in an incubator. There are a wide variety of petri dish sizes available.

BOD Bottle

The BOD samples are incubated in special 300 mL bottles called BOD bottles. These bottles are accurate to within 1 mL. Air is prevented from entering the bottle because of a special ground glass stopper.

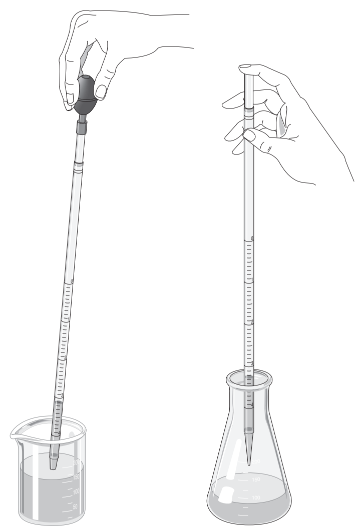
Basic Laboratory Techniques

Introduction

In order to understand the following laboratory testing procedures it is necessary to explain three basic laboratory techniques. These are pipetting, titrating and reading liquid volumes.

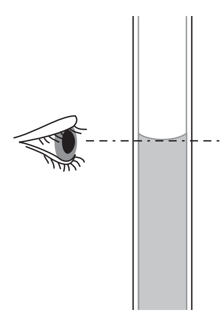
Pipetting

Liquid is drawn into a pipette by use of a vacuum placed on the top of the pipette. This vacuum is commonly created with a rubber bulb that is placed over the end of the pipette. The flow of liquid out of the pipette is controlled by placing the end of one finger over the opening at the end of the pipette. While this sounds easy it takes considerable practice to be able to perform this task with high accuracy.



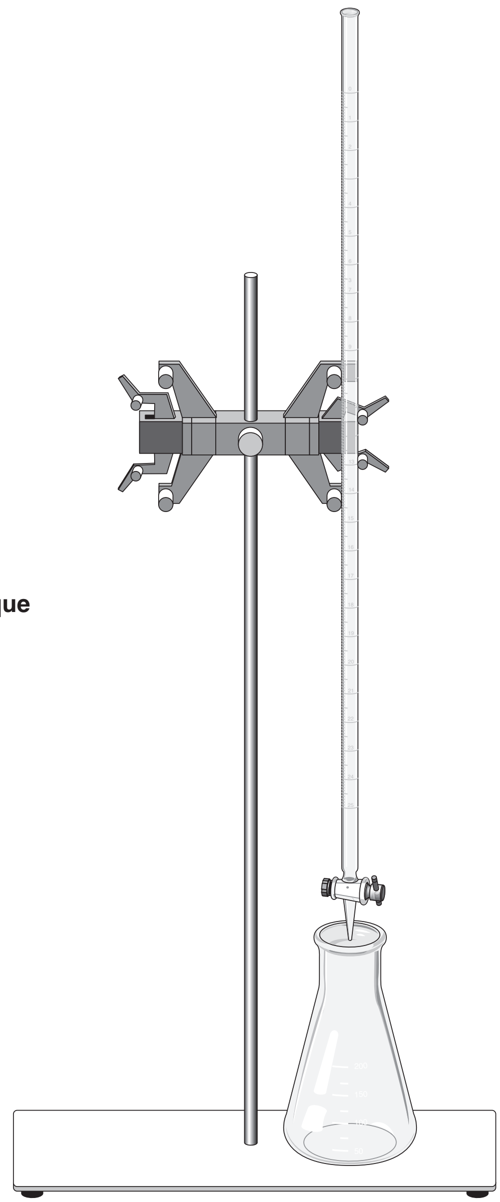
Reading volumes

When a fluid is placed in a glass measuring device such as a graduated cylinder, volumetric flask, pipette or burette the quantity must be recorded. Most fluids adhere to the side walls of a glass container. In doing this the surface becomes concaved. This concaved surface is called a meniscus. To properly read the level of fluid in a glass device, read along the bottom of the meniscus.



Titrating

Titrations are performed in many of the test procedures. This process requires a burette and erlenmeyer flask. A sample and some chemical are placed in the flask. A second chemical is placed in the burette. When the two chemicals mix a color is developed or they cause a color to disappear. The normal procedure is to twirl the flask while allowing a controlled rate of flow from the burette to enter the flask. When a specific color point is reached the volume used is determined from the burette and used to calculate the concentration in the flask. This procedure is a little like rubbing your stomach with one hand and patting your head with the other.



Titration Technique

Laboratory Safety*

Introduction

Preventing Hazards

The wastewater laboratory is not necessarily a dangerous place. However, when the laboratory is used by inexperienced and/or careless operators accidents can easily happen. The basic tests covered in this manual requires a minimum of laboratory experience and are not highly hazardous as long as basic safety precautions are observed.

Procedures

Proper procedures and techniques can be placed into two general groups: 1) personal protection and 2) proper handling of chemicals and bacteriological materials.

Personal Protection

Introduction

The most important aspect of laboratory safety is to protect yourself and others around you.

Eye Protection

Eyes must be protected from splashing chemicals, chemical dust, high pressure water and broken glass. Protection is provided by wearing chemical safety glasses or goggles anytime the operator is performing laboratory tests, handling glassware or chemicals.

Safety Equipment

Each wastewater laboratory should be equipped with the following safety equipment:

- Fire extinguisher - halon, dry chemical or CO_2
- Fully equipped first-aid cabinet
- Fire blanket
- Chemical eye-wash

Operators should be trained in the use of this equipment and know its location.

Pipetting

When transferring chemicals or measuring a sample with a pipette, always use a pipette fill bulb. **Never suck the solution into the pipette with your mouth.**

Handling Samples

Wastewater samples should not be handled with bare hands. Use disposable latex gloves to protect against infections.

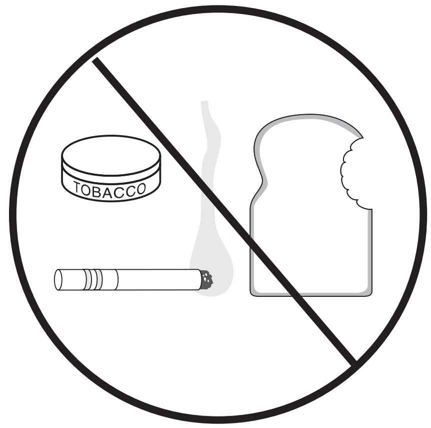
Wash-Up

To prevent the transfer of chemicals to the eyes and the transfer of disease, wash hands with hot water and soap after handling sewage samples.

* The author wishes to thank and acknowledge Linn-Benton Community College and Dr. Carnegie for their contribution to the safety portion of this lesson. The material provided for this section was gleaned from the Linn-Benton Water and Wastewater Laboratory Manual.

Eating

To prevent accidental intake of chemicals or ingesting pathogenic organisms, never use laboratory glassware for serving food or drink. Never smoke in a laboratory. Never eat or drink in a laboratory.



Labels

Containers of chemicals received from a manufacturer have the proper labeling. When a chemical is transferred to a storage bottle the following information must be placed on the label:

- Name of chemical
- Chemical formula - if known
- Concentration
- Date
- Initials of the person preparing the container.

In addition it is desirable to place an **NFR**[4] label on the container. If the container is removed from the treatment plant the NFR label must be on the chemical.

Handling Chemicals and Samples

Introduction

The wastewater operator may be required, as part of the job, to handle a variety of hazardous materials. It is beyond the scope of this manual to discuss all of the chemicals an operator may encounter in the lab. Caution: chemicals which are handled improperly, or randomly mixed together can produce heat, toxic fumes or even explode. In order to properly handle, control and dispose of these materials it is important that the operator review the **MSDS**[5] for each chemical used with care. The following is a brief and general discussion of handling precautions. However, this information does not substitute for the MSDS.

[4] **NFR** - National Fire Rating System - This system provides the users of chemicals with a four diamond placard that indicates the health concern, flammability, and reactivity levels of the chemical.

[5] **MSDS** - (Material Safety Data Sheet) A document produced by a chemical manufacturer and/or supplier. The document contains information on, health effects, safe handling and use of the chemical, how to store and how to handle a spill.

MSDS

A current MSDS must be on-site for each chemical that is in the laboratory. It is the responsibility of the employer to see that each person who may use a chemical is aware of the location of the MSDS and has been trained in how to read the MSDS.

Corrosive Chemicals

Acids

Examples

Operators may handle sulfuric, hydrochloric, nitric and glacial acetic acids. All acids are classified as corrosive and may cause burns to the skin if contacted.

Spills

The specifics on how to handle a spill are found in the MSDS. However, in general the spill may be controlled by dilution with large and immediate quantities of water or neutralized with sodium bicarbonate. The spill area should then be cleaned and dried.

Contact with Skin

Contact with acids can quickly cause severe burns to the skin. The area should be immediately washed with large quantities of cool water and neutralized with sodium bicarbonate.

Pipetting

As with other materials, acids should only be pipetted using a pipette bulb.

Diluting with Water

When diluting an acid with water, always add the acid to the water. **Never add the water to the acid.**

Bases

Examples

Operators and laboratory technicians may handle sodium hydroxide, potassium hydroxide, and ammonium hydroxide. These are all strong bases that are corrosive to clothing and can cause burns to the skin. First aid is provided by immediately washing the area with large quantities of cool water.

Infectious Material

The Concern

While it is unlikely that an operator would contract a disease while handling wastewater samples or bacteriological samples at a wastewater plant, the possibility does exist. An operator can prevent disease by following a few simple rules.

Open Wounds

Sewage and sewage samples contain bacteria, viruses and protozoa that can cause disease. One of the methods of contacting these microorganisms is through breaks in the skin. Keep wounds covered by wearing disposable latex gloves when handling sewage samples.

Ingestion

When handling sewage samples or fecal coliform plates it is easy to transfer microorganism to the hands and then transfer them to your mouth while eating or smoking. Therefore, wash your hands thoroughly after handling samples, even if latex gloves are worn.

Clothing

In the performance of routine wastewater laboratory work the operator can easily collect pathogenic microorganisms onto their clothes. These microorganisms can then be transferred to the home. Therefore, change clothing at the plant and wash up before going home. If a shower is available, it is a good idea to shower and change clothes before leaving the plant.

Sampling Procedures

Must be Representative

Sampling is often the most neglected technique in laboratory control testing. A sample must accurately represent the body of water intended for study. Although a test may be performed carefully and accurately, the result is meaningless if the sample is not representative of the water source from which it was taken.

Obtaining Representative Samples

Over the years operators and technicians have developed specific sampling techniques and procedures that, when used properly, provide representative samples. These are called the principles of sampling.

Principles of Sampling

Three Cardinal Rules

Wastewater samples are taken from a wide variety of locations under many different conditions. Sampling sites should be selected to meet the requirements of the information desired. Sampling methods should be carefully considered. Regardless of the site or method chosen, there are Three Cardinal Rules that apply to all samples. They are cleanliness, documentation and preservation.

Cleanliness

Appropriate Cleanliness

All containers including caps and measuring devices with which the sample comes in contact must be cleaned.

Example

Process control samples should be taken in containers washed in soap and water. Fecal coliform samples must be taken in a special sterilized container.

Documentation

Label Information

The sample label should note:

- The type of sample
- Source the sample is collected from
- Location of sampling point
- The date and hour sampled
- Name of sampler
- The temperature of the sample
- Recent weather conditions
- Flow at time of sampling

Location Expanded

A sample is only a representation of the conditions at the point of sampling. For example, the conditions in an aeration basin may vary greatly from one end of the basin to the other. Therefore, it is imperative that the exact basin sample location be included in the documentation. For example, we would write "east end of basin two feet back of overflow weir". We would **not** write "sample taken from aeration basin".

Preservation

Why?

Samples may contain living organisms which continue to grow unless the life processes are slowed by lowering temperatures or halted by addition of chemicals. In addition, chemical degradation can also occur if samples are not properly preserved and stored prior to testing.

Preservation Methods

The correct form of preservation must be practiced, and will vary with the type of sample. In general, samples containing living organisms (bacteriological samples) may be preserved up to 6 hours if refrigerated at 4˚C. Chemical samples may need to be stored out of the light or have a specific chemical added.

Other Sampling Considerations

Representative Location

Samples must be selected from a location that is representative of the conditions. Typically, this is a location where the flow is well mixed.

Number and Volume

In order for the sampling to be representative, there must be the proper number and volume of samples collected.

Large Particles

Large particles should be excluded from the sample. They are not representative of the sample stream.

Deposits and Growths

Deposits and growths that have accumulated at the sampling site must be avoided in the sample.

Aseptic Conditions

The process of maintaining the quality of a bacteriological sample is called aseptic handling. This means avoiding contamination from skin, clothing, equipment, water, and adjacent surfaces.

Data

Unless the proper data is recorded with the sample the sample is not valid.

Mixing

Always mix the sample before removing a portion.

Time Frame

Samples should be tested as soon as possible – always within the permissible time interval after sampling.

Summary

A good sample location is one where the flow is well mixed, has easy access and the flow is representative of the overall conditions.

Types of Samples

Three Types

There are three types of samples collected by wastewater plant operators:

- Grab samples
- Composite samples
- Proportional composite samples

Each type of sample has its proper function.

Grab Samples

Definition

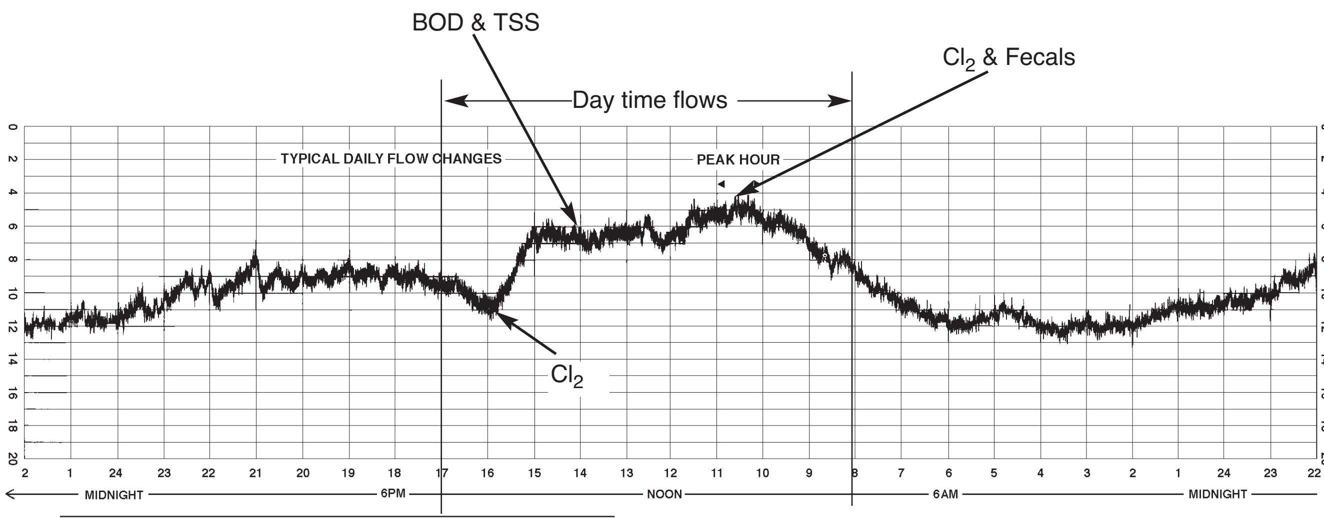
A "grab" sample is a sample that is taken at one particular time. Grab samples are taken because they are required or because there is a lack of time to collect composite samples. For some tests, grab samples are preferred.

Use of Grab Samples

Tests such as residual chlorine, dissolved oxygen, and **pH**[6] are determined from grab samples because they cannot be preserved and a grab sample is the most representative.

Sampling & Flow - Chlorine

If only one chlorine residual sample can be taken per day, it is best to take this sample at peak flow. Chlorine residuals are normally at their lowest during peak flow. This is because, even with flow proportional chlorinators the feed rate is not increased at an exact proportion to flow. If at all possible chlorine residual samples should be taken at minimum and at peak flows. This will provide the operator with a view of the residual ranges found in the effluent. If the effluent discharges into a fisheries sensitive stream the maximum chlorine residual in the effluent is an important value to monitor.



[6] **pH** - An expression of the intensity of the basic or acidic strength of a water. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion concentration. pH may range from 0 to 14, where 0 is the most acid, 14 most alkaline, and 7 neutral.

Sampling & Flow - Fecals

Because fecal coliform numbers in the final effluent are directly related to chlorine levels it is best to sample for fecal coliform at the same time that samples are collected for chlorine residuals.

Sampling for TSS and BOD

When it is necessary to collect grab samples for BOD and TSS the following considerations can be used to determine when to sample:

- When a system experiences high I & I the BOD and TSS may be minimum during high flows. However, if the plant is hydraulically flooded, the BOD and TSS may be at their highest at the start of the flooding. At the start of flooding solids are commonly being washed out of the plant.
- When a system experiences normal flows, sampling at average flow will provide adequate results.

Sampling for pH

In order for pH readings to be representative of the plant conditions they should be taken at maximum and minimum flows. If, due to time constraints, they can only be taken once a day, then they should be taken at the same time each day.

Composit Samples

Definition

A composite sample is a series of grab samples poured together to make one sample. The simplest type of composite sample consists of grabs of equal volume and is applicable only to situations of uniform flow.

Use of Composite Samples

A composite sample is only representative if the flow at the point of sampling remains constant throughout the sampling period.

Flow Proprotional Composit Samples

Definition

In proportional composite samples, the volume of each portion is adjusted to the flow at the time the portion is collected. All portions are mixed together to produce a final sample representative of the flow during that particular collection period. Composite samples are representative of the character of the flow over a period of time. The effects of intermittent changes in strength and flow are eliminated. The portion collected should be obtained with sufficient frequency to obtain average results.

Uses of Flow Proportional Samples

Biochemical oxygen demand, settleable solids, and suspended solids tests are best determined from proportional composite samples.

Discharge Permit Required Lab Testing

Requirements

The EPA Wastewater Discharge Permit specifies which lab tests will be required of a specific plant. This section covers the most common of these required tests. All permit dischargers are required to perform and report specific laboratory tests.

Federal and State Permits

State wastewater discharge permits are issued by the local state agency. EPA may issue federal permits under the National Pollution Discharge Elimination System (**NPDES**[7]).

The following material is a discussion and description of the listed tests, no intent for step-by-step instruction is implied.

DO (Dissolved Oxygen)

Two Methods

There are two accepted methods of measuring the dissolved oxygen content of a sample. One method is to use a special DO meter with a probe which measures the DO directly. The second method is a chemical method called the Winkler Method.

DO Meter

The advantage of the DO meter is the ability to obtain fast readings.

Winkler Method

The Winkler method is much more complicated, but can be used to check the accuracy of the D.O. meter and probe.

BOD (Biochemical Oxygen Demand)

Introduciton

Definition of Test

The biochemical oxygen demand (BOD) is defined as the quantity of oxygen used in the biochemical oxidation of organic matter in a specific time, at a specific temperature, and under specific conditions. The standard BOD test performed on domestic wastewater is carried out for 5 days at 20° C.

Measure Strength of Sewage

The BOD test is used as a measure of the organic strength of sewage. If the sewage is strong, for example, it will contain a large amount of decomposable organic material. In such a case, the oxygen requirement and BOD would be high. Sewage containing low amounts of decomposable organic materials would have a small BOD or low oxygen demand.

[7] **NPDES** - **N**ational **P**ollutant **D**ischarge **E**limination System permit is the regulatory agency document designed to control all discharges of pollutants from point sources into U.S. waterways. NPDES permits regulate discharges into navigable waters from all point sources of pollution, including industries, municipal treatment plants, large agricultural feed lots and return irrigation flows.

Ranges

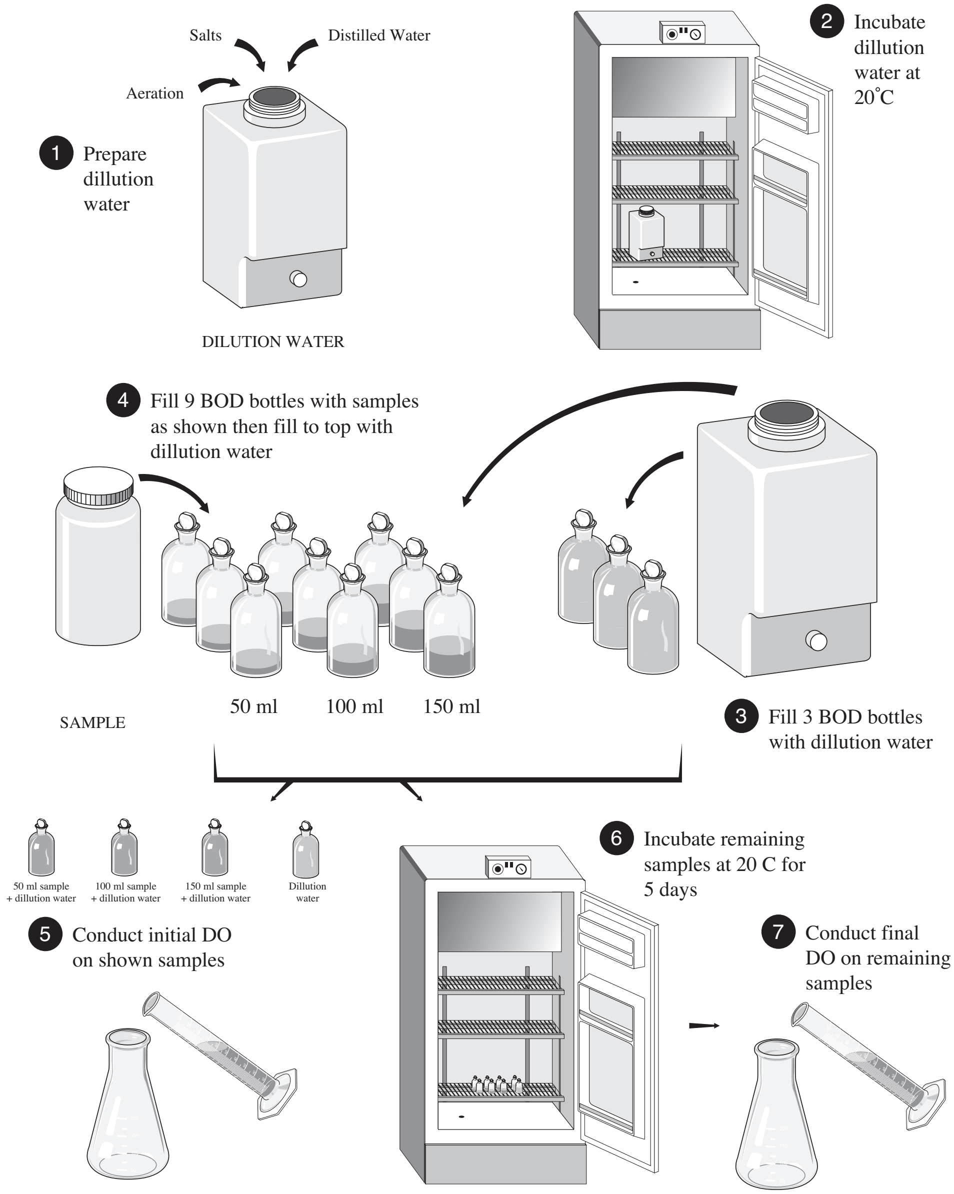
Typical BOD ranges are:

Raw Domestic Sewage	100 - 300 mg/L
Primary Effluent	50 - 150 mg/L
Secondary Effluent	15 - 30 mg/L

General Description

The test is performed by adding a known amount of wastewater (or effluent) to a 300-milliliter BOD bottle. Aerated distilled water with special nutrients and buffers needed for bacterial activity called dilution water is added to the sample in the bottle. The bottle is sealed to prevent oxygen from entering or escaping and incubated for 5 days at 20°C. The dissolved oxygen measured at the end of the test is compared to the amount recorded at the beginning. The decease in oxygen is then converted to mg/L of oxygen used by the microorganisms present in the sample.

BOD Procedure Sequence



BOD Calculations

BOD = (IDO - FDO) x DF

IDO = Initial DO of sample

FDO = Final DO of sample

DF = Dilution Factor (300 mL / mL of sample added to bottle)

BOD Example

IDO = 8.0

FDO = 4.0

DF = 10 (300 / 30 mL of sample added to bottle)

IDO of dilution water 8.0 mg/L

FDO of dilution water 7.8 mg/L

BOD = (8.0 - 4.0) x 10

= 40 mg/L

TSS (Total Suspended Solids)

Introduction

Description

Total suspended solids (**TSS**[8]), also called suspended solids, are those solids which can be trapped on a glass fiber filter. Suspended solids will also include settleable solids.

Use of TSS

The suspended solids test is one of the primary criteria used to evaluate effluent quality. A well-run RBC plant should operate below 30 mg/L of suspended solids in the final effluent and an activated sludge plant below 10 mg/L suspended solids in the final effluent.

TSS Ranges

Typical ranges for TSS would be:

Raw Sewage	150 - 400 mg/L
Primary Effluent	60 - 160 mg/L
Secondary Effluent	5 - 30 mg/L

General Description

This test is performed by filtering a given volume of sewage (influent, effluent or mixed liquor), drying and weighing the filter on an analytical balance to determine the increase in weight from the solids captured on the filter.

[8] **TSS - Total Suspended Solids** - The quantity of material deposited when a quantity of water, sewage, or other liquid is filtered through a glass fiber filter.

Calcualtions

$$TSS\ mg/L = \frac{Sample\ \ Wt, g\ X\, 1{,}000}{Sample\ \ Volume, L}$$

EXAMPLE

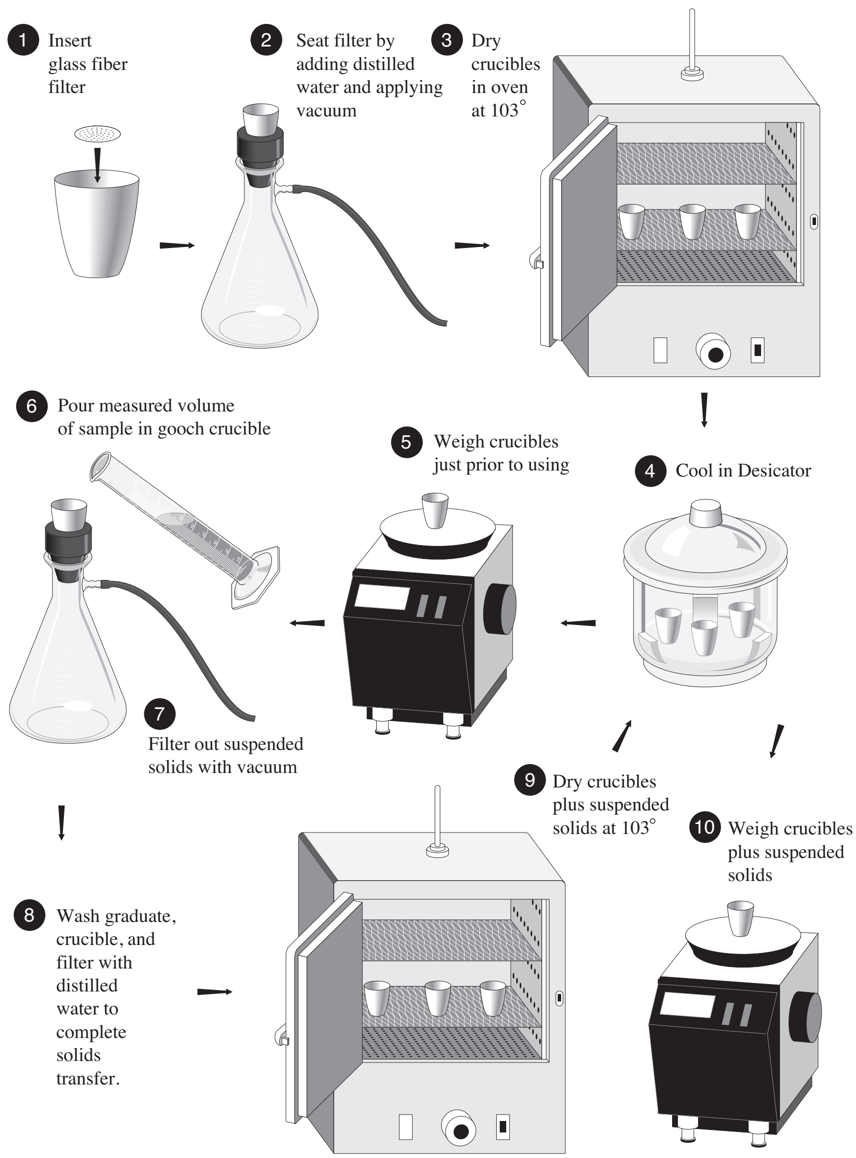
A 100mL sample was filtered with the following results.

Pan plus filter plus sample	10.6501 g
Pan plus filter	10.6245 g
Sample	0.0256 g

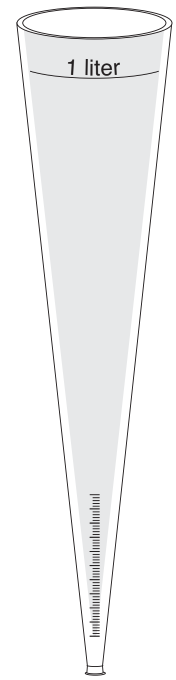
for 100 mL sample

$$TSS\ mg/L = \frac{0.02567\, g\ X\, 1{,}000}{0.1\, L}$$

TSS Procedure Sequence



Settleable Solids



Description

The settleable solids test is performed by pouring one liter of a sample into a tapered glass or plastic cone called an imhoff cone. The sample is allowed to stand for one hour. All solids that settle in the hour are measured in milliliters. Settleable solids are reported in milliliters per liter (mL/L).

pH

Introduction

Definition

pH is a measure of hydrogen ion (H^+) concentration and is generally used to describe a system as being acidic or basic.

Function of Test

pH measurements are taken at various points throughout treatment plants. Any abnormal readings can be an indication of an upset system. Abnormal raw sewage pH can be a clue to imminent plant problems.

Equipment

Methods

There are two methods used to measure pH; the electronic pH meter and the color comparator device.

Color comparators are acceptable for in-plant control checks. pH measurements for **DMR's**[9] are to be made with the meter only.

pH Meter

The heart of the pH meter is the probe. At the end of the probe is a semipermeable glass bulb. Inside the bulb is a solution of potassium iodide and two wires. In order to measure pH some fluid must pass through the bulb. The measurement is converted into an electrical potential which is recorded on the meter scale.

Standardizing

When using a pH meter, it is necessary to standardize the meter using a solution called a standard buffer. The three most common standard buffers are pH 4, 7 and 10. The instrument should be calibrated each day prior to use with two fresh pH buffers. Two pH buffers spanning the range of the samples should be selected.

Rinse the Probe

After the meter has been standardized the probe should be rinsed with distilled water.

[9] **DMR - Discharge Monitoring Report** - The form that is used to report effluent quality and quantity to a state agency or EPA.

Chlorine Residual

DPD

Introduction

Reason for the Test

The amount of chlorine remaining in wastewater effluent is important to water quality and as assurance that any waterborne pathogen which may enter the receiving stream has been effectively destroyed.

Using DPD

The DPD method is acceptable to measure wastewater treatment effluent chlorine residuals. DPD color comparators are not approved by EPA for NPDES monitoring; however, these kits have been approved for use by the ADEC.

Sampling

Samples for chlorine residual cannot be stored or transported. They must be tested within ten minutes of collection.

Equipment

Color Comparators

A color comparator is a device utilizing a color wheel or color bar and one or two glass sample cells. A chemical (DPD) is placed in one of the sample cells with 5 mL of the water to be tested. The DPD reacts with the chlorine to form a pink color. The intensity of the pink color is directly related to the chlorine concentration. The color of the sample is compared visually with the color wheel or bar and the chlorine residual determined.

Spectrophotometer

The use of a small, hand-held and portable spectrophotometers is a relatively new addition to the chlorine residual measuring process. This device uses the DPD chemical to develop a pink color which is directly related to the chlorine concentration. A light source and special filter allow the intensity of the color to be determined electronically and the results shown on an analog meter. The spectrophotometers have proven to be much more precise and reliable than the color comparators and provide a high level of repeatability.

Fecal Coliform

Membrane Filtration Technique

Introduction

Function of Test

The fecal coliform test is one of the basic monitoring parameters required by most discharge permits. Coliform bacteria can be of fecal or non-fecal origin. Fecal coliform is an excellent indicator of fecal contamination since it lives in the intestines of warm-blooded animals. The concentration of fecal coliforms in chlorinated wastewater measures the effectiveness of the disinfection process.

Selection Process

Members of the fecal coliform group can be differentiated from other coliforms found in other environments by use of specific selective media and incubation at elevated temperatures. The test used is the same as the Standard Total Coliform Procedure except for culture medium, incubation temperature, and colony characteristics. Typical fecal coliform colonies develop after 24 hours incubation at 44.5 ± 0.2° C.

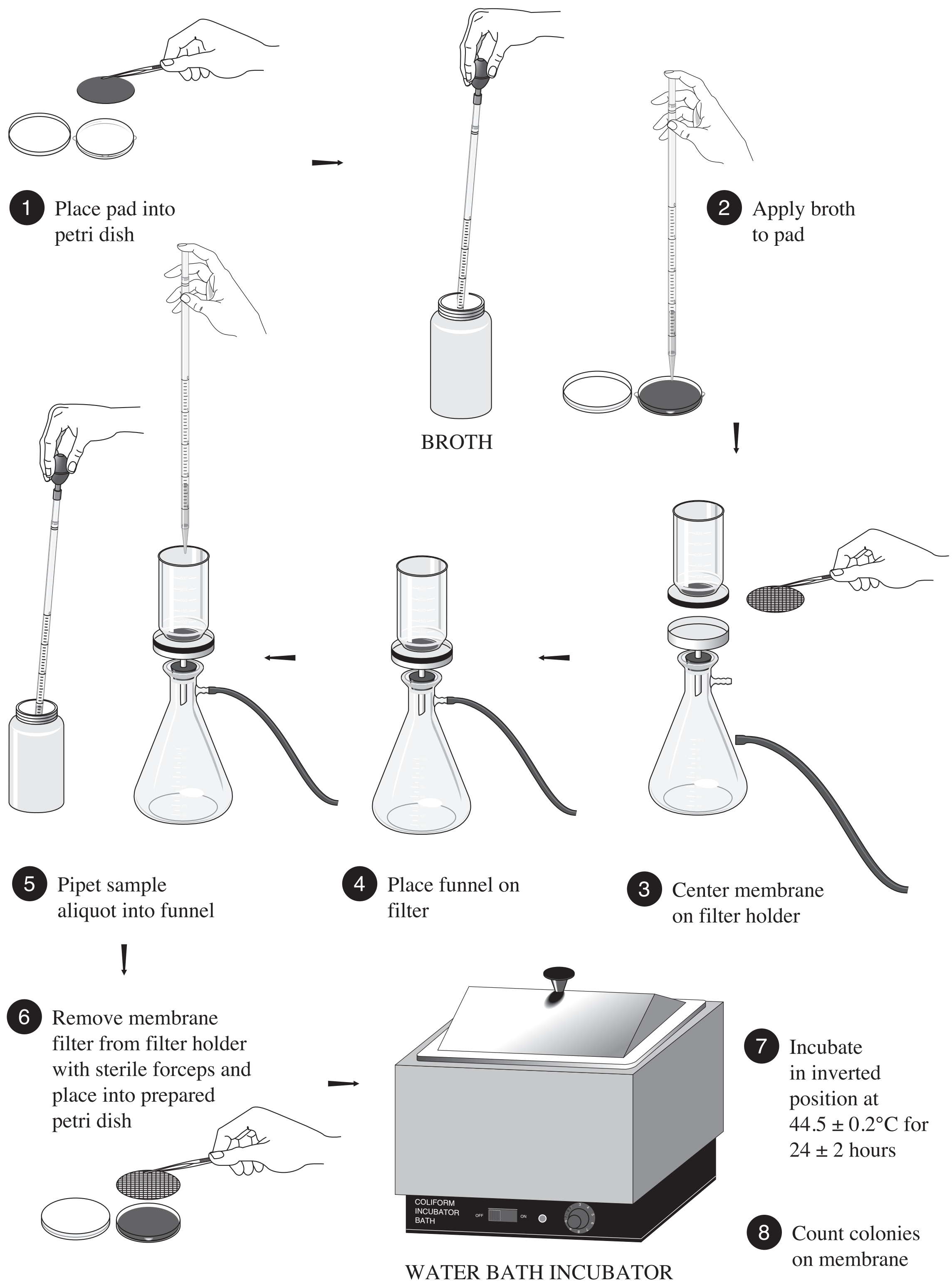
Sample Preparation

Containers

Fecal coliform samples must be collected in well-cleaned sample bottles which have been given a final rinse with distilled water and sterilized by autoclaving at 120° C and 15 psi for 15 minutes or 170° C for 1 hour in a dry oven.

Chlorinated Sample

If the sample is chlorinated, sodium thiosulfate must be used to neutralize the chlorine. The sodium thiosulfate should be added to the clean bottles before sterilization.


1 Place pad into petri dish
BROTH
2 Apply broth to pad
5 Pipet sample aliquot into funnel
4 Place funnel on filter
3 Center membrane on filter holder
6 Remove membrane filter from filter holder with sterile forceps and place into prepared petri dish
COLIFORM INCUBATOR BATH
OFF
ON
WATER BATH INCUBATOR
7 Incubate in inverted position at 44.5 ± 0.2°C for 24 ± 2 hours
8 Count colonies on membrane

Process Control Testing

Introduction

The following laboratory tests are designed for the operator to analyze the secondary biological system. The tests listed here are not required by the regulatory agency, but are included for process control considerations.

Settleometer

Introduction

Function of Test

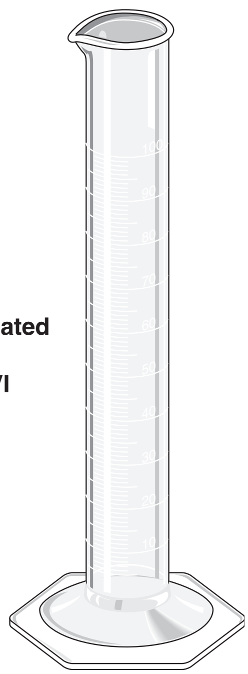
The settleometer test is used to analyze the activated sludge process. The test can determine **settling** characteristics of the activated sludge and, if run on a consistent basis, will help the operator determine **wasting requirements** of the system.

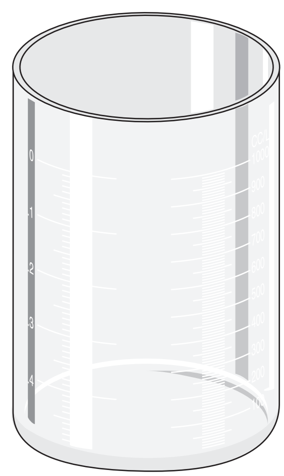
Equipment

Common

While there are various methods of performing a settleometer test the most common method uses a wide mouth 2000 mL settleometer jar. A stirring paddle and a timer with a buzzer are also required.

1000 mL Graduated Cylinder Used for SVI





2000 mL Settleometer

SVI

When the settling test is performed using a 1000 mL graduated cylinder the results are called **SVI**[10] (Sludge Volume Index). The results of the settleometer and the graduated cylinder cannot normally be compared.

[10] **SVI - Sludge Volume Index** - The volume in milliliters occupied by one gram of activated sludge after settling for thirty minutes.

Procedure

1. Collect the sample

The sample should be collected from the same place and at the same time each day. The activated sludge sample should be taken at a point nearest to the effluent of the aeration basin.

2. Set up the Settleometer

Mix well and pour the activated sludge into the settleometer to the 1,000 mL/L mark.

Stir well again, stop the swirling motion with the paddle.

Begin timing the settleometer.

3. Record the data

Record the settling rate every 5 minutes for 30 minutes then every 10 minutes for the last 30 minutes.

4. Interpret the data

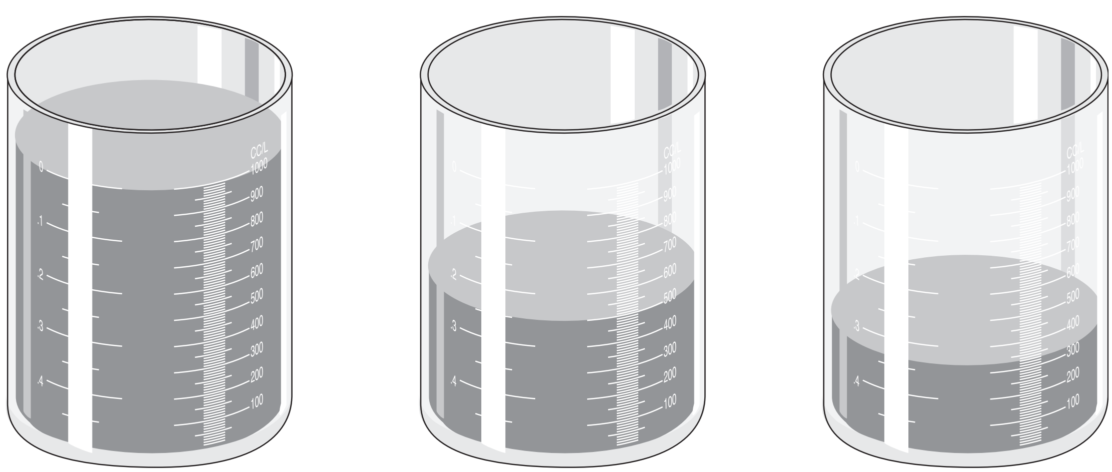
The results of the settleometer should be correlated with the performance of the secondary clarifier. It is ideal to begin running and reading the settleometer when the plant is operating well, so a baseline can be determined. There are no “right” numbers as each plant operates differently.

Critical Time

The most critical observations of a settleometer occur during the first five minutes of the test. The operator should observe how the sludge agglomerates, how the interface is formed and the initial settling process. Over time these observations, when compared to the secondary clarifier, will provide the operator with critical information on plant performance.

Normal Sludge

A textbook sludge will form a discrete interface between the sludge and the supernatant. The sludge will settle slowly and evenly, but reach 1/2 of the volume (500 mL/L) in 30 minutes and 1/3 (300mL/L) of the volume in 60 minutes. The supernatant should be clear and the floc should show definite large particles that seem to capture loose floc fragments.



0 Time | 30 Minutes | 1 Hour

SVI

Procedure

The SVI test is run in a similar manner to the settleometer test. With the SVI test the sample is poured into a 1000 mL graduated cylinder and allowed to stand for 30 minutes before it is read. The volume is then used along with **MLSS**[11] to determine the volume occupied by one gram of sludge. This is used as an indicator of sludge quality.

$$\text{SVI} = \frac{\text{mL of settled solids}}{\text{MLSS, mg/L}} \text{ X } 1{,}000$$

Results

Good settling sludge will have a SVI of about 100. The "magic number" is 125. A slow settling sludge will have an SVI above 200 (usually light MLSS and high settled sludge volume). A fast settling sludge will have an SVI below 100 (usually a heavy MLSS and low settled sludge volume).

MLSS

Introduction

Two Methods

The MLSS or mixed liquor suspended solids test is a measure of the mixed liquor concentration. There are two methods of making this determination:

- The suspended solids test is conducted using a Buchner funnel instead of a Gooch crucible. Because of its size, the Buchner funnel allows a larger volume of sample to be tested. The results are reported in mg/L
- The centrifuge or spin test. This procedure is preferred by many operators because it can be performed easily and quickly. The test requires only 15 minutes rather than the 1 to 2 hours required by the suspended solids test.The results are reported in percent (%).

Function of Test

This test is used to determine the quantity of mixed liquor under aeration, the quantity of the returned sludge and the quantity of the wasted sludge. This information is used in conjunction with other data to determine wasting and return sludge flow rates. The concentration of MLSS is controlled by wasting.

When to Test

A MLSS test should be run and a sample collected at the same time and place each day in order to identify the trend of the aeration basin MLSS concentration.

Interpretation of data

MLSS Range

Experts agree that the MLSS generally run between 2000 mg/L and 5000 mg/L. This is a tremendous range. The best concentration for a specific plant is

[11] **MLSS - Mixed Liquor Suspended Solids** - The suspended solids content of the mixed liquor of an activated sludge facility.

usually determined by frequent testing and comparison with the effluent quality.

Range for Spins

When mixed liquor concentration is determined with a centrifuge the results are often referred to as spins. The concentration is recorded and reported as percent. A typical range for a well operated activated sludge plant would be 2% to 5%.

Controlled by Wasting

A MLSS concentration should not change in any drastic manner whatsoever. Wasting and return rates will impact the aeration basin concentration with wasting providing the greatest influence. It is important to waste in a consistent manner and maintain a consistent MLSS concentration.

BLT - Blanket Level Thickness

This reading is taken at the secondary clarifier. An actual measurement of the **sludge blanket**[12] thickness (**BLT**[13])is taken in conjunction with the MLSS test, the settleometer test, any centrifuge spin tests and dissolved oxygen. This data is considered a“snapshot” of the system conditions and is used to evaluate activated sludge system.

Procedure

Thickness

There are two methods of determining the blanket thickness. One is using a long plastic tube (called a Sludge Judge™) with a valve at the bottom. The tube is lowered to the bottom of the clarifier and raised. The blanket thickness can be seen inside of the tube.

Depth

The second method is to determine how far it is from the water surface to the blanket, this measurement is called **DOB**[14] (Depth of Blanket). This can be determined physically using a tube with a lens and a light on the bottom. The tube is lowered into the clarifier and the operator observes the blanket by looking down inside of the tube. This level can also be determined with an electronic device that uses a light and photo cell. When the device passes the interface between the water and the sludge, the photo cell sends a signal that is converted to an audible or meter output.

Interpretation of data

Return Sludge Rates

The blanket thickness, while influenced by MLSS is controlled by return sludge flow rates. In many small plants, the operator has very little control over return sludge flows.

[12] **Sludge Blanket** - The portion of the clarifier containing sludge.

[13] **BLT - Blanket Thickness** - The depth of the sludge blanket.

[14] **DOB - Depth of Blanket** - The distance from the water surface to the top of the blanket.

DO (Dissolved Oxygen)

Need to Measure

Since the secondary biological systems in use today utilize aerobic bacteria to stabilize the organics, maintaining a residual amount of dissolved oxygen is very important. The measurement of dissolved oxygen is one of the most important process control tests for aerated treatment systems.

Equipment

In order to effectively measure DO in any of the plant processes, a portable DO meter should be used.

Procedure

Dissolved oxygen should be measured in aeration basins daily. This oxygen reading should be at least 2.0 mg/L at all times. The aerobic bacteria require oxygen at all times of the day or night in order to process the wastewater. An operator may want to read DO at peak loading to determine if oxygen is available when most needed.

pH

Function of Test

pH readings in the aeration basin, digester, or other secondary biological tank, (such as RBC basin) is important for troubleshooting process problems. The aerobic bacteria that provides treatment in the wastewater plant do not survive if the pH is outside the 6.8 - 7.2 range. Chemical addition may be necessary if a pH problem is observed.

Equipment

A portable pH meter is the only viable method of checking pH in a plant.

Where and When to Test

The pH at the influent end and the effluent end of the process should be checked at least once a week.

QA/QC

Quality Assurance/Quality Control

Definition

Quality assurance and quality control is often referred to as QA/QC. This term refers to a program that includes methods and procedures used in the lab to guarantee the validity of the numbers reported on monitoring reports. A QA/QC program can be a required component of a wastewater laboratory operation or may be part of the general procedure of the laboratory. These QA/QC programs outline specific procedures and activities required to meet federal quality control requirements and also to meet some states' laboratory accreditation processes.

Examples

Some examples of quality assurance/quality control tests include:

- Checking or calibrating lab thermometers to **NIST**[15] standard thermometers
- Determining the BOD of a glucose/glutamic acid sample that has a known BOD of 200 $\pm$ 37 mg/L
- Running duplicates of suspended solids tests to determine if results are repeatable
- Incubating a sample of raw sewage with the fecal coliform test to assure coliforms can be grown on a given media and all test procedures were performed correctly

Value of QA/QC

QA/QC tests are not only required, they are a good way to check and assure the validity of test results. Lab tests take a tremendous amount of time and energy to perform. Lab results are a basis for future construction and planning. Test results need an assurance and some controls to determine their accuracy.

[15] **NIST -** National Institute of Standards and Technology, formally the National Bureau of Standards

RecordKeeping

Required monitoring

There are many levels of recordkeeping and criteria for both preparing and storing records. The following are a few basic considerations that can apply to all recordkeeping systems.

Blue Ink

Keep all records in blue ink.

Do Not Alter

Records should never be altered by erasing or white-out, but incorrect numbers should be crossed out and initialed by the operator.

Initials

Initials or signatures should accompany all recorded readings. A listing of all initials or signatures should be on file on the premises.

For 5 Years

All records should be kept on-site for at least 5 years.

Process Control Records

Neatness

While these records are not influenced by the regulations as as much as the effluent and influent water quality records, all records should be neatly prepared, signed, and kept on site for a reasonable length of time.

Conclusion

Content

This section has covered the discharge permit required laboratory testing and a few process control tests and their interpretation.

Relationship to Sample

The overall bottom line of laboratory testing is that the test and its results are no better than the sample, or the actual portion of wastewater that is tested. It is critical that the sample be taken and the test run on a sample that represents the proper overall objective.

Sample Types

If you are looking for what the plant has produced in 24 hours, a composite sample is required. If a “snapshot” of what is happening at a specific moment is desired, a grab sample should be collected and the appropriate test performed.

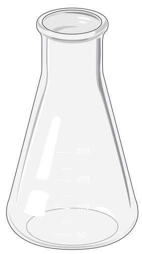
Wastewater Laboratory

Worksheet

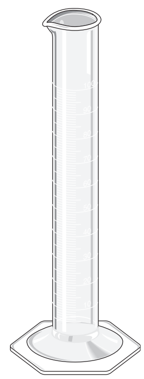
1. Identify the following pieces of laboratory equipment.

A. ______________

B. ___________________



C. __________



D. ___________________

E. ___________________

2. The process of precisely transferring small volumes of liquid from one container to another is called what?

3. The process of precisely metering one fluid into another is called ______________.

4. Never use your _________________ to fill a pipette.

5. Safety precautions for handling a specific chemical can be found in the ____________ for the chemical.

6. When diluting an acid with water always add the ____________ to the _________.

7. The three different types of samples are:

   a. ______________________________

   b. ______________________________

   c. ______________________________

8. Describe a good sample location.

9. Grab samples should be collected for which test?

10. A bacteriological sample can be held for up to ________ hours if refrigerated at __________° C.

11. Describe when the daily flow cycle samples should be collected for each of the following tests and why?

    a. Chlorine residual ____

    b. TSS ____

    c. Fecal Coliform ____

    d. BOD ____

    e. Settleable solids ____

    f. pH ____

12. When running the BOD test the samples are incubated for _________ days at __________ °C.

13. A BOD bottle holds ________________ mL.

14. The BOD of a wastewater sample is expressed in ________/________.

15. When running the TSS test the sample material is collected on a glass ________________ ____________________ held in a _______________ __________________.

16. The test that uses the Imhoff cone is the ______________________ solids test.

17. The solution used to standardize a pH meter is called a ____________________. After standardization the pH probe should be rinsed with _________________ _____________.

18. The chemical used in the chlorine test that produces a pink color is _____________.

19. When performing a fecal coliform test the sample is incubated for __________ hours.

20. What special cleaning method is used on equipment used in the fecal coliform test?

21. The device used to measure the settleability of sludge in an activated sludge plant is called a __________________ and typically contains __________________ mL. The results of this test can also be used to determine _____________________ requirements.

22. The settleability test on an activated sludge plant takes ________ (min). During this time the sludge volume should be read every _______ minutes during the first ________ minutes and every _______ minutes during the next ________ minutes.

23. A ____________________ cylinder is used to obtain data for the SVI test. Besides this test data the _____________________ concentration must also be known in order to determine the SVI.

24. Properly settling sludge will settle to _______________ of its volume by the mid point in the test and to _________________ of its volume at the conclusion of the test.

25. A good settling sludge will have an SVI of approximately _______________, while a fast settling sludge will have an SVI above _______________.

26. Mixed liquor suspended solids can be determined using a _________________ funnel or a ____________________________. The latter provides the results in percent.

27. While MLSS and settleability can be used to determine wasting it is the __________________ that is basically used to determine return sludge flows.

28. What is the difference between:

    a. BLT

    b. DOB

29. Describe what good sludge will look like in a settleometer.

30. Describe QA/QC and its value?

31. The permit required records should be:

    a. Written in _________________ ink

    b. Changes ______________ out and ______________.

    c. The ___________ of the person running the test should be placed next to the readings.

    d. The records should be maintained for _____________ years.

Pumping Systems

Introduction

Content

This lesson is divided into three sections. The sections are:

- Wastewater Hydraulics
- Pump Equipment
- Electrical Basics & Electrical System

Layout

Each of these sections has its individual listing of the lesson content, key words and worksheet. While these sections can be studied independently they are all needed in order to understand typical pumping systems found in wastewater facilities.

Wastewater Hydraulics

What is in this Lesson?

1. The weight of a cubic foot of water
2. How to convert between cubic feet and gallons
3. The difference between force and pressure and what impacts them
4. How to convert between psi and feet of head
5. The difference between psi and feet of head
6. The relationship between flow in cubic feet per second and gallons per minute
7. The terms used to describe static and dynamic hydraulic conditions
8. Headloss and its causes
9. The terms used to describe pumping conditions

Key Words

- Amperage
- Dynamic
- Force
- gpm
- Headloss
- Inertia
- Pressure
- Specific Gravity
- Suction Lift
- Total dynamic head
- Velocity
- Wet Well Lift Station
- Dry Well Lift Station
- Feet of head
- gpd
- Head
- Horsepower
- MGD
- psi
- Static
- Suction Head
- TDH
- Velocity head

Wastewater Hydraulics

Hydraulic Basics

Introduction

This brief discussion on hydraulics is intended as a background necessary to understand the pumping and piping systems at a beginning level. The lesson is divided into two parts; 1) basic hydraulic terms and concepts and 2) pumping hydraulics

Basic Hydraulic Terms and Concepts

Hydraulic Terms

Pressure

psi = Pounds per square inch (lbs/in^2), a common term used to identify **pressure**[1].

Feet of Head = A term usually used when defining pumping capabilities or describing the loss of energy to friction (headloss). It is common to convert pressure in psi to pressure in feet of head when performing pumping calculations. One foot of head is equivalent to 0.433 psi or 1psi = 2.31 feet of head.

Head = A general term used to describe pressure in pumping. The same as feet of head.

Flow

gpm = Gallons per minute (gal/min). The common term used to describe rate of flow.

cfs = Cubic feet per second (ft^3/sec). A flow rate that is commonly used when calculating the flow in a stream. One cfs is equivalent to 448 gpm.

gpd = Gallons per day (gal/day). This term is commonly used to describe the total amount of wastewater that flows into a small plant in one day or the volume of the effluent.

gpcpd= Gallons per capita per day. The amount of wastewater produced by one person in a day.

MGD = Million gallons per day. A common term used to describe the flow rate and capacity of a wastewater plant; 2,000,000 gpd can be expressed as 2MGD.

[1] **Pressure** - The force exerted on a unit area. Pressure = Weight x Area. In water, it is usually measured in psi (pounds per square inch). One foot of water exerts a pressure of 0.433 pounds per square inch.

Weight Volume Relationship

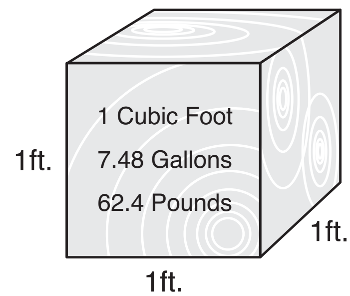
Weight per Cubic Foot

Cubic feet and gallons are both used to describe a volume of wastewater. There is a defined relationship between these two methods of measurement. The specific weight of wastewater is defined relative to a cubic foot. One cubic foot of wastewater weighs 62.4 pounds.

1 ft^3 H_2O= 62.4 lbs (H_2O is the chemical form for water)

Volume per Cubic Foot

One cubic foot contains 7.48 gallons of wastewater. With these two relationships we can determine the weight of one gallon of wastewater. This is accomplished by dividing the weight of the cubic foot (62.4 lbs) by the volume in gallons (7.48 gallons per cubic foot).



$$\text{wt. of 1 gal of water} = \frac{62.4\,\text{lbs}}{7.48\,\text{gal}} = 8.34\,\text{lbs/gal}$$

Summary

1 ft^3 of H_2O = 7.48 gallons

1 gallon of H_2O = 8.34 pounds

Conversion ft^3 to gallons

With this information we can convert cubic feet to gallons by simply multiplying the number of cubic feet by 7.48 gal/ft^3.

Example

Find the number of gallons in a basin that has a volume of 2,673.8 ft^3,

2,673.8 ft^3 X 7.48 gal/ft^3 = 20,000 gallons

Specific Gravity (SG.)

Definition

Specific gravity[2] is the relationship of the weight of a substance to the weight of an equal volume of a reference substance. Water at 4° C is used as the reference for liquids and solids. Substances that weigh less than water will have a specific gravity of less than one and will float (oil, plastic, wastewater scum). Substances that weigh more than water will have a specific gravity greater than one (sand, grit and sludge).

[2] **Specific Gravity** - The weight of a substance in relation to the weight of an equal volume of water at a set temperature. Water at 4°C has a specific gravity of 1.0. Particles found in wastewater have a specific gravity between 0.8 and 2.6.

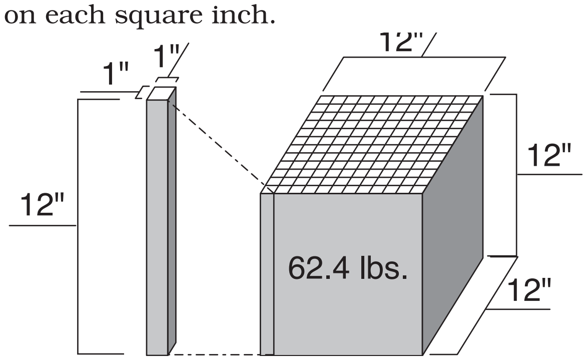
Force & Pressure

Force

In the English system of measurement **force**[3] and weight are often used in the same way. The weight of a cubic foot of wastewater is 62.4 pounds. The force exerted on the bottom of the one foot cube is 62.4 pounds. If we have two cubes stacked on top of one another the force on the bottom will be 124.8 pounds.

Pressure

Pressure is a force per unit of area. Pounds per square inch or pounds per square foot are common expressions of pressure. The pressure on the bottom of our cube is 62.4 pounds per square foot. It is normal to express pressure in pounds per square inch (psi). This can be accomplished by determining the weight of one square inch of our cube one foot high. Since the cube is 12 inches on each side, the number of square inches on the bottom surface of the cube is 12 X 12 = 144 in^2. Now by dividing the weight by the number of square inches we can determine the weight on each square inch.



$$\text{psi/ft} = \frac{62.4\ \text{lbs/ft}^3}{144\ \text{in}^2/\text{ft}^2} = 0.433\ \text{psi/ft}$$

This is the weight of a column of wastewater one inch square and one foot tall. If the column of wastewater were two feet tall and the pressure would be 2ft X 0.433 psi/ft = 0.866 psi

1 ft of wastewater = 0.433 psi

Conversion feet to psi

With the above information we can convert feet of **head**[4] to psi by multiplying the feet of head times 0.433 psi/ft.

Example

A digester is 20 feet tall. Find the pressure at the bottom of the digester.

20 ft X 0.433 psi/ft = 8.6 psi

[3] **Force** - Influence (as a push or pull) that causes motion. Physics - The mass of an object times its acceleration F = ma.

[4] **Head -** The measure of the pressure of water expressed as height of water in feet - 1 psi = 2.31 feet of head.

Conversion of psi to feet

The conversion of psi to feet is simply made by dividing the psi by 0.433 psi/ft.

Example

Find the height of wastewater in an aeration basin if the pressure at the bottom of the tank is 6.5 psi.

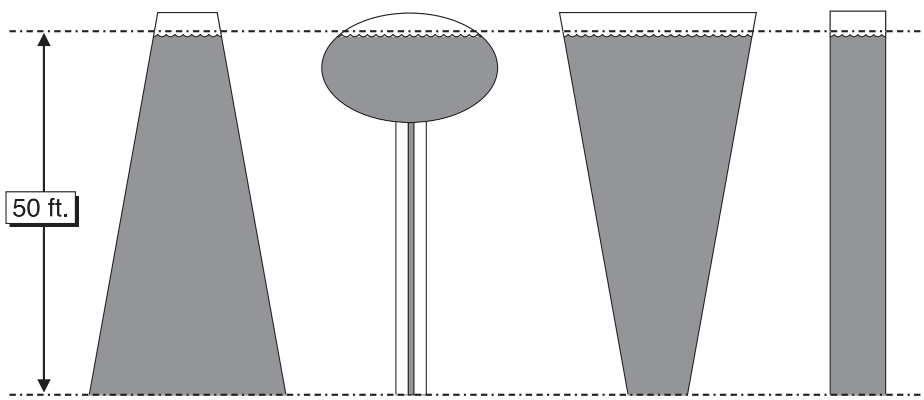
$$\text{Feet} = \frac{6.5\,\text{psi}}{0.433\ \text{psi/ft}} = 15\,\text{feet}$$

Pressure and Head

Pressure is directly related to the height of a column of fluid. This height is called head or feet of head. From the discussion above we see there is a direct relationship between feet of head and pressure. The relationship is that for every 1 foot of head there is a pressure of 0.433 psi.

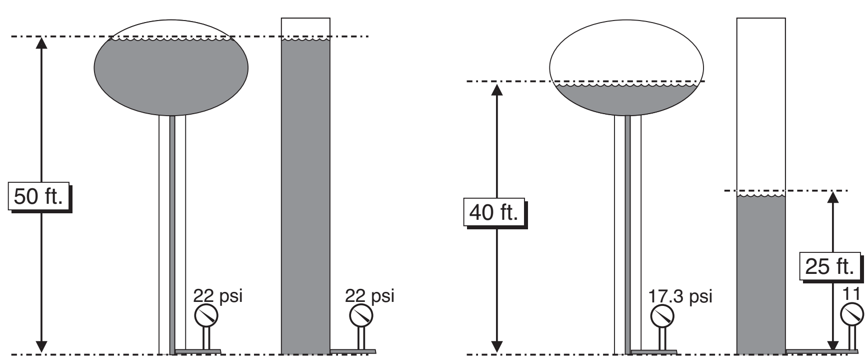
Pressure Relative to Container Size

The pressure at the bottom of a container is only affected by the height of wastewater in the container and not by the shape of the container. In the drawing below there are four containers all of different shapes and sizes. Because each has 50 feet of head, the pressure at the bottom of each is the same.



Pressure and volume

The pressure exerted at the bottom of a tank is relative only to the head on the tank and not the volume of wastewater in the tank. For example, below are two tanks. The pressure at the bottom of each is 22 psi. If half of the wastewater were drained from the tanks the pressure at the bottom of the elevated tank would be 17.3 psi (40 ft) while the pressure at the bottom of the standpipe would be 11 psi (25 ft).



Velocity & Flow

Velocity

Velocity[5] is the speed that the wastewater is moving along a pipe or through a basin. Velocity is usually expressed in feet per second, ft/sec.

Flow

Flow is commonly expressed in gallons per minute (gpm) and/or cubic feet per second (cfs). There is a relationship between gallons per minute and cubic feet per second. One cubic foot per second is equal to 448 gallons per minute.

1 cfs = 448 gpm

Flow Equation

The basic equation for determining flow is:

$Q = VA$; Flow = Velocity X Area

Where:

Q = cfs

V = ft/sec

$A = ft^2$ (This is the area of the flow. For instance if a pipe were flowing full then the area is equal to the area of the pipe. If the pipe is flowing one-half full then the area would be equal to one-half of the area of the pipe.)

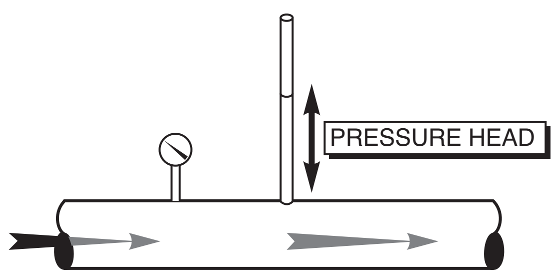
Static and Dynamic[6] Conditions

Static Pressure

The pressure measured when there is no wastewater moving in a line or when a pump is not running is called **static**[7] pressure or static head. This is the pressure represented by the gauges on the tanks in the discussion above.

Dynamic Pressure

When wastewater is allowed to flow through a pipe and the pressure (called pressure head) is measured at various points along the way, we find that the pressure decreases the further we are from the energy sources.



Headloss

The reason for this reduction in pressure is a phenomenon called **headloss**[8]. Headloss is the loss of energy due to friction. The energy is lost as heat.

5 **Velocity** - The speed at which wastewater moves, expressed in feet per second.
6 **Dynamic** - A condition in which there is motion, or the application of force as a result of motion.
7 **Static** - A non-moving condition.
8 **Headloss** - The loss of energy, commonly expressed in feet, as a result of friction. The loss is actually a transfer to heat.

Explanation

When we hear that the headloss in a certain pipe is 25 feet, that means the amount of energy required to overcome the friction in the pipe is equivalent to the amount of energy that would be required to lift this amount of wastewater straight in the air 25 feet.

Factors Contributing to Headloss

In a pipe the factors that contribute to headloss are:

- Roughness of pipe
- Length of pipe
- Diameter of pipe
- Velocity of wastewater

Comparison of factors

In general, if the roughness of a pipe were doubled, the headloss would double. If the length of the pipe were doubled, the headloss would double. If the diameter of a pipe were doubled, the headloss would be cut in half and if the velocity of the wastewater in a pipe were doubled, the headloss would be increased by about four times. It should be apparent that velocity, more than any other single factor, affects headloss. To double the velocity, we would have to double the flow in the line.

Example

500 feet of four inch line with a flow of 110 gpm has a headloss of 7.5 feet. At a flow of 220 gpm the headloss jumps to 26 feet or an increase of 3.5 times.

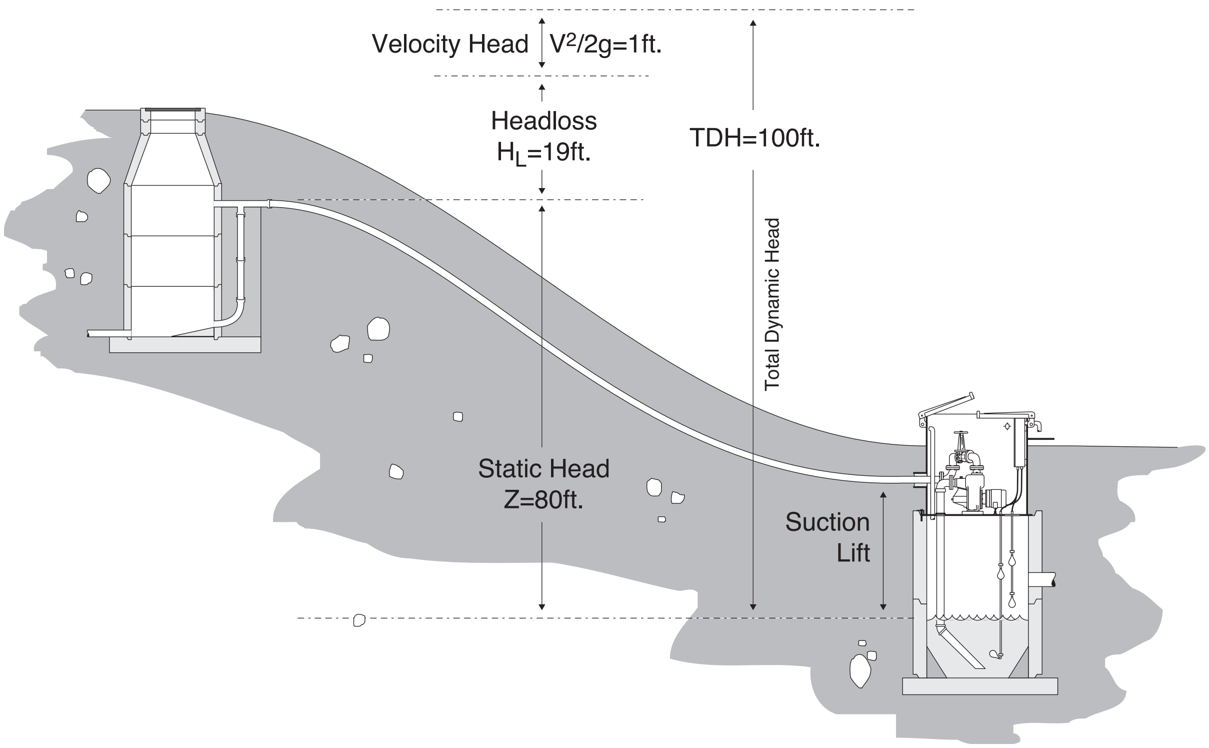
Fittings & Headloss

Each type of fitting has a specific headloss depending upon the shape of the fitting and the velocity of wastewater through the fitting. For instance, the headloss though a check valve is two and one quarter times greater than through a ninety degree elbow and ten times greater than the headloss through an open gate valve.

Pumping Hydraulics

Using the Diagram

One of the ways to become familiar with pumping hydraulics is to refer to the diagram below.



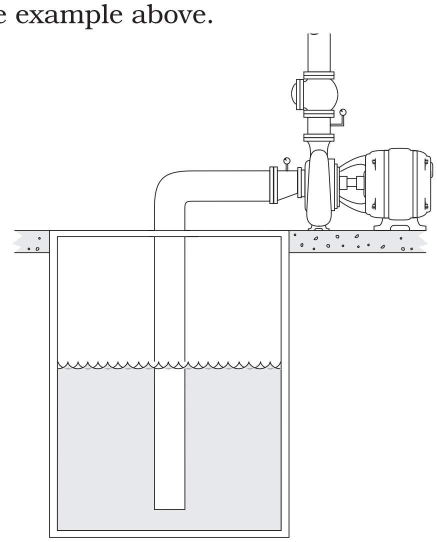
Basic Terms

Static Head

Static head is the distance between the suction and discharge wastewater levels when the pump is shut off. Static head conditions are often indicated with the letter Z. 80 feet in the example above.

Suction Lift

Suction lift[9] is the distance between the wastewater level and the center of the pump impeller.This term is only used when the pump is in a suction lift condition. A pump is said to be in a suction lift condition any time the eye (center) of the impeller is above the wastewater being pumped.

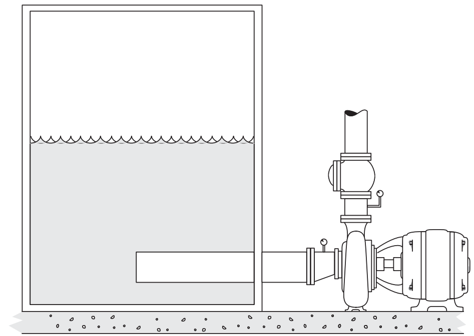


Suction Lift Condition

[9] **Suction Lift** - A pumping condition where the eye of the impeller of the pump is above the surface of the water from which the pump is pumping.

Suction Head

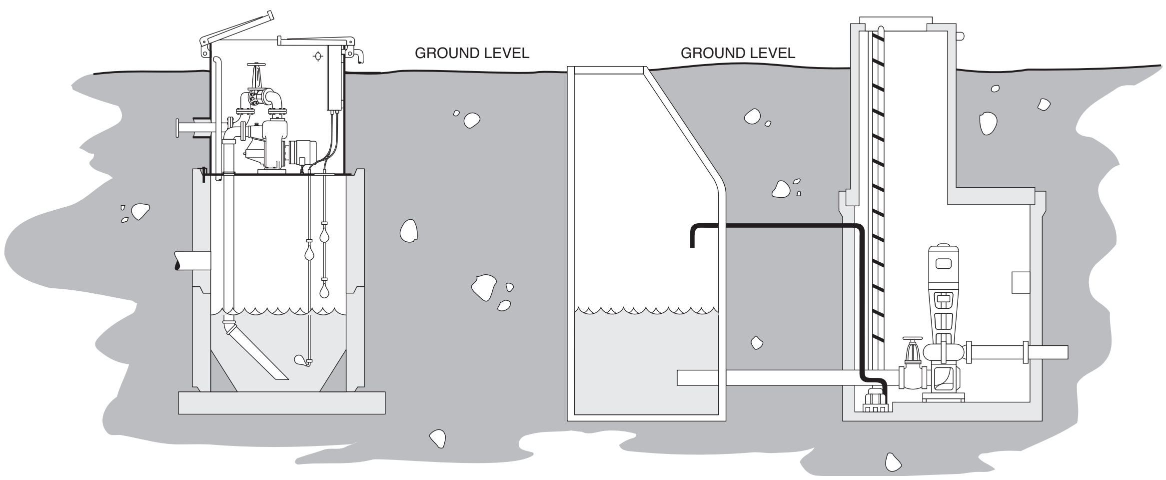
Suction head[10] is the distance between the suction wastewater level and the center of the pump impeller when the pump is in a suction head condition. A pump is said to be in a suction head condition any time the eye (center) of the impeller is below the wastewater level being pumped.



Suction Head Condition

Suction Conditions and Lift Stations

There are two basic lift station designs. The wet well and dry well stations. The basic difference between the two is the number of tanks. The wet well lift station has one tank and the dry well station has two tanks.



Wet Well Lift Station

Dry Well Lift Station

Suction Conditions/Dry Well

As you can see from the drawing above, the **dry well station**[11] has a pump installed in a suction head condition. Being able to place the pump in a suction head condition is the primary reason for selecting a dry well station.

Suction Conditions/Wet Well

In the drawing above the **wet well station**[12] has a pump installed in a suction lift condition. In order to install a pump in a suction head condition in a wet well station a submersible pump must be used.

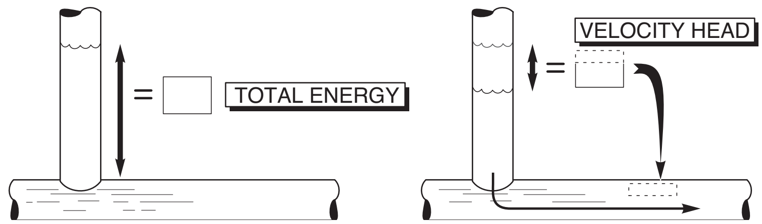
[10] **Suction Head** - A pumping condition where the eye of the impeller of the pump is below the surface of the water from which the pump is pumping.

[11] **Dry Well Lift Station** - A lift station composed of two tanks. One tank contains the wastewater and the second tank contains the pumps. Dry well lift stations are used so that the pumps may be dry and in a suction-head condition.

[12] **Wet Well Lift Station** - A lift station in which there is a single tank. Pumps can be installed in a wet well lift station in either a suction lift or suction head condition.

Velocity Head

Velocity head[13] is the amount of energy required by the pump and motor to overcome **inertia**[14] and bring the wastewater up to a specific speed. Velocity head is often shown mathematically as $V^2/2g$. (g is the acceleration due to gravity - 32.2ft/sec^2).



Total Dynamic Head

Total dynamic head[15] (TDH) is a theoretical distance. It is the static head, velocity head and headloss that must be overcome in order to get the wastewater from one point to another.

Horsepower

Horsepower[16] is a measurement of the amount of energy required to do work. Motors are rated in horsepower. The horsepower of an electric motor is called brake horsepower. The horsepower requirements of a pump are dependent on the flow and the total dynamic head.

Horsepower and Amperage

The horsepower output of an electric motor is directly reflected in the **amperage**[17] that the motor draws. Any increase in horsepower requirements will give a corresponding increase in amperage.

Pump Response

For centrifugal pumps, as the total dynamic head is increased, the pump will pump less wastewater and will require less horsepower.

13 **Velocity Head -** The amount of energy required to bring a fluid from a standstill to its velocity. For a given quantity of flow, the velocity head will vary indirectly with the pipe diameter.
14 **Inertia** - The tendency of matter to remain at rest or in motion.
15 **Total Dynamic Head** - The total energy needed to move water from the center line of a pump (eye of the first impeller of a lineshaft turbine) to some given elevation or to develop some given pressure. This includes the static head, velocity head and the headloss due to friction.
16 **Horsepower** - A measurement of work, 33,000 foot pounds per minute of work is 1 horsepower.
17 **Amperage** - The measurement of electron flow.

Wastewater Hydraulics

Worksheet

1. One cubic foot of wastewater weighs__________ pounds, and contains ___________ gallons.

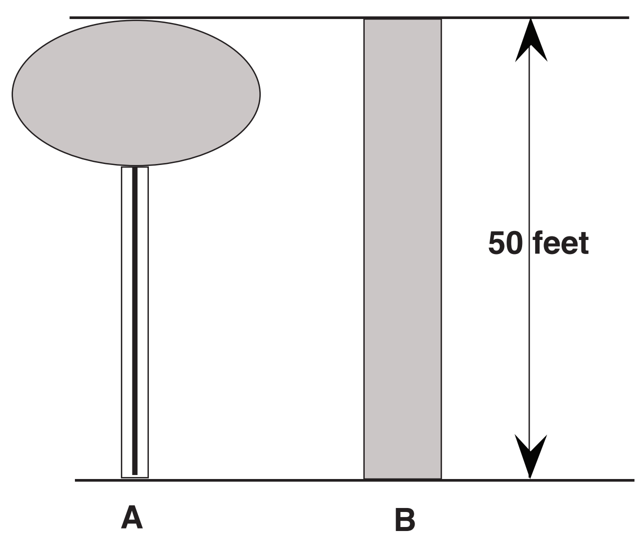
2. One gallon of wastewater weighs _____________lbs.

3. Looking at the two tanks below, will the pressure at the bottom be:

    ______ a. The same

    ______ b. Greater in tank A

    ______ c. Greater in tank B



4. A tank contains 500 cubic feet. This converts to how many gallons?

5. A flow of one cubic foot per second is equivalent to __________ gpm.

6. Headloss is the result of _____________. The energy given off as a result of headloss is given off as _____________.

7. In a standard sewage lift station. Water is pumped from the wet well to a downstream manhole. The water level in the manhole is at a higher elevation than the water in the wet well. What is the term used to identify the difference in elevation between the water in the wet well and the manhole?

8. Total Dynamic Head (TDH) is composed of three measurements, they are:

    a.______________________ head

    b. _____________________ head

    c. head ________________

9. What is the difference between suction lift and suction head?

10. What units are used to measure the energy required to do the work of pumping wastewater?

11. It is 60 feet in elevation from the level of wastewater in a manhole to the pump in a lift station. What is the static wastewater pressure at the lift station?

12. ____________ ___________ is used to express the relationship between the weight of a substance and the weight of an equal volume of wastewater.

Pump Equipment

What is in this Lesson?

1. The function of pumping systems
2. Common pump types
3. Basic theory of operation of centrifugal pumps
4. The basic theory of operation of diaphragm pumps
5. The major components of a pumping system, including the building and piping system
6. The terms used to identify common pumps and their components
7. The function of the major components of a centrifugal pump
8. The pumping process used by a pneumatic ejector
9. The components of an air lift pump

Key Words

- Centrifugal force
- Centrifugal pump
- Close-coupled pumps
- Concentric reducer
- Displacement pumps
- Dynamic pumps
- Energy
- Eccentric reducer
- End suction centrifugal pumps
- Frame-mounted pumps
- Impeller
- Mechanical seal
- Packing
- Seal water
- Shroud
- Stuffing box
- Volute

Pumping Equipment

Introduction

Section Content & Purpose

This section is intended to provide an overview of the major pumping related components found in small wastewater systems. The focus of the lesson will be on basic theory, descriptions of components, common names of components and their general functions.

Pump System Uses

Functions

Wastewater pumping systems in small communities are used to:

- Pump wastewater through portions of the collection system - a lift station
- Pump wastewater from an individual house into a pressure collection system
- Pump wastewater effluent from the plant or septic tank to a receiving body
- Pump wastewater from a major collection point into a treatment facility
- Circulate glycol through a heat exchanger or heating loop
- Pump chemicals into the system

Major Components

A pump station is composed of four sets of components:

- The structure, including the wet well;
- The hydraulic system; the pump and related piping.
- The electrical system; the motor and its related components.
- The control system; pressure, flow and level switches.

Structure/Buildings

Introduction

In a wastewater system the most common pumping structure is the lift station. This is typically a concrete or steel structure placed in the ground with a fiberglass or wooden building placed over the wet well. Having a building over the wet well provides improved access to the equipment during the months of bad weather.

Basic Consideration

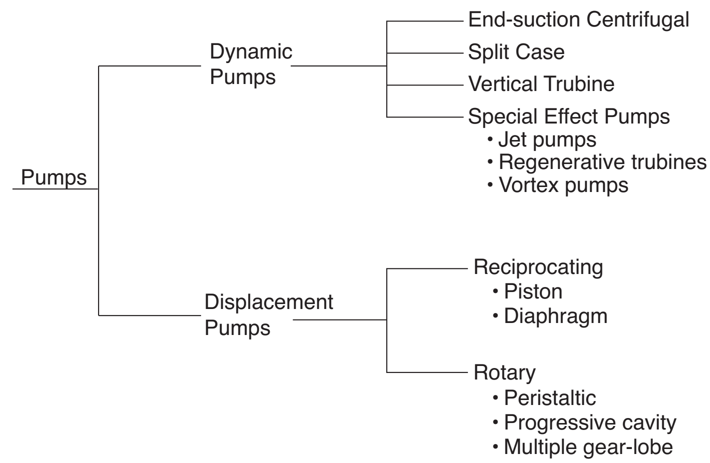
Regardless of the design, most lift station buildings are designed with the door opening out. This allows access should there be a broken discharge line in the building. The buildings should be vandal resistant, well heated in the winter and properly vented in the summer.

Hydraulic System

Pump Types

Two Types

The pumps used in small wastewater systems can be divided into two general categories; **dynamic pumps**[1] and **displacement pumps**[2]. One type of dynamic pump, centrifugal pumps, are the most common pumps used in wastewater systems. Displacement pumps are also called positive displacement pumps. The most common positive displacement pump is the diaphragm pump used to pump chlorine solutions.



Special Pumps

Collection systems may also use a special pumping device called a pneumatic ejector. Small wastewater treatment plants often use air lift pumps for pumping return activated sludge and waste activated sludge.

Dynamic Pumps

The basic differences between the two pump types have to do with their response to changes in discharge pressure. Dynamic pumps are used in conditions where high volumes are required and a change in flow is not a problem. As the discharge pressure on a dynamic pump is increased the quantity of wastewater pumped is reduced. Dynamic pumps can be operated for short periods of time with the discharge valve closed.

Displacement Pumps

Displacement pumps are used in conditions where relatively small, but precise volumes are required. Displacement pumps will not change their volume with a change in discharge pressure. Operating a displacement pump with the discharge valve closed will damage the pump.

[1] **Dynamic Pumps -** Pumps in which the energy is added to the water continuously and the water is not contained in a set volume.
[2] **Displacement Pumps -** Pumps in which the energy is added to the water periodically and the water is contained in a set volume.

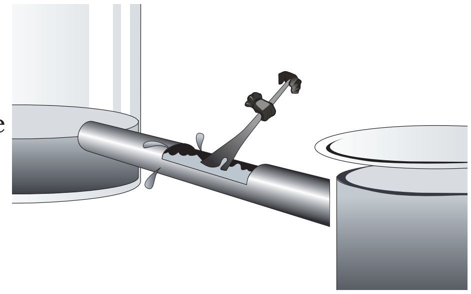
Centrifugal Pump Theory

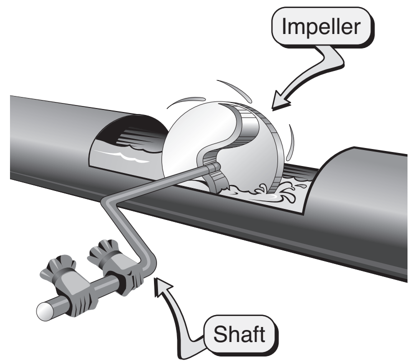
Energy Input Device

A pump is a device that puts **energy**[3] into the wastewater. This energy can be expressed in two ways; an increase in pressure or an increase in flow.

Centrifugal Pumps - Energy Input

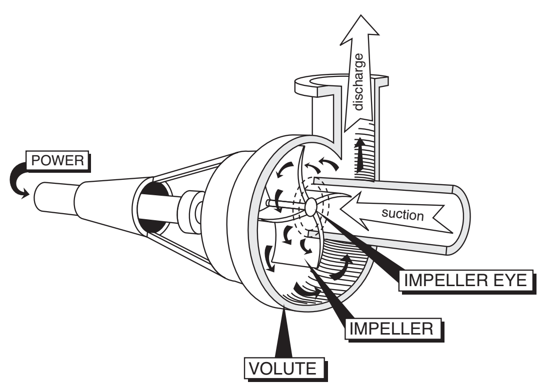
If we cut a section out of the top of a pipe and used a canoe paddle to move the wastewater we would have a pump. It would not be very efficient but we would be inputting energy into the wastewater. If the paddle were reshaped into an **impeller**[4] we would be able to place more energy into the wastewater. The energy is transferred from the impeller to the wastewater due to the friction between the impeller and the wastewater. However, notice that a lot of the wastewater would splash out onto the floor. This is because **centrifugal force**[5] causes the wastewater to fly outward away from the impeller.





The Pump Case

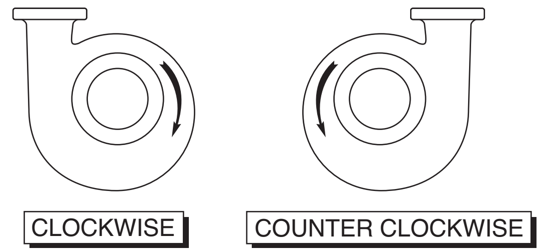
If we surround the impeller with a case we can control the wastewater and obtain a more efficient energy transfer. The case that is used is shaped like a spiral and is called a volute. **Volute**[6] is a geometrical shape; like a circle, a square, etc. A snail shell is volute shaped. The shape of the case helps us to determine the direction of rotation of the pump.



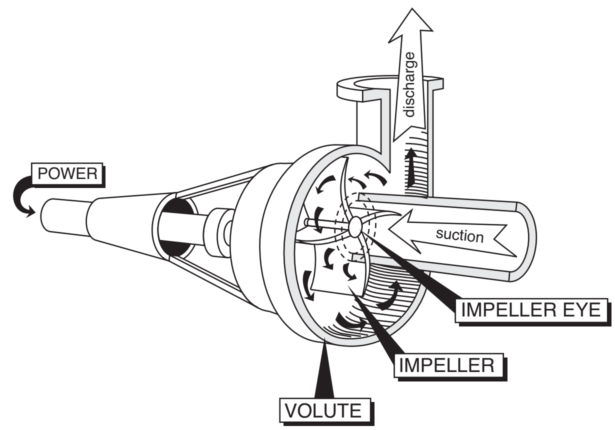
[3] **Energy -** The ability to do work. Energy can exist in one of several forms, such as heat, light, mechanical, electrical or chemical. Energy can neither be created nor destroyed, but can be transferred from one form to another. Energy also can exist in one of two states - either potential or kinetic.
[4] **Impeller** - A rotating set of vanes designed to impart rotation to a mass of fluid.
[5] **Centrifugal Force** - The force that when a ball is whirled on a string, pulls the ball outward. On a centrifugal pump, it is the force which throws water from the spinning impeller.
[6] **Volute** - The spiral shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

Pump Rotation

The direction of rotation should be determined when we are looking into the suction side of the volute case.



Observing the case below, the direction of rotation is counter clockwise.



Summary

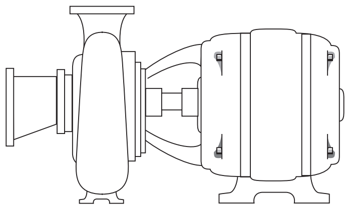
In summary, there are two theories that explain how a **centrifugal pump**[7] works. They are: energy transfer, the transfer of energy from the shaft to the impeller and from the impeller to the wastewater; and centrifugal force, the force used to throw the wastewater from the impeller.

Centrifugal Pump Configuration

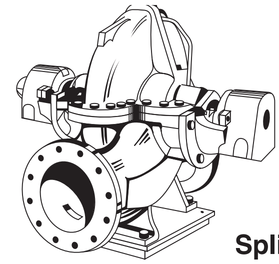
Three Different Configurations

Centrifugal pumps can be divided into one of three classifications based on their configuration. The three are: **end suction centrifugal**[8], **split case** [9]and **vertical turbine**[10]. Split case and vertical turbine pumps are seldom found in wastewater systems and therefore will not be discussed in this lesson.

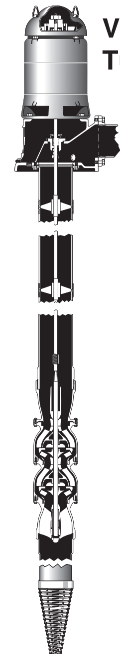
[7] **Centrifugal Pump** - A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, having an inlet and discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.
[8] **End Suction Centrifugal Pumps** - The most common style of centrifugal pump. The center of the suction line is centered on the impeller eye. End suction centrifugal pumps are further classified as either frame-mounted or close-coupled.
[9] **Split Case Pumps** - A centrifugal pump designed so that the volute case is split horizontally. The case divides on a plane that cuts though the eye of the impeller.
[10] **Vertical Turbine Pumps** - A classification of centrifugal pumps that are primarily mounted with a vertical shaft; the motor is commonly mounted above the pump. Vertical turbine pumps are either mixed or axial flow devices.



End-suction Centrifugal



Split Case



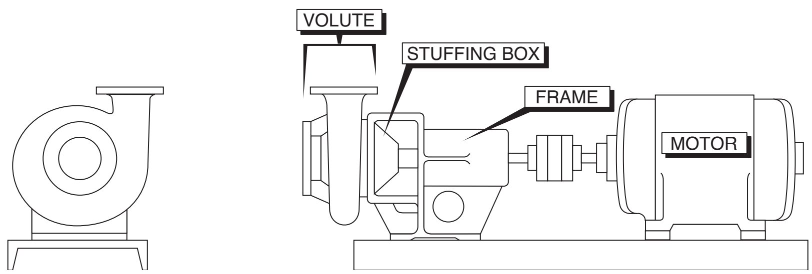
Vertical Turbine

End-Suction Centrifugal - Types

The end-suction centrifugal pump is the most common centrifugal pump and is the one we usually picture in our mind when we think about centrifugal pumps. There are two types of end-suction pumps; **close-coupled**[11] and **frame mounted**[12].

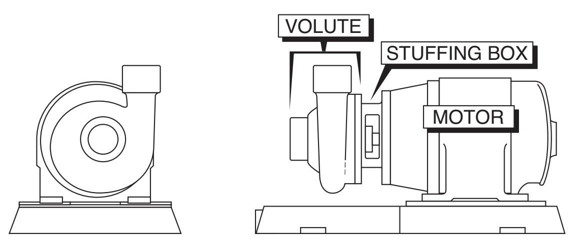
Frame Mounted

The frame mounted pump has a shaft and bearings separate from the motor. A coupling is required to get the energy from the motor to the pump.



Close-coupled

A close coupled pump has only one shaft and one set of bearings; the motor shaft and bearings. The pump impeller is placed directly onto the motor shaft. Close-coupled pumps require less space and are less expensive than frame-mounted pumps.

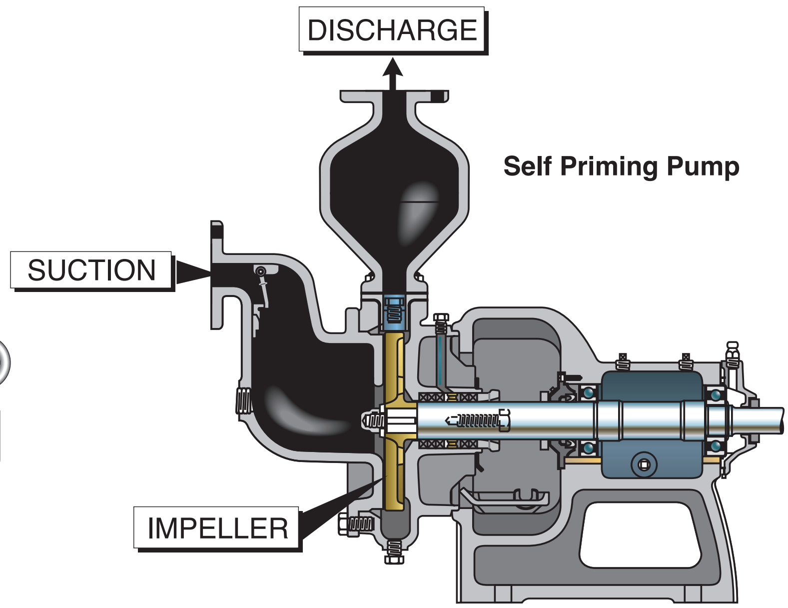


[11] **Close-coupled Pumps** - End suction centrifugal pumps in which the pump shaft and motor shaft are the same shaft. The pump bearings and motor bearings are also the same. The impeller is attached directly onto the end of the motor shaft.

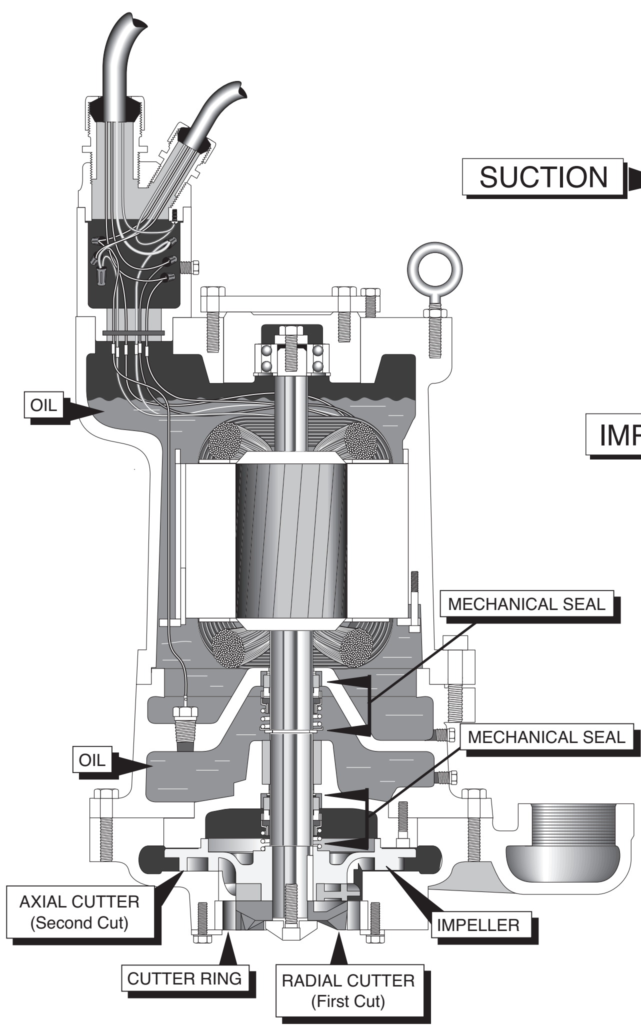
[12] **Frame-mounted Pumps -** End suction centrifugal pumps designed so that the pump bearings and pump shaft are independent of the motor. This type of pump requires a coupling between the pump and the motor in order to transfer energy from the motor to the pump.

Special Wastewater Configurations

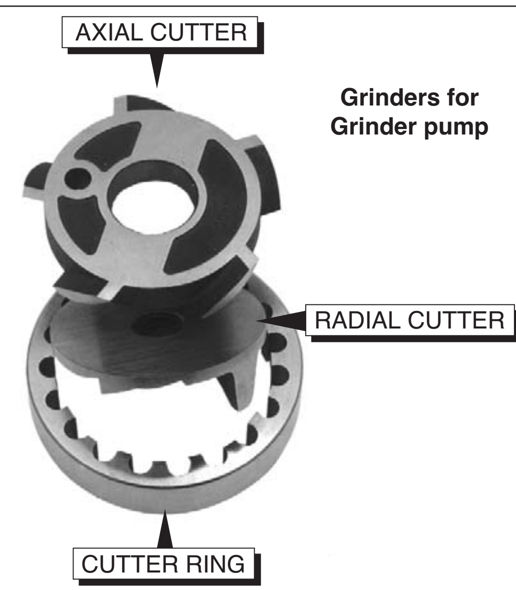
There are two special configurations commonly used in wastewater lift stations, they are the self-priming and submersible pumps. Both pumps are end-suction centrifugal pumps. The self priming pump has the suction connection attached above the impeller eye helping to maintain a level of water in the volute case. The submersible pump is a close coupled end-suction pump that uses a motor that can be submersed in water. One common variation of the submersible pump is the grinder pump. This is a standard submersible pump with a grinder built into the volute case. The grinder pump is used to reduce the size of solids in the system and thus reduce damage to the pump and piping system.



Self Priming Pump



Grinder Pump

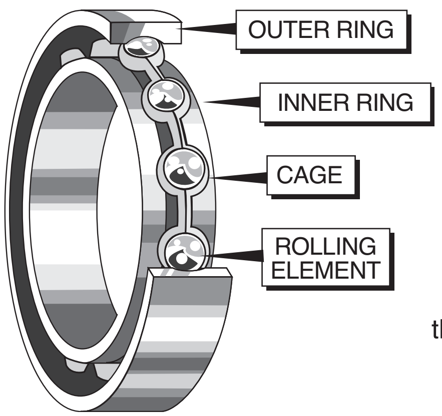


Grinders for Grinder pump

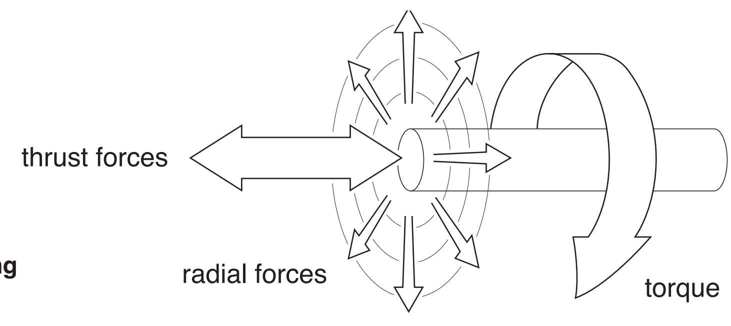
End-suction Centrifugal pump Components

Shaft & Bearings

The shaft is used to transfer energy from the motor to the impeller. The most common shaft materials are high carbon steel and stainless steel. Each shaft is supported by bearings which must support loads along the shaft, called thrust loads, and loads at right angles to the shaft, called radial loads.

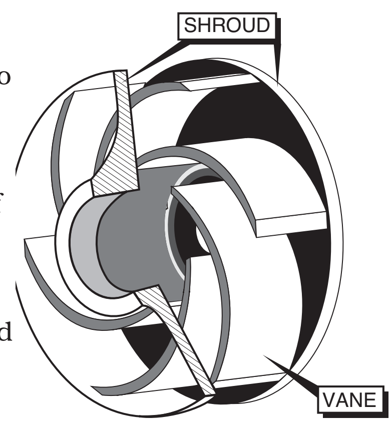


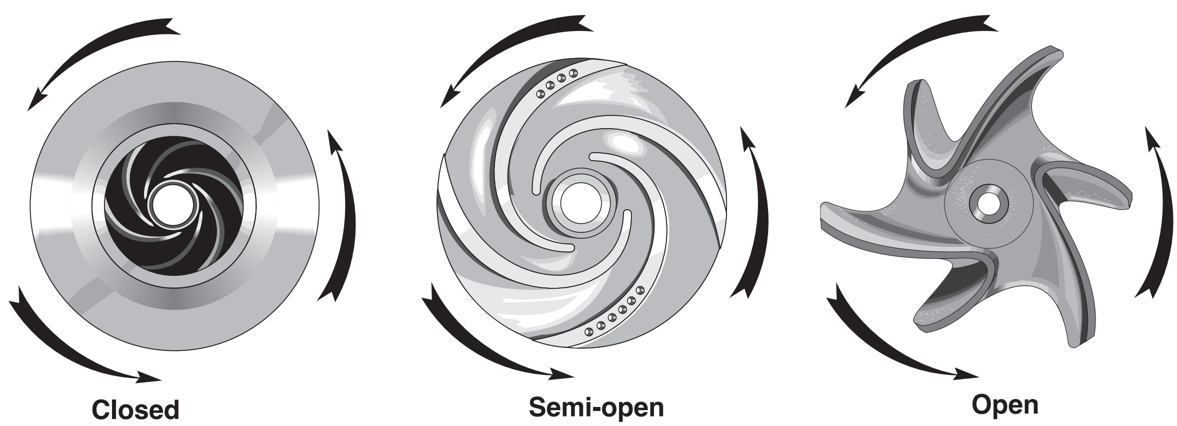
Single row deep groove ball bearing



Impellers

The energy is transferred from the shaft to the impeller and from the impeller to the water. There are three classes of impellers based on the position and number of **shrouds**[13]. When an impeller has a shroud in the front and in the back it is called a closed impeller. When there is only a shroud in the back of the impeller, it is a semi-open impeller and when there are no shrouds, the impeller is an open impeller. The impeller type is selected by the pump manufacturer to meet specific conditions.



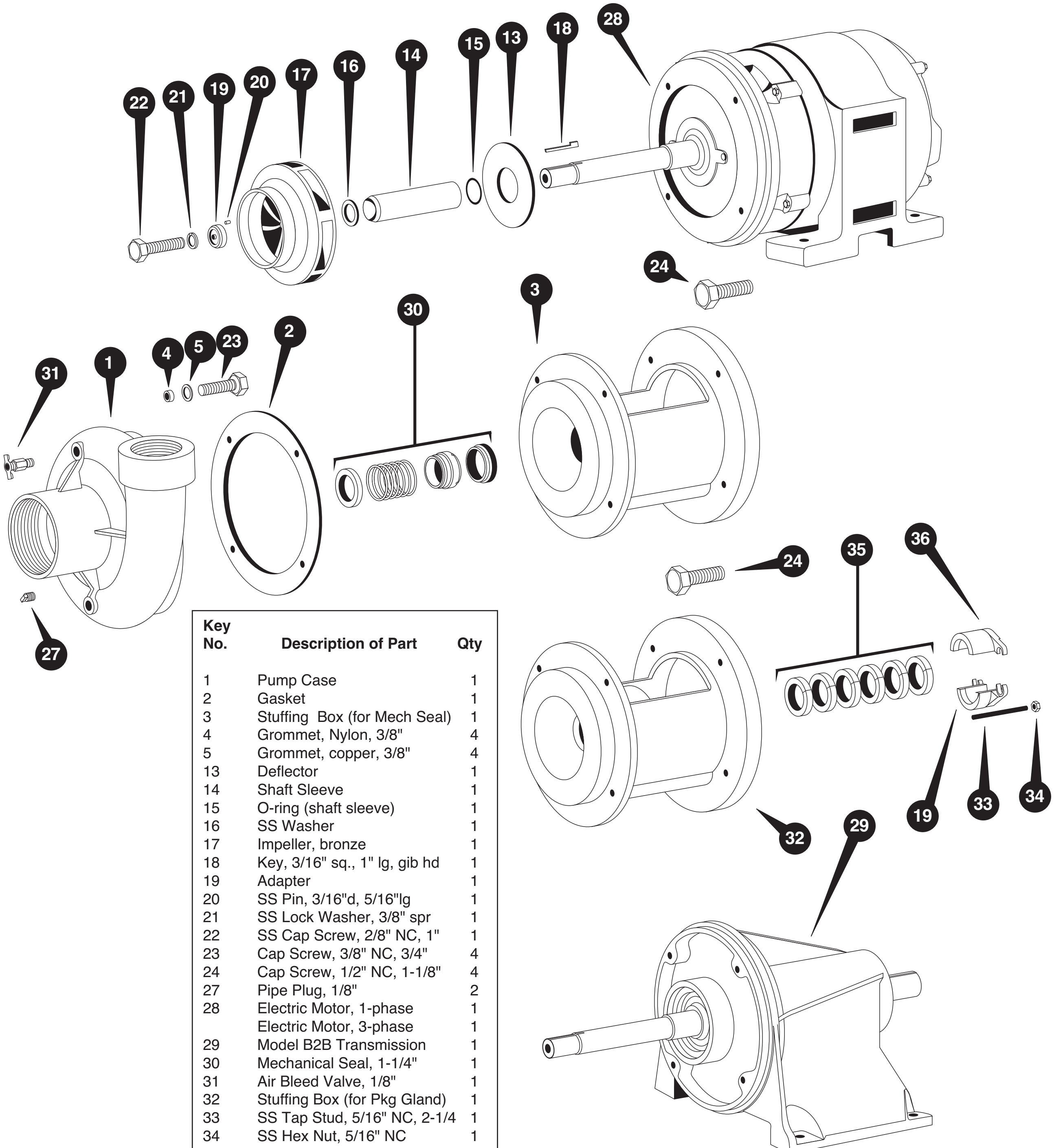


[13] **Shroud** - The front and /or back of an impeller.

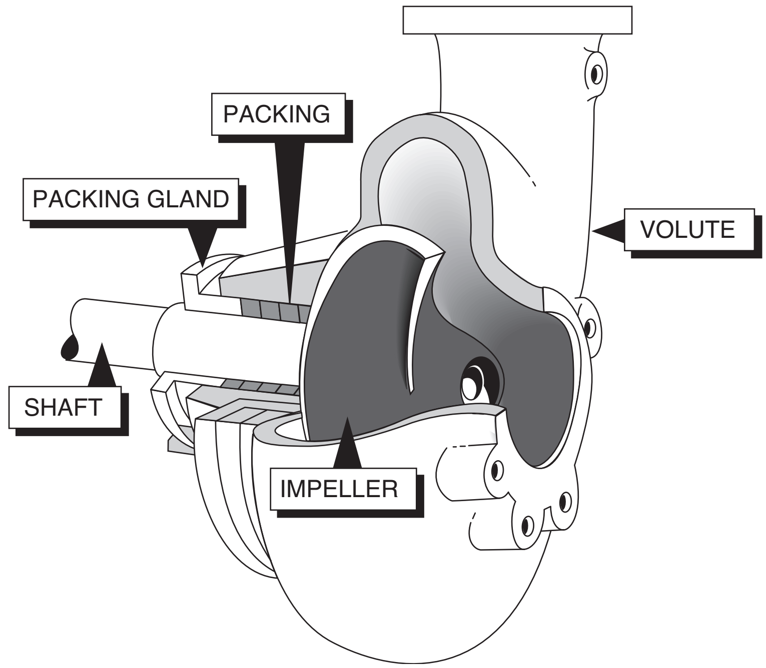
Section 300 Page R1012 August 1, 1969	R E P A I R P A R T S	Jacuzzi JACUZZI BROS. INC.

Series D

with Integral HP Close-coupled Pump Motors
and Model B2B Transmission Heads

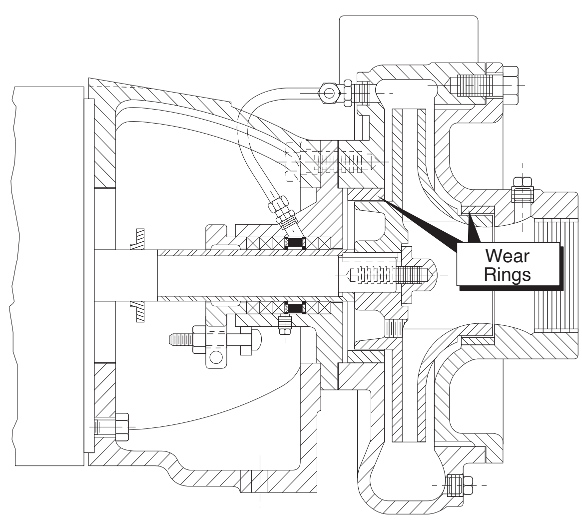


Key No.	Description of Part	Qty
1	Pump Case	1
2	Gasket	1
3	Stuffing Box (for Mech Seal)	1
4	Grommet, Nylon, 3/8"	4
5	Grommet, copper, 3/8"	4
13	Deflector	1
14	Shaft Sleeve	1
15	O-ring (shaft sleeve)	1
16	SS Washer	1
17	Impeller, bronze	1
18	Key, 3/16" sq., 1" lg, gib hd	1
19	Adapter	1
20	SS Pin, 3/16"d, 5/16"lg	1
21	SS Lock Washer, 3/8" spr	1
22	SS Cap Screw, 2/8" NC, 1"	1
23	Cap Screw, 3/8" NC, 3/4"	4
24	Cap Screw, 1/2" NC, 1-1/8"	4
27	Pipe Plug, 1/8"	2
28	Electric Motor, 1-phase	1
	Electric Motor, 3-phase	1
29	Model B2B Transmission	1
30	Mechanical Seal, 1-1/4"	1
31	Air Bleed Valve, 1/8"	1
32	Stuffing Box (for Pkg Gland)	1
33	SS Tap Stud, 5/16" NC, 2-1/4	1
34	SS Hex Nut, 5/16" NC	1
35	Packing Rings (set of 6)	1
36	Pkg Gland (set of 2 pcs)	1



Wear Rings

With closed impellers the impeller fits very close to the case. As a result, the case is worn by material passing from the high pressure side of the impeller to the low pressure side. To protect the case brass or stainless steel wear rings are inserted into the case.



Volute Case

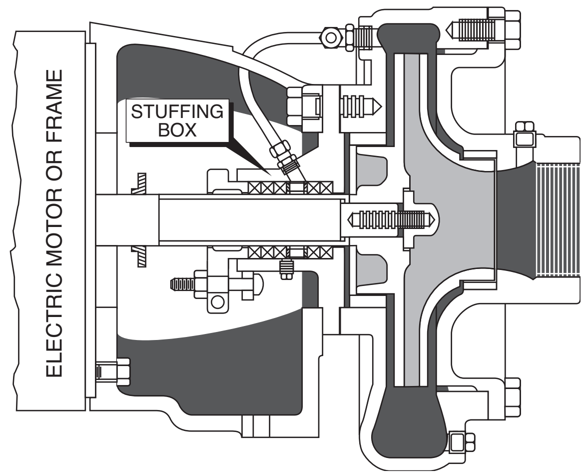
Around the impeller is the volute case. The volute case gathers the water that is being thrown from the impeller and directs it in a single direction.

Backing Plate

Behind the volute case is the backing plate. The backing plate forms the back of the volute case.

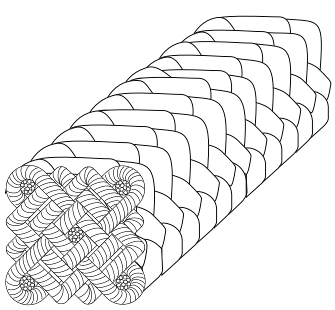
Stuffing Box

Attached to, and sometimes part of, the backing plate is the **stuffing box**[14]. The stuffing box is where we place material that controls the leakage of water from around the shaft. The material that is placed in the stuffing box is either **packing**[15] or a **mechanical seal**[16].

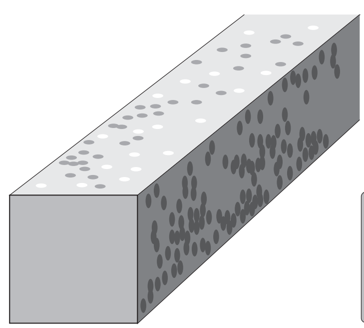


Packing

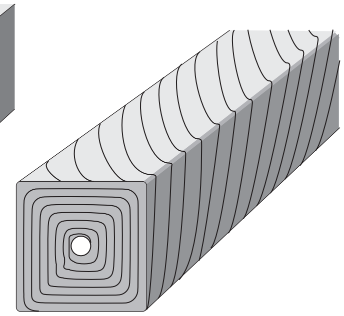
Packing is installed in the stuffing box to control leakage of water out of the stuffing box and air into the volute case. Three of the common packing configuration are; braided, formed and compressed metal. The most common type of packing used in wastewater systems is braided. Braided packing is composed of some type of fiber, like cotton and some type of lubricant, like graphite or Teflon™.



BRAIDED FABRIC



PLASTIC

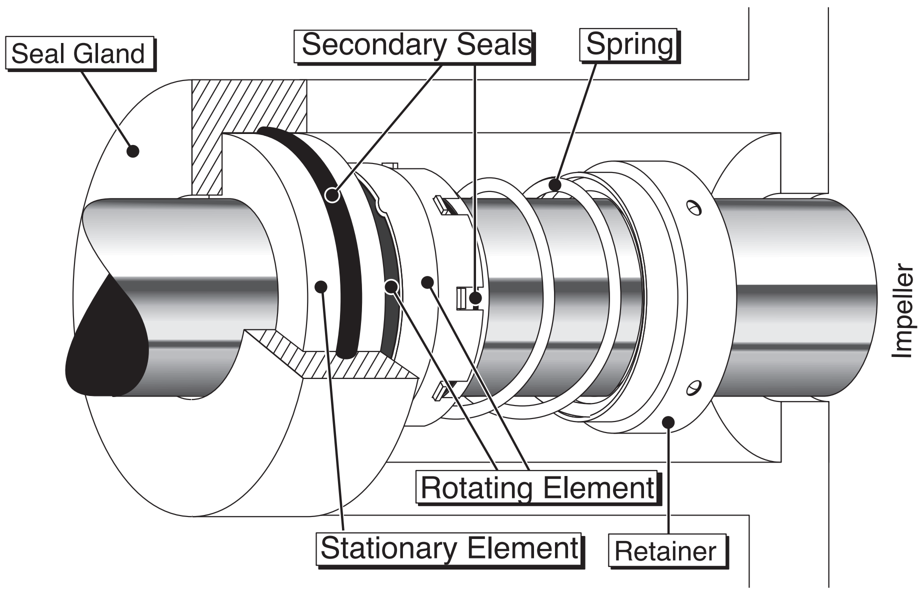


METAL FOIL

[14] **Stuffing Box -** That portion of the pump which houses the packing or mechanical seal. Usually referred to as the dry portion of the pump, the stuffing box is located in back of the impeller and around the shaft.
[15] **Packing -** Material made of woven animal, plant, mineral or metal fiber and some type of lubricant, placed in rings around the shaft of a pump and used to control the leakage from the stuffing box.
[16] **Mechanical Seal** - A mechanical device used to control leakage from the stuffing box of a pump. Usually made of two flat surfaces, one of which rotates on the shaft. The two flat surfaces are of such close tolerances as to prevent the passage of water between them.

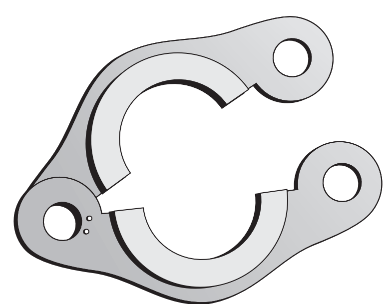
Mechanical Seals

Mechanical seals are installed in the stuffing box for the same purpose as packing, to control leakage through the stuffing box. A mechanical seal is composed of two sets of components, primary components and secondary components. The primary components are made up of two pieces, a rotating component and a stationary component. One of these must be made of a hard material (usually ceramic) and one of a soft material (usually carbon). One component must be stationary and the other must rotate on the shaft. The tolerance between these two faces prevents water from passing. The secondary portion of the mechanical seal is composed of secondary seals that prevent water from leaking along the shaft, a spring or set of springs that provide pressure on the faces and some type of retainer used to hold the rotating element on the shaft.



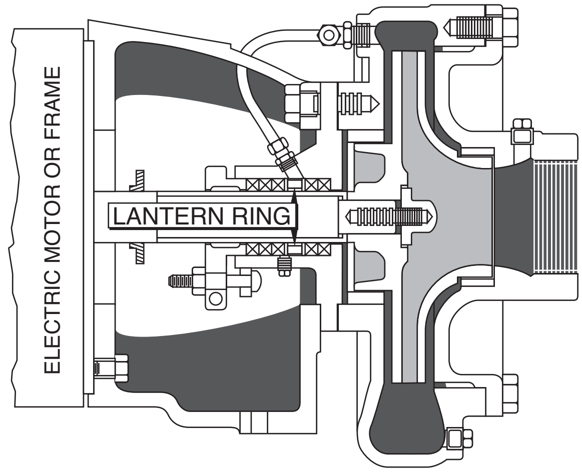
Packing Gland/Seal Gland

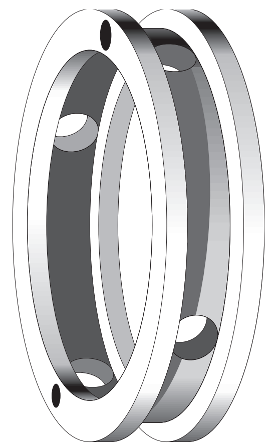
In order to control leakage with packing, pressure must be placed on the packing. This pressure is applied by the packing gland, two pieces of metal at the back of the stuffing box. When a pump uses a mechanical seal this component is called a seal gland.



Lantern Ring

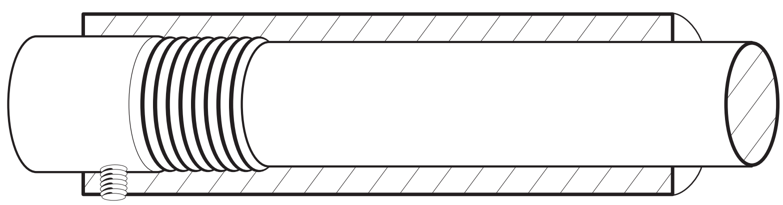
It is often desirable to lubricate and cool the packing with external water or oil. When water is used it is called **seal water**[17] or flush water. The seal water is distributed into the stuffing box through the lantern ring. The lantern ring is commonly a brass ring with holes that allow the water to easily pass.





Shaft Sleeve

To protect the shaft from damage due to the packing, a shaft sleeve can be installed. A shaft sleeve is a brass or stainless steel sleeve that fits tightly over the shaft.



17 **Seal Water -** The water supplied to the stuffing box to lubricate and flush the packing or the mechanical seal.

End-suction Centrifugal Pump - Piping System

Suction Piping

The suction piping more than any other external factor can impact pump performance. In order to reduce the impact of the piping system the suction piping is usually designed one pipe size larger than the inlet of the pump, with smooth piping material and fittings. Isolation valves on the suction side of a pump should only be knife gate or plug valves. As the piping reaches the pump it is reduced to meet the pump connection using an **eccentric reducer**[18]. The eccentric reducer prevents air accumulation in the piping.

Discharge Piping

The discharge side of a pump usually starts with a **concentric reducer**[19] taking the pipe up to one pipe size larger than the pump discharge. An isolation valve, preferably a knife gate or plug valve, is normally installed on the discharge. To reduce repair cost a flange by flange spool or expansion joint is placed between the isolation valve and the pump.

Check Valve

To prevent the flow of water back through the pump a check valve is often placed in the discharge line. The check valve could be a swing check or ball check.

Gauges

In order to evaluate pump operating conditions, pressure gauges are placed on the suction and discharge sides of a pump. Ball valves are installed at the base of the gauges to allow easy replacement and to shut the gauges off when not in use, extending their life.

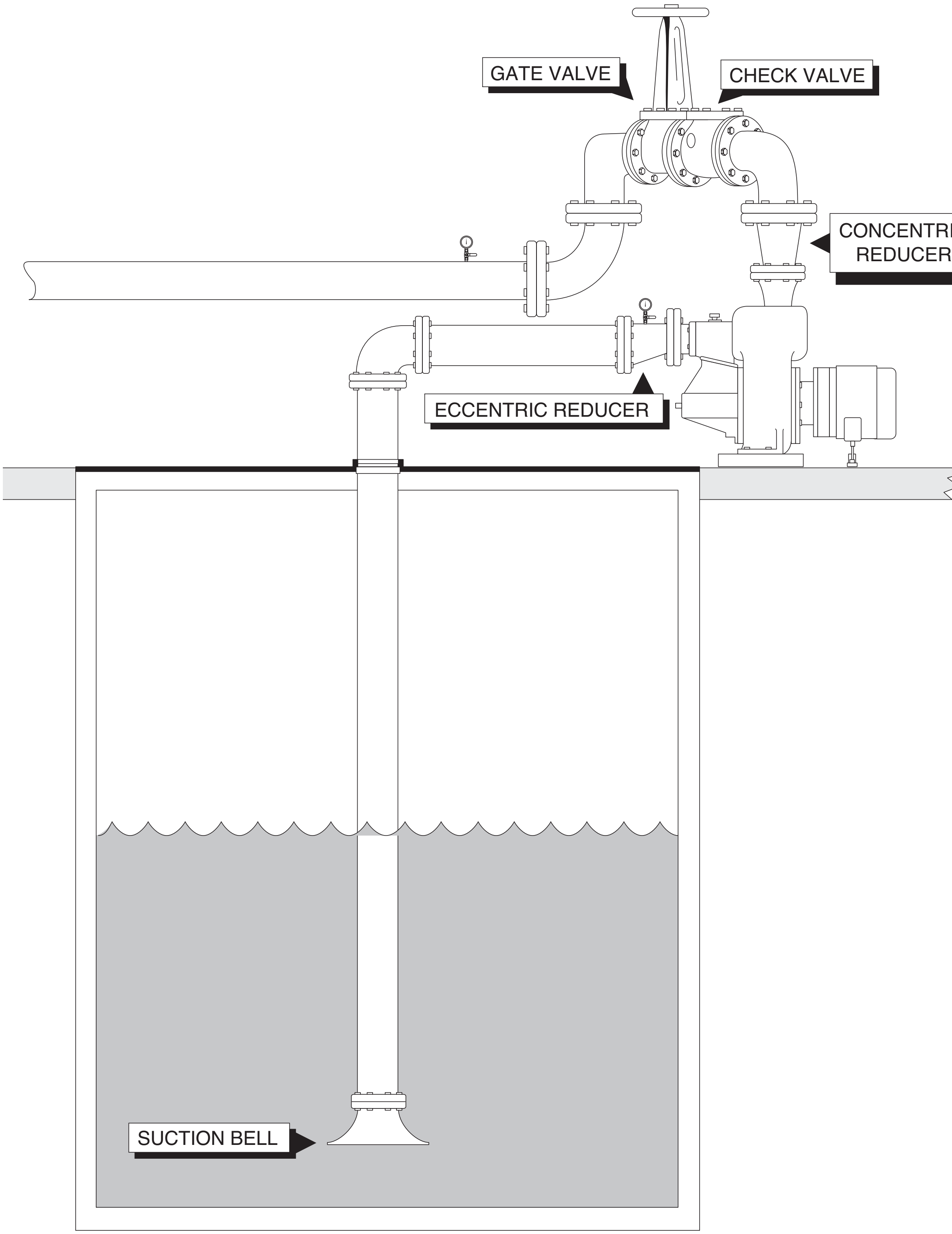
Seal Water

Seal water is used to cool packing and prevent material from entering the stuffing box from the volute case. When the pump utilizes a mechanical seal rather than packing, the seal water is used to lubricate the faces of the seal. Seal water is supplied from the discharge of the volute case or an external source. A pressure gauge should be installed in the seal water line in order to assure that flow of seal water is into the stuffing box. If the seal water source is the drinking water system then an air gap must be placed between the drinking water system and the wastewater pump. This air gap prevents contamination of the drinking water system as a result of backflow from the wastewater pump.

More Information

Additional information on the piping system found in a typical lift station can be found in the lesson on collection systems.

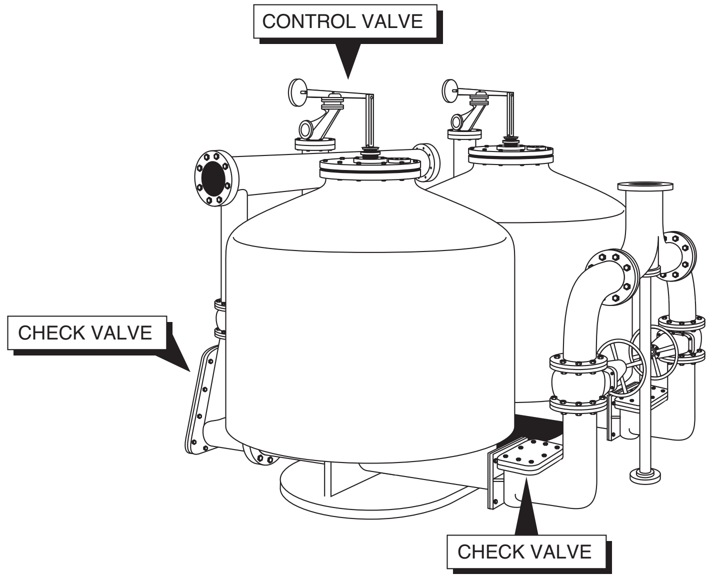
[18] **Eccentric Reducer -** A device used to connect a large pipe to a smaller pipe so that one edge of both pipes is aligned.
[19] **Concentric Reducer** - A device used to connect a large pipe to a smaller pipe so that the center lines of both pipes are aligned.


GATE VALVE
CHECK VALVE
CONCENTRIC REDUCER
ECCENTRIC REDUCER
SUCTION BELL

Pneumatic Ejector

Configuration

The pneumatic ejector consists of one or two steel or cast iron pots, which receive wastewater by gravity. When the pots become full, air is introduced into the top of the pots, displacing the sewage. These devices are available in sizes from 20-80 gpm and deliver heads of approximately 80 feet, with an efficiency of 15% or less.



Nomenclature

Pots

The sealed pots may be constructed of steel or cast iron. The pot size determines both capacity and flow capacity in gpm; that is, a 30 gallon pot is a 30 gpm device. When two 30 gallon pots are used, the system is still a 30 gallon system or can be described as a 30 gpm ejector system with a duplex pot arrangement.

Check Valves

Swing type check valves are placed on the inlet and discharge piping of the pots. These valves control the direction of flow. During the fill cycle, the inlet valve is open and the discharge valve is closed. Air pressure applied to the pot causes the discharge valve to open and the inlet valve to close. When air pressure is discontinued, back pressure of sewage closes the discharge valve. The inlet valve is opened by head developed from sewage in the inlet piping.

Controls

Liquid level in the pots is sensed by mechanical or electrical control.

Air

Air is supplied by an air compressor. In some cases, an air storage tank is used in conjunction with the air compressor, this allows the use of a low volume low voltage air compressor allowing the device to be used in remote locations.

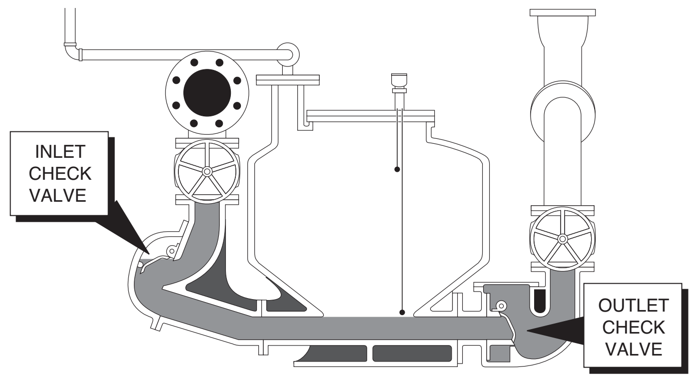
OPERATION sequence

Three Steps

The operation of the ejector is relatively simple and involves three basic steps–filling, filled and discharge.

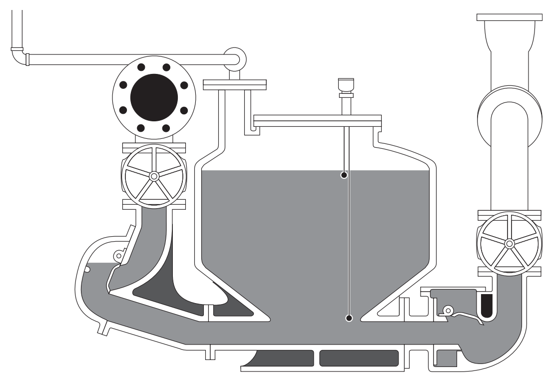
Filling

During the filling stage, the discharge check valve is held closed by a downstream head above the valve. The inlet valve is forced open by incoming sewage. Air in the pot is vented to the upstream manhole through the air inlet line.



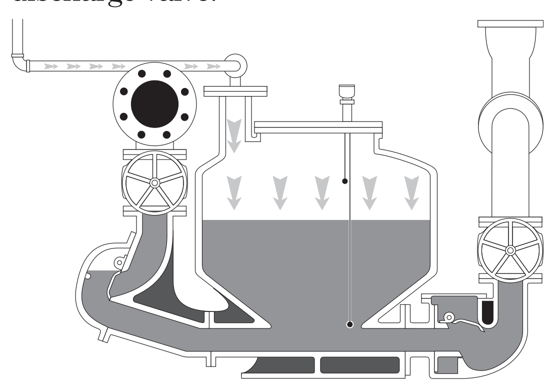
Full

When the tank becomes full, the air control valve shuts off the vent line and allows air into the pot.



Discharging

As the air pressure in the pot increases, the inlet check valve is closed and the sewage is forced out past the discharge valve.



Air Lift Pumps

Configuration

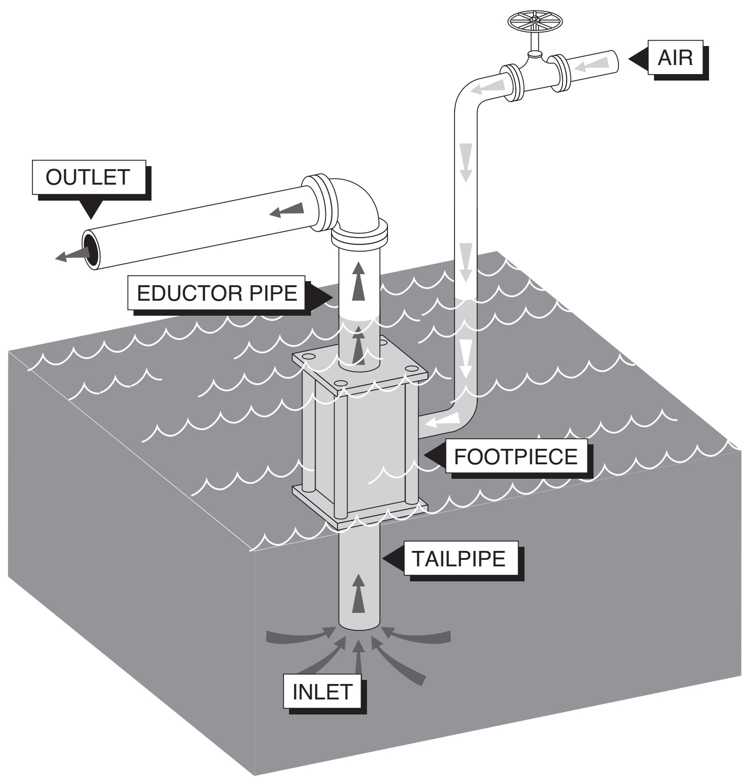
The air lift pump is relatively simple, consisting of a large pipe extending into a fluid and an air supply that introduces air into the pipe below the water level. This air supply pipe may extend down inside or outside the pump pipe.

Use

Air lift pumps are used as the return and waste sludge pump on many small activated sludge treatment plants.

Components

The main components of an air lift pump include an air supply, air inlet line and control valve. The air inlet line is connected to a footpiece. Below the footpiece is the fluid inlet pipe called the tailpipe. Above the footpiece is the eductor pipe and outlet piping.



Theory of Operation

Drop in Specific Gravity

As air is introduced into water inside the pump, the specific gravity of the wastewater inside is reduced below that of the wastewater outside the pump. This difference in specific gravity causes the wastewater on the outside of the pump to rush into the pipe, thus pushing the wastewater in the pipe up and out.

Velocity Carries Solids

As the wastewater approaches the entrance of the pump, its velocity carries large amounts of solids through the pump.

Positive Displacement Pumps

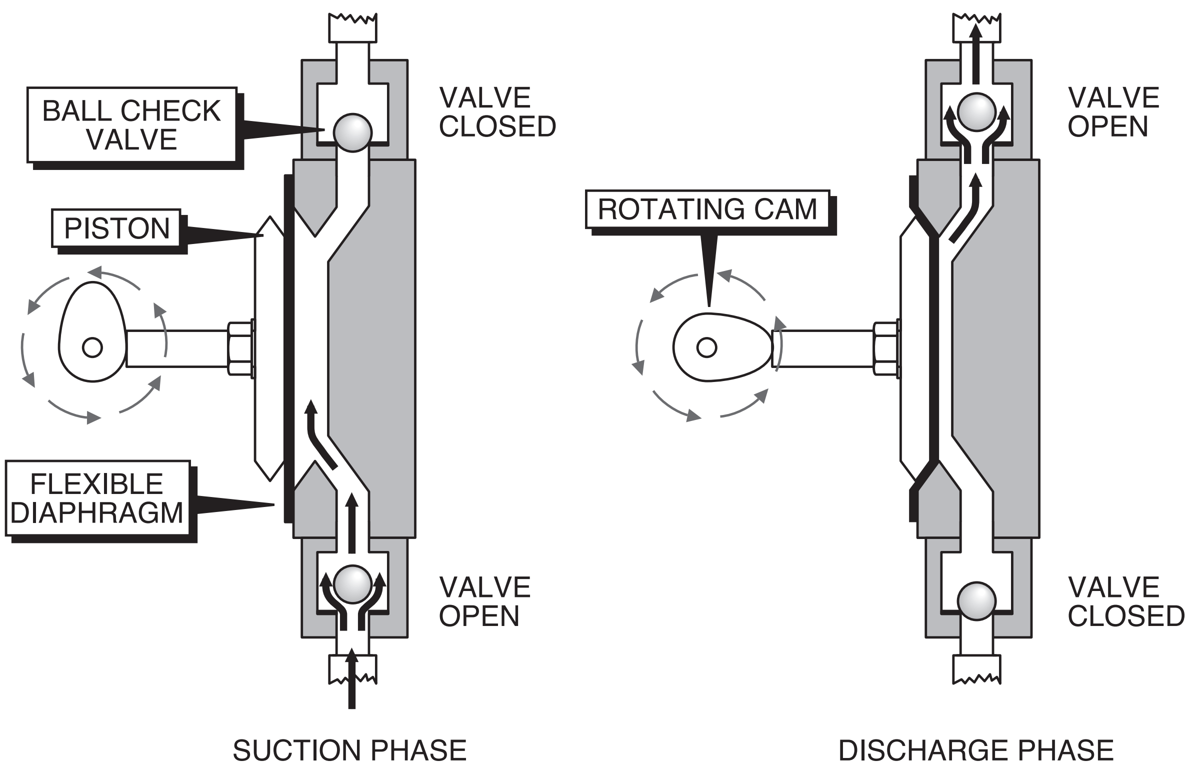
Major Components

While there are several different types of positive displacement pumps available, this discussion will be limited to diaphragm pumps. Diaphragm pumps are used to pump chlorine solutions for disinfection. The diaphragm pump is composed of:

- A chamber used to pump the fluid
- A diaphragm that is operated by either electric or mechanical means
- Two valve assemblies - a suction and a discharge valve assembly.

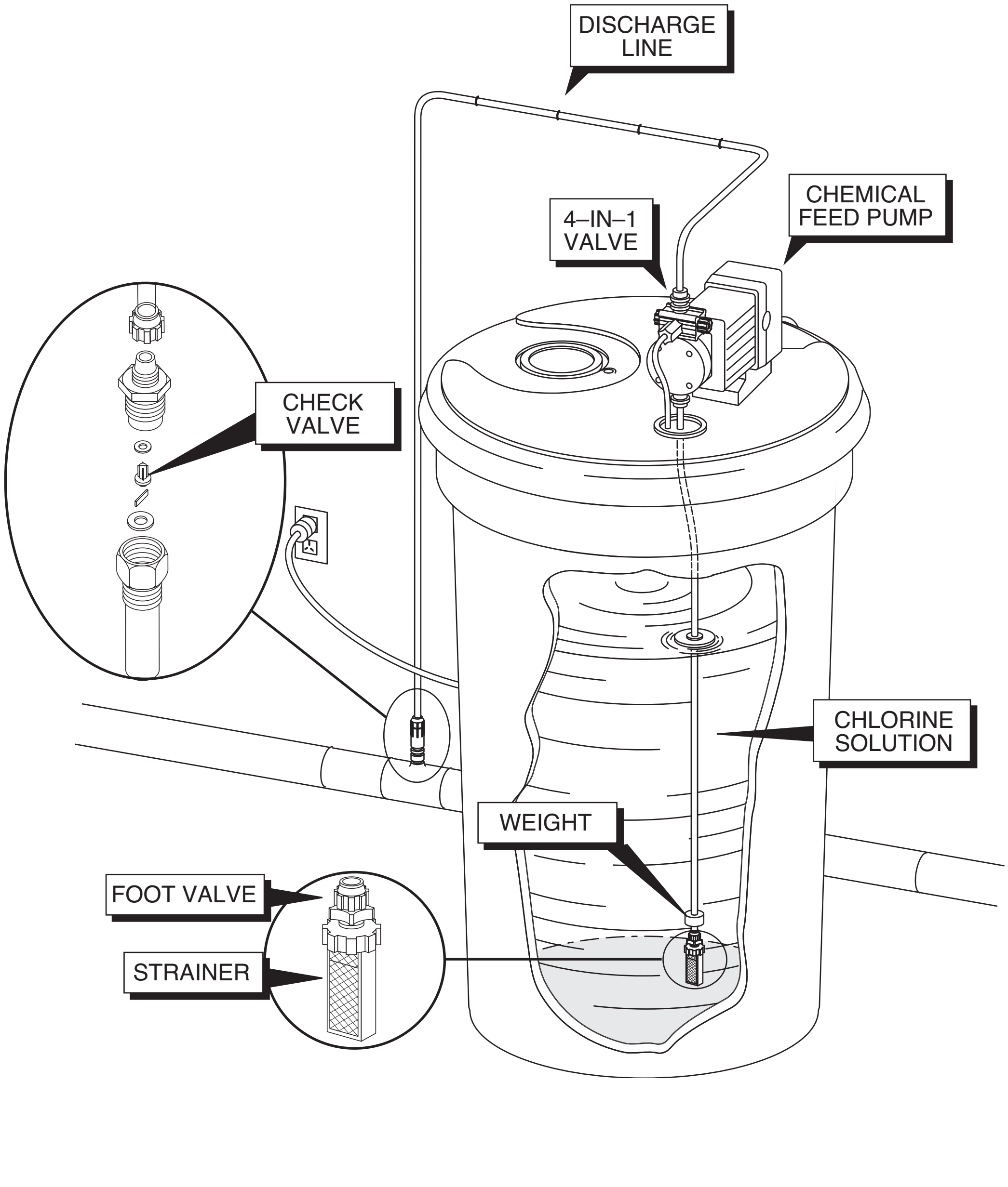
Operation

When the diaphragm is pulled back a vacuum is created in the chamber in front of the diaphragm. This vacuum causes the discharge valve to be forced closed against its seat. The vacuum allows atmospheric pressure to push fluid up against the outside of the suction valve opening the valve and filling the chamber. When pressure is returned to the diaphragm, forcing it toward the front of the chamber, the increased pressure causes the suction valve to be forced closed and the discharge valve to be forced open. The fluid is pushed out of the chamber and the pumping cycle starts over.



Piping System

The piping system for diaphragm pumps, used to pump chemicals includes a foot valve and screen on the suction line and a check valve on the end of the discharge line. The foot valve prevents loss of prime. The discharge check valve prevents the system water from flowing back into the chemical feed tank.



Pumping Equipment

Worksheet

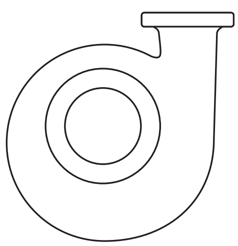
1. What are the two major categories of pumps?
   a. ______________________________
   b. ______________________________

2. How is energy transferred from the impeller of a centrifugal pump to the water?

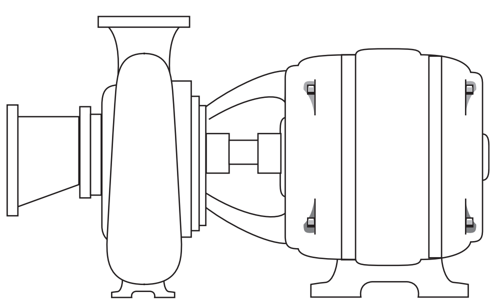
3. The two theories that are used to explain why a centrifugal pump works are:
   a. ________________________ transfer, and
   b. ________________________ force.

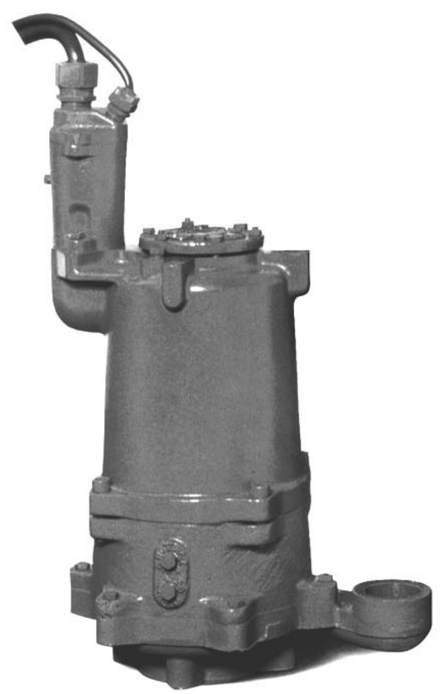
4. The energy placed into the water by a pump can be expressed as an increase in __________________ and an increase in ___________________.

5. Observe the volute case below. What is the proper direction of rotation?



6. Describe the pumps below by configuration.





7. Identify the components indicated in the drawing below. Compare the numbers on the drawing to the list provided.

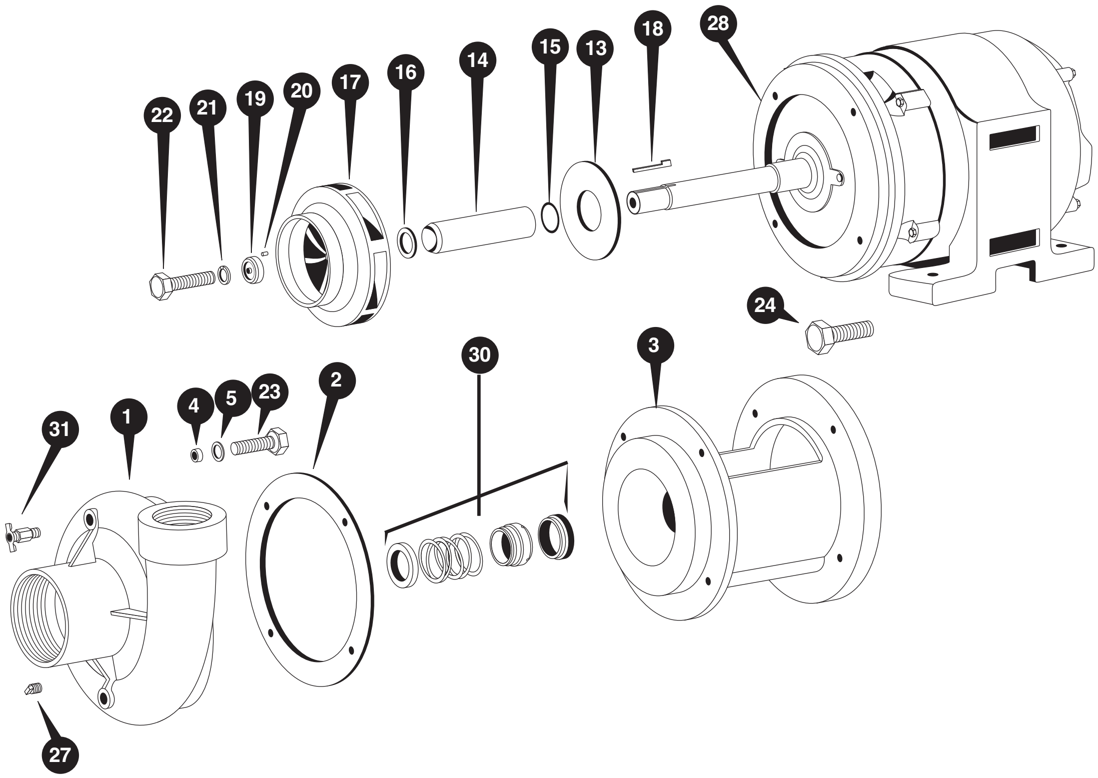
   ______ a. Volute case

   ______ b. Mechanical seal

   ______ c. Impeller

   ______ d. Stuffing Box

   ______e. Shaft sleeve



8. What is the energy source used to operate a pneumatic ejector?

9. Pumps are rated in ____________ per _________________.

10. There are two items in a centrifugal pump that are designed to wear out and at the same time protect a portion of the pump. They are:

    a. The ______________________ _______________ - designed to protect the shaft.

    b. The ______________________ _______________ - designed to protect the volute.

11. Identify the components indicated in the drawing below. Compare the numbers on the drawing to the list provided.

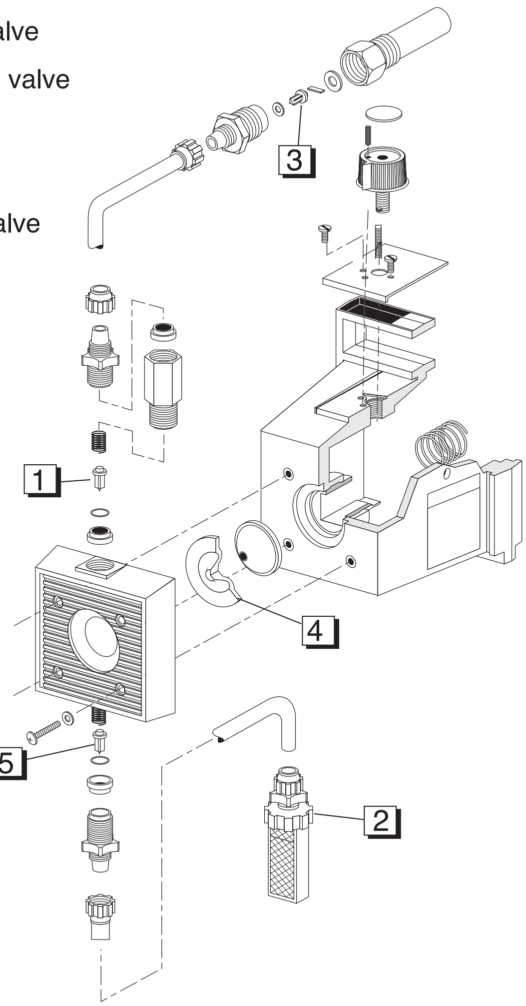
_______ a. Pumps suction valve

_______ b. Pumps discharge valve

_______ c. Diaphragm

_______ d. Foot valve

_______ e. Injection check valve



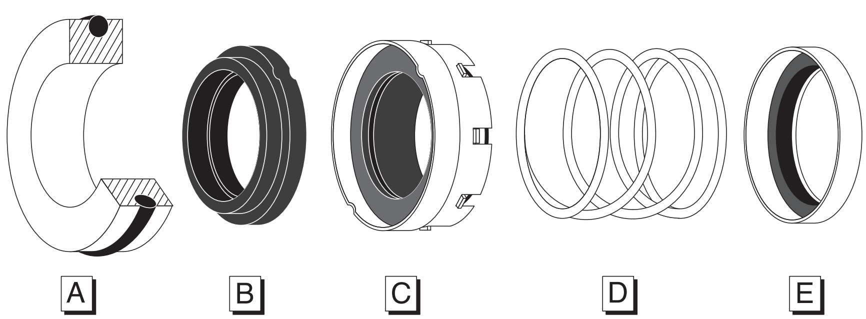
12. Identify the components in the drawing below. Compare the letters on the drawing to the list provided.

_______ a. Boot or secondary seal

_______ b. Spring

_______ c. Stationary component

_______ d. Carbon face - rotating component



13. _______________ water is used to cool the packing and provide lubrication to the mechanical seal.

14. Packing and mechanical seals serve the same purpose, __________________ leakage through the stuffing box.

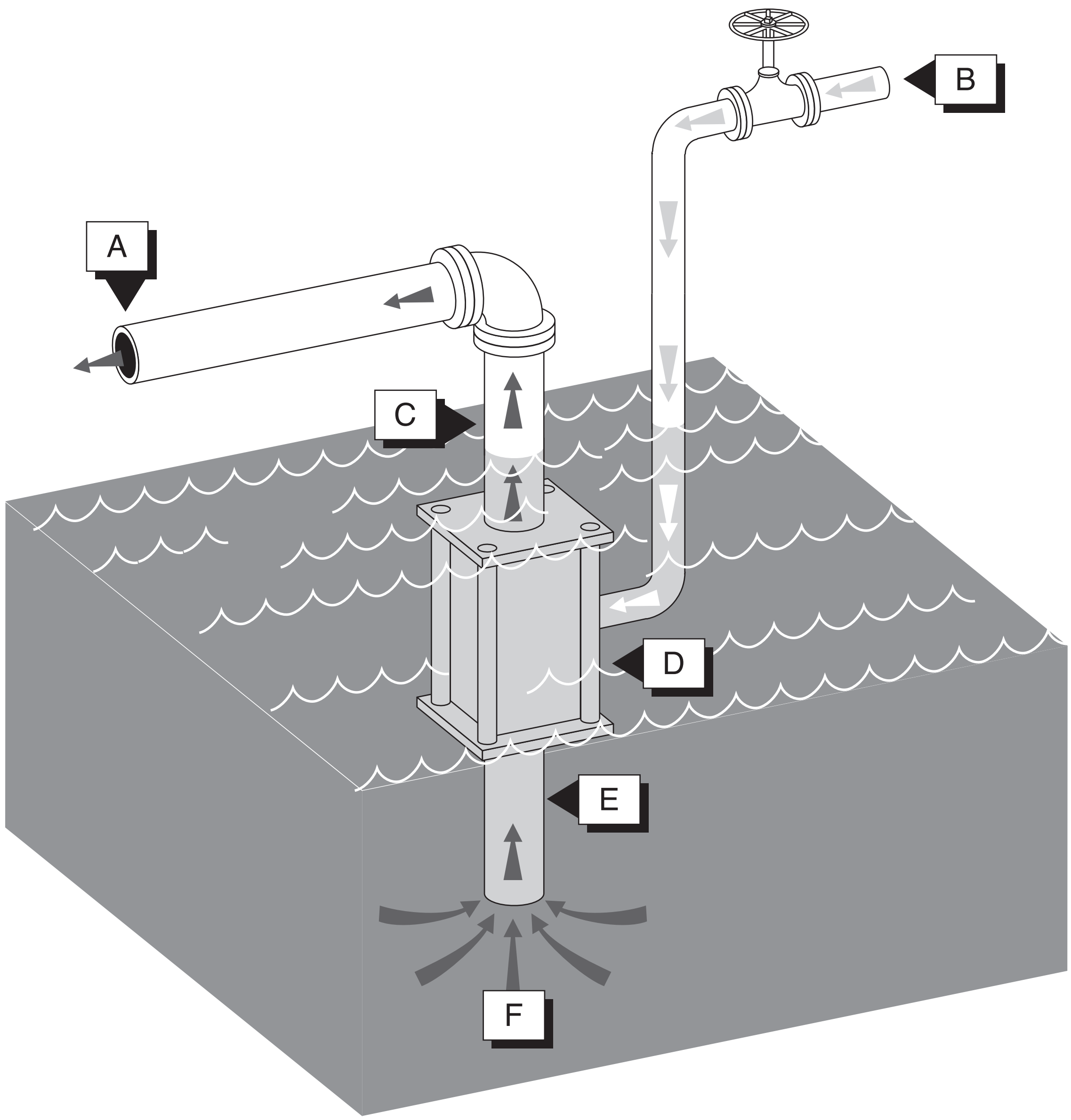
15. Identify the components indicated in the drawing below. Compare the letters on the drawing to the list provided.

    ______ a. Eductor pipe

    ______ b. Tailpipe

    ______ c. Air supply

    ______ d. Footpiece



Electrical Basics & the Electrical Systems

What is in this Lesson?

1. The basic components of an atom
2. Basic electrical units and symbols
3. The difference between a conductor and an insulator
4. The difference between open and closed circuits
5. The difference between AC and DC power
6. An explanation of single and three phase power
7. How electromagnets work
8. The function of common electrical components found in small wastewater systems
9. Identification of the basic electrical components found in a lift station

Key Words

- AC
- Atom
- DC
- Electron
- EMF
- Hertz
- Magnetic Breaker
- Neutron
- Resistance
- Three phase power
- Amperage
- Brake horsepower
- Conductor
- Electromagnetism
- Heater
- Insulator
- Magnetic Starter
- Proton
- Single phase power
- Voltage

Electrical Basics

Introduction

In order to develop a basic understanding of how electrical equipment works we need to review basic electrical theory. One of the basic electrical theories is based on the atomic theory, so we need to start with a review of atomic theory.

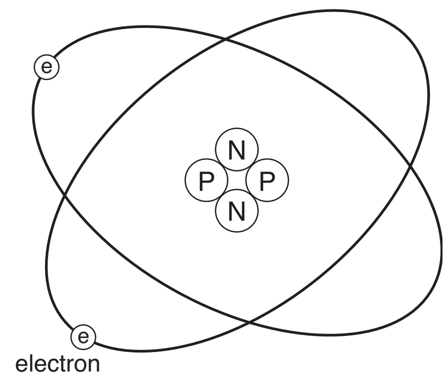
Atomic Theory

The Atom - Nucleus

If we break matter into its smallest component the base unit will be the **atom**[1]. An atom is composed of three components, the center is called the nucleus and may contain two type of particles, protons and neutrons. The protons have a positive charge and the **neutrons**[2] have a neutral or zero charge.

The Electron

Orbiting around the nucleus are one or more electrons. The **electron**[3] is extremely small. It travels at nearly the speed of light and has an electrical charge that is negative. This negative charge is equal in value to the positive charge of the **proton**[4].



Stability of the Atom

The electrons remain a constant distance from the nucleus of the atom. There are two forces that hold them in this position. One is the electrical attraction between the negative electrons and the positive protons. This tends to pull the electrons into the nucleus. The second force is centrifugal force. Centrifugal force tries to make the electrons fly away from the nucleus. The two forces counteract each other and hold the electrons stable in their orbits.

Electron Shells

The electrons in an atom form shells or orbits around the nucleus. Each shell has a precise number of electrons. Each element has a different number of electrons. The atoms of the heavier elements have multiple shells. Regardless of the element, atoms are most stable when they have eight electrons in their outermost shell.

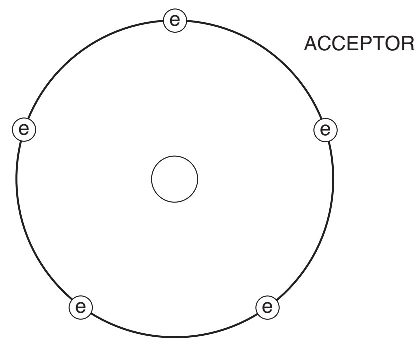
1 **Atom** - The smallest part of an element which still retains the properties of that element.
2 **Neutron** - A neutral charged particle in the nucleus of an atom. This particle has the same weight as a proton, an atomic weight of 1.
3 **Electron** - A negative charged particle that travels around the nucleus of an atom.
4 **Proton** - A positive charged particle in the nucleus of an atom. They have an atomic weight of 1 and an atomic charge of plus 1.

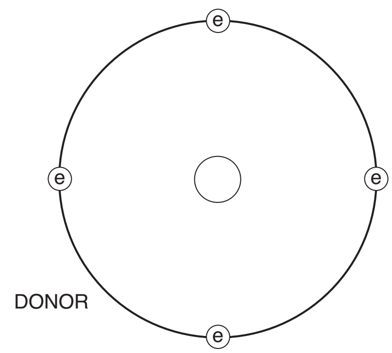
Less than Eight

When an atom has less than eight, but five or more electrons in its outer shell, the atom prefers to gather more electrons to be satisfied. This type of material is called an acceptor. Electrically, materials that are acceptors are called **insulators**[5]**.** They do not allow the flow of electrons easily. Examples would be glass, plastic, and rubber.

Less then Five

When an atom contains less than five electrons in its outer shell, it is easier for it to give up the excess than to gain more electrons. Atoms with less than five electrons are called donors. Electrically, materials that have fewer than five electrons are called **conductors**[6]. These atoms allow electrical current to flow easily. Examples would be, copper, gold, aluminum and iron.



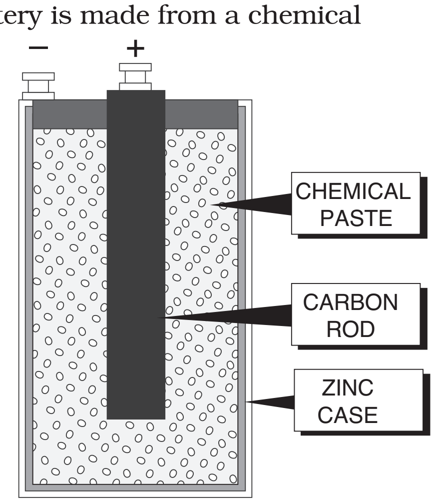


Making Electrons Move

In order to cause the electrons of a donor material to leave the atom, sufficient energy must be applied to cause the electron to speed up enough to overcome the attraction of the nucleus. Energy can be applied mechanically by a generator, by light, by pressure, by chemical reactions and by heat.

Battery

The simplest way to look at electrical energy is with a battery. A dry cell battery is made from a chemical paste and two electrodes. The chemical reaction between the chemical paste and the electrodes causes an excess of electrons to accumulate on one post creating an electrical charge difference between the two posts. If a conductor is connected between the two posts, electrons will flow from one post to another.



[5] **Insulator** - A substance, body, or device that prevents the flow of electrical current.
[6] **Conductor** - A substance, body, device or wire that readily conducts or carries electrical current.

Flow of Electrons in a Conductor

Electrons do not flow through a wire in the way that water flows through a pipe. Electrons move from one atom to another in a random pattern. This random flow of electrons is called electrical current. According to the electron flow theory the electrons flow from the negative terminal of the battery to the positive terminal. With a battery or AC power source the negative terminal is commonly called the neutral or ground because in a AC system it is connected to ground.

Measurements of Electricity

Pressure

The battery can be viewed as an electrical pump. There is an electrical force difference between the two poles. This electrical difference is called electromotive force or **EMF**[7] for short. If the battery were visualized as a water pump, this difference would be the difference in pressure between the suction and discharge of the pump.

Pressure - Volts

Electrical pressure is called **voltage**[8]. The units of measurement are volts. The symbol for volts can be "E" (for EMF) or " V" for volts. Voltage is measured with a volt meter.

Flow

The flow of electrons from one point to another is called current. Current is measured as **amperage**[9], or amps for short. Current or amps is similar to flow in gallons per minute in a water line. The electrical symbol for amps is "I" or "A". Amperage is measured using an amp meter.

Resistance

The **resistance**[10] to the flow of electrons is called resistance. This is similar to headloss in a water line. Resistance is measured as ohms. Electrically the symbol for resistance is "Ω" (the Greek letter omega) or "R".

Summary

Electrical Measurement	**Units**	**Symbols**	**Water Equivalent**	**Water Units**
Pressure (EMF)	Volts	E or V	Pressure	psi
Current	Amps	I or A	Flow	gpm
Resistance	Ohms	Ω or R	Headloss	Feet

Electrical Measurements

A common meter used by operators is a VOM. VOM stands for Volt, Ohm, Milliamp meter. This meter is also called a multimeter. A VOM is used to measure AC and DC voltage, resistance and amperage up to 300 milliamps (mA) or 0.3 Amps. This is much lower than the amperage flow to an electric motor. In order to measure the amperage that flows to an electrical motor a clamp-on amp meter must be used.

[7] **EMF - Electromotive Force** - The electrical pressure (voltage) which forces an electric current through a conductor.
[8] **Voltage** - The measurement of EMF between two points.
[9] **Amperage** (AM-per-age) - The measurement of electron flow.
[10] **Resistance** - The opposition offered to the flow of electrical current. Usually measured as Ohm's.

Types of Circuits

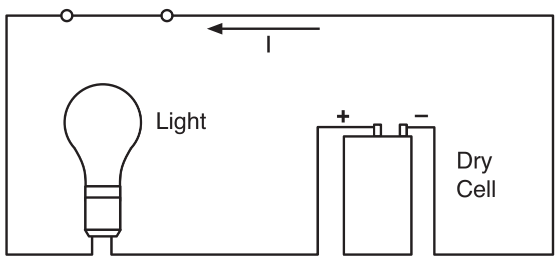
There are two types of electrical circuits that we need to be concerned with; open and closed circuits.

Open Circuits

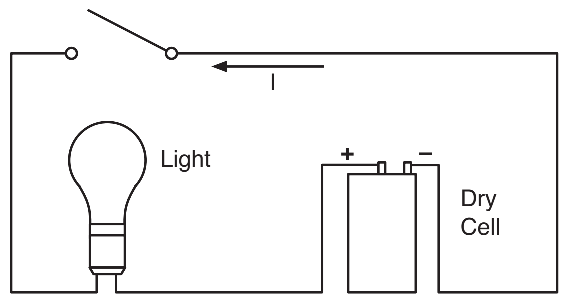
An open circuit is similar to having the light switch in the "off" position. There is no electrical current flow. There is no connection between the light and the power system, thus there is no flow of electrons.

Closed Circuits

A closed circuit exists when the switch is closed (in the "on" or run position) so that electrons can flow from the power source to the light, and the light comes on. Note the flow is from the negative pole (also called the ground or neutral) to the positive pole of the battery.



Closed Circuit



Open Circuit

Two Types of Current

Direct Current

There are two basic types of current, direct current (**DC**[11]) and alternating current (**AC**[12]). With direct current the electrons are always flowing in a single direction. This is the type of current available from a battery. Most electronic equipment, such as computers, the TV and stereos use direct current internally. DC was found to have a serious disadvantage-it is difficult to deliver over long distances.

Alternating Current

The current we are most familiar with is alternating current or AC. This is what is available at the electrical outlets in the room and is used to operate the pumping control system and electrical motor. With AC current the electrons flow first in one direction and then the other. This flow in one direction, reversal of flow in the other direction, reversing and getting ready to start all over again is a cycle. In most places, 60 of these cycles occurs each second. Thus we get the term 60 cycle AC. A newer term for cycles per second is **Hertz**[13](Hz).

[11] **DC - Direct Current** - A flow of electrons in a single direction at a constant rate so that the value remains stable.
[12] **AC - Alternating Current** - An electric current of constantly changing value which reverses direction of flow at regular intervals.
[13] **Hertz** - The frequency at which a cycle repeats within one second. For instance, a repeat of a cycle at a rate of 60 times per second is called 60 Hertz.

Generators

A mechanical device called a generator is used to produce AC electricity. A generator can be powered by water (called hydroelectric generators) steam or diesel engines.

Converters

It is possible to convert DC to AC and AC to DC. A device used to transfer DC to AC is a special electrical component called a converter.

Rectifiers

We convert AC to DC for our electronic equipment such as computers, the TV and stereos. An electrical device called a rectifier is also used to used to convert AC to DC.

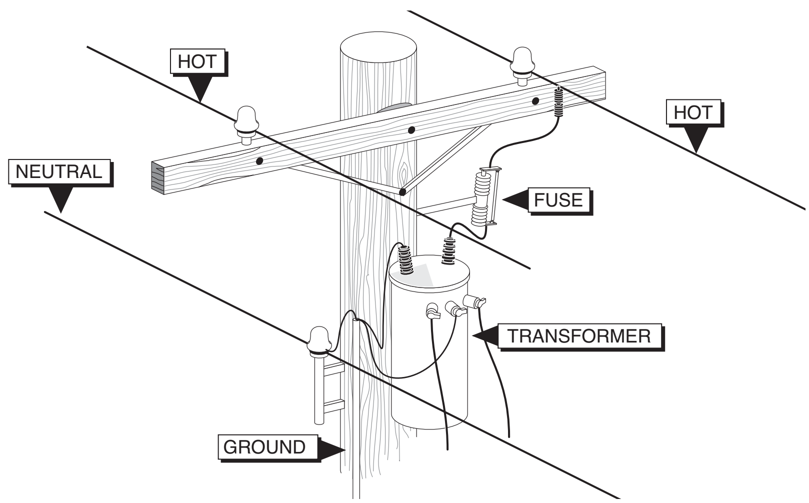
Single and Three Phase Power

Introduction

When we are talking about pumping stations we often ask, "is it **single**[14] or **three phase**[15]?". Without some background these terms can have very little meaning. The following is a brief introduction into the difference between single phase and three phase power.

Single Phase

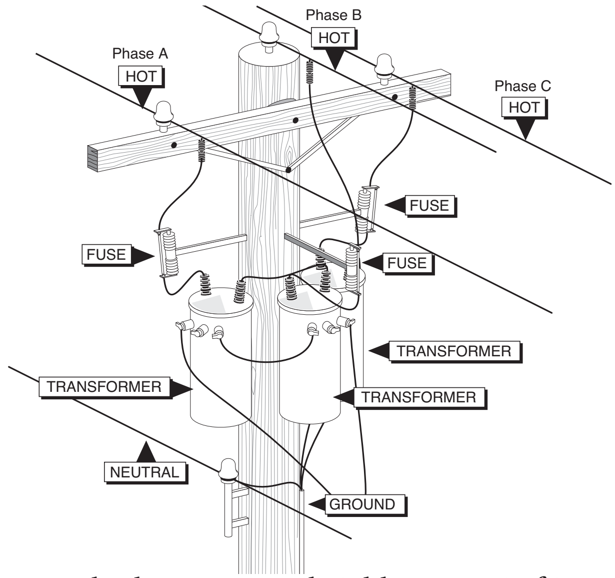
Phases can be equated to sources. With single phase power there is a single source of power. There would be two wires leading to the building, one that is called the hot lead and one that is called the neutral. Most homes have three lines leading to the building. There are two hot leads and one neutral. While this is really two phase power it is called single phase. For a household service this system provides 120 volts and 240 volts on two "hot" legs and a neutral (the ground).



Three Phase

Three phase power can be equated to three power sources. Each source is a different phase. At a pump station or treatment plant three phase power would have four wires coming from the pole transformer to the building. There would be three hot leads and one neutral (the ground).

14 **Single Phase Power** - A circuit or generator in which only one alternating current is produced.
15 **Three Phase Power** - A circuit or generator in which three power sources 120° out of phase with each other are produced.



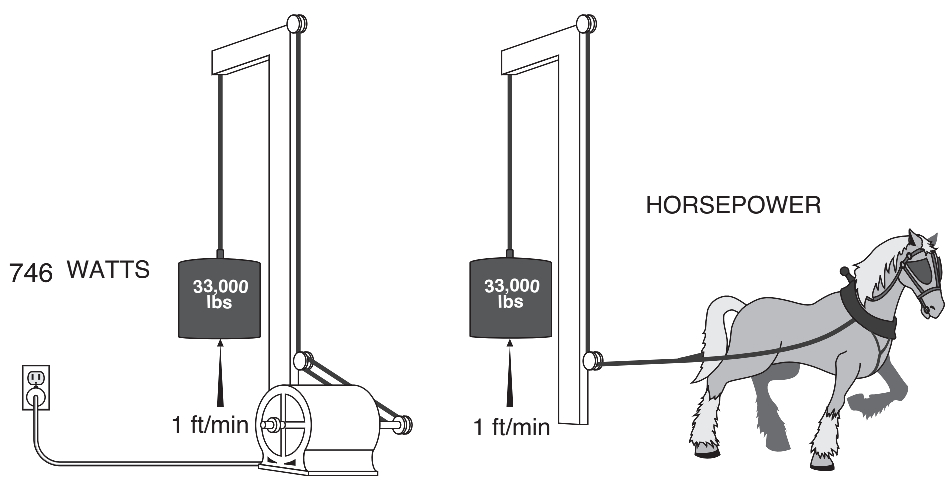
Advantage of Three Phase

Because each phase is a predictable amount of time out of time with the others we can use this phenomena to easily start an electrical motor without the use of switches or capacitors. This reduces motor manufacturing and maintenance cost. Electric motors have to be built to operate with either single phase power or three phase power. They cannot be built to operate on both.

Horsepower

Doing Work

Moving wastewater from one location to another is defined as work and requires energy. One of the ways to measure the amount of energy required to do work is in foot-pounds. One foot-pound of work is the amount of energy required to lift one pound of water one foot in elevation. In pumping situations the amount of work done will be in the thousands of foot-pounds. Because we do not like to use large numbers we have defined another term for work. When 33,000 foot-pounds of work is performed in one minute we call it one horsepower.



Electric Motors

Electric motors are rated in horsepower. The output of the motor is the nameplate horsepower and is called **brake horsepower**[16].

Horsepower to Electricity

In order to provide the horsepower required, electricity is needed. The amount of electricity used is a combination of the voltage and the amperage and is called power and given the unit watts. There is a relationship between horsepower and watts.

1 HP = 746 watts

Power Use

The electrical company measures and sells power based on the number of kilowatts used and how long they were used. Using one kilowatt for one hour is called a kilowatt hour. A kilowatt is equal to one thousand watts.

1,000 watts = 1 Kilowatt (KW)

KW Meters

The device used to measure power consumption is the KW meter (Kilowatt meter). There are two types of KW meters. The standard meter and the demand meter. The standard meter records the amount of watts used. The demand meter records the watts used and the highest watt demand that occurred during the previous time period (usually one month).

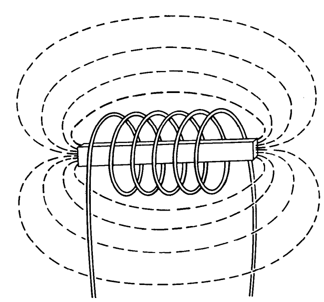
Electromagnetism[17]

Electromagnetic Field

When current is passed through a conductor an electromagnetic field is developed around the conductor. This field is very much like the field that exist between the north and south poles of a permanent magnet. It makes no difference if the current passed through the wire is AC or DC. The same electromagnetic field is produced.

Making A Magnet

If we wind a wire around a piece of metal and pass a current through the wire the piece of metal will become a magnet with a north and south pole.



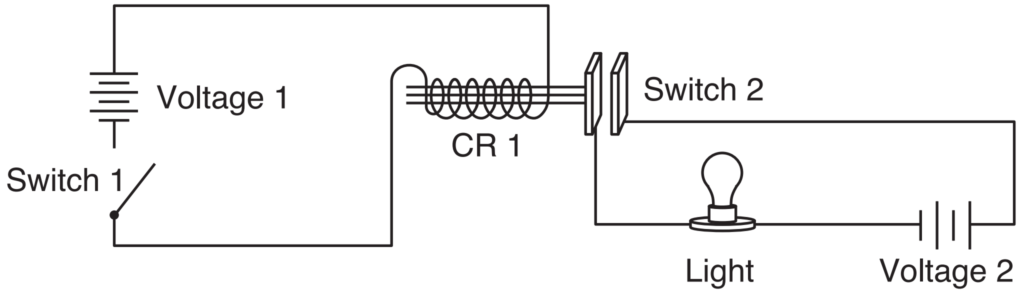
Turning The Magnet into a Switch

Lets use the electromagnet to operate a switch. A simple switch could be made by placing a metal bar close to the end of the magnet. Connect the bar to one side of an electrical supply. Connect a second bar and light to the other side of an electrical source. If we close switch #1 power is applied to the electromagnet the bar that is part of switch #2 is

[16] **Brake Horsepower** - The output horsepower of an electric motor. The representation of the amount of work that the motor can perform. Providing work of 33,000 foot pounds per minute is equivalent to one horsepower.

[17] **Electromagnetism** - (1) The magnetic force produced by an electric current (2) The science which studies the interrelation of electricity and magnetism.

pulled down by the electromagnetic field and the light is energized.



Use of the Electromagnet

The electromagnet is used to operate relays, solenoids, magnetic starters and magnetic breakers. When an electromagnet includes one or more switches, such as shown in the drawing above the device is called a contactor. Contactors include relays and magnetic starters. However, the word contactors is commonly used to describe a contact relay.

Contactors

The contact relay is one of the most common electromagnetic devices found in a control panel. (It is also called a relay, contactor or contact relay.) These simple electromagnets are used to open or close a switch. These same devices are also available to open a switch. There are contactors available with multiple contacts that can turn equipment and lights on and at the same instant turn other equipment and lights off. All of this can be done with a single contactor. Remember a contactor contains a coil of wire (an electromagnet) and one or more switches that are opened or closed by the electromagnet.

Contactor or Contact Relay

Magnetic Starters

A magnetic starter is nothing more than a large contactor. The switch that provides power to the electric motor is closed by applying power to an electromagnet (the coil). In most instances the power to the motor is much higher voltage (240, 460, 480 etc) than the power applied to the electromagnet (the coil), which is typically 120 volts. The power applied to the electric motor is referred to as the power system and the power applied to the coil is part of the control power system. Diagrams showing the parts of a magnetic starter and these different power systems are found in the following section.

Pumping Electrical Systems

Introduction

The electrical system associated with lift stations is composed of two independent but associated systems: the power system and the control system.

Power System

Transformers

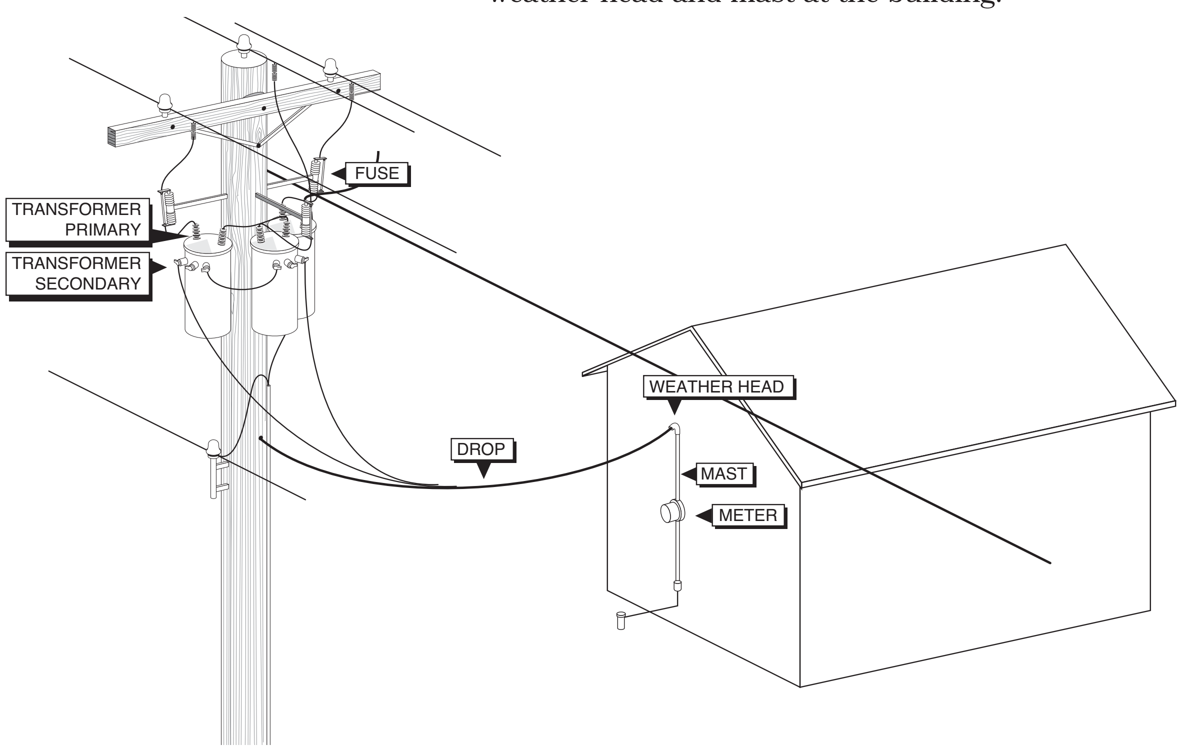
The power system starts at the power company's transformer. Transformers are electrical devices that change voltage. They can be used to step voltage up or step voltage down. The transformer on the pole outside of the pumping station or treatment plant is always a step-down transformer. In most instances there is a second step-down transformer in the control panel to step the voltage down from that needed for the motors to 120 volts for the control system. There are two sides to a transformer, the primary side and the secondary side. The primary side is the inlet and the secondary side is the outlet. The primary side of a step-down transformer is the high voltage side.

Fuses

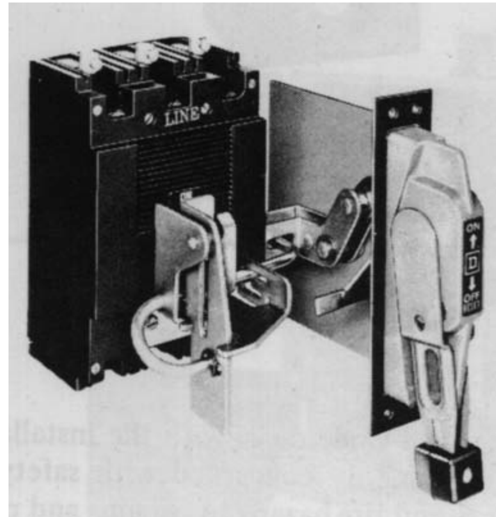
The primary side of the transformer is fused to prevent a short in the pump station from causing excessive damage to the power system. A fuse is a device that either burns through or trips when there is an overcurrent condition. Fuses are used to prevent the building from catching on fire when there is a short circuit. A short circuit is a direct connection between two “hot” leads or one of the “hot” leads and ground.

Drop

The lines leading from the transformer to the lift station are called the drop. The drop connects to the weather head and mast at the building.



Disconnect, Breaker or Fuse



The wires lead down the mast to a disconnect. The disconnect is used to disconnect the power from the entire system. From the disconnect, power goes to the **magnetic breaker**[18] or **fuses**[19]**.** In some cases the disconnect and the magnetic breaker may be the same item. The magnetic breaker and fuses both serve the same purpose, overcurrent protection. Should a short circuit occur the breaker or fuse would prevent a fire in the building or wiring.

Neutral Bus & Ground Rod

The neutral wire from the pole is connected inside the control panel to the neutral bus (see the drawing on page 343). This bus is commonly connected, physically, to ground by using a ground rod. A ground rod is a copper rod eight to twenty feet in length that is driven into the ground. This rod forms the physical and electrical ground necessary for the safe operation of the electrical equipment.

Ground Fault

Because the loss of the connection to the ground rod creates a safety hazard most new control panels include an electrical device called a ground fault interrupter or detector. These devices will disconnect power to the system if there is a loss of ground or a short to ground.

Magnetic Starter

From the breaker, power is wired to the **magnetic starter**[20]. The magnetic starter is an electrically operated switch (a contactor). The switch is closed when an electromagnet is energized. When the electromagnet is de-energized a spring disconnects the switch. Power to operate the electromagnet is supplied through the control circuit.

Heaters

At the bottom of the magnetic starter is the **heater**[21] assembly (thermal overload). The heaters are composed of two sections. One section is a device that senses the amount of amperage flowing through the

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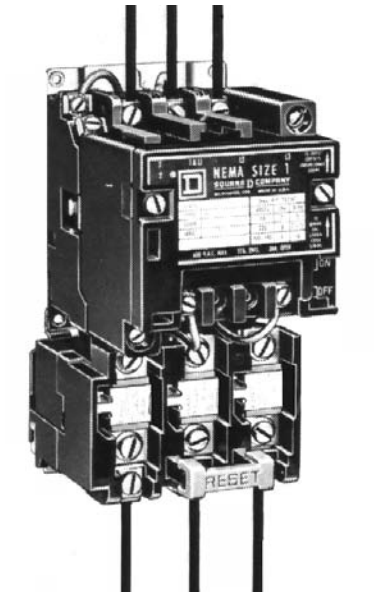
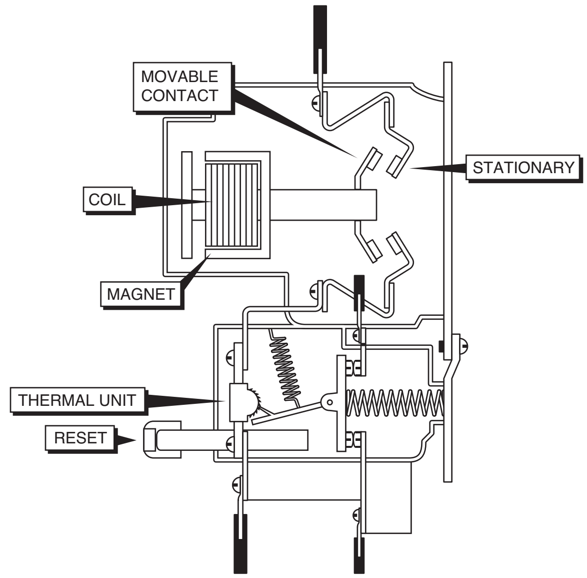
18 **Magnetic Breaker** - An electrically operated mechanical device used for overcurrent protection.
19 **Fuse** - A safety device used to prevent overloading a circuit. It consists of a short length of conducting metal which melts at a certain temperature and breaks the circuit.
20 **Magnetic Starter** - An electrically operated mechanical switch used to connect power to an electric motor.
21 **Heater -** A device designed for overload protection of electric motors. The device is heat sensitive and is placed in the power circuit with an electrical connection to the control circuit.

starter, by sensing the heat created by this amperage. The second section is a set of contacts that are wired into the control circuit. If the motor draws high current the thermal unit will heat up. When they heat to a preset point they physically release their contacts that are in the control circuit and disconnect the control circuit stopping the motor before it burns up.





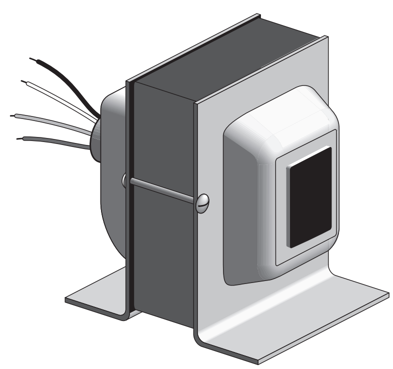
Control Circuit

Power Source

The power for the control circuit comes from one leg of the power circuit. This control voltage is usually tapped from the power circuit above the magnetic starter. The voltage above the starter is usually greater than the 120 volts desired for the control circuit. Typical power circuit voltages are 460v and 480v.

Transformer

A step-down transformer is used to obtain the 120 volts. A transformer used to provide power for the control circuit is usually called the control power transformer and designated as, CPT in the electrical drawings.

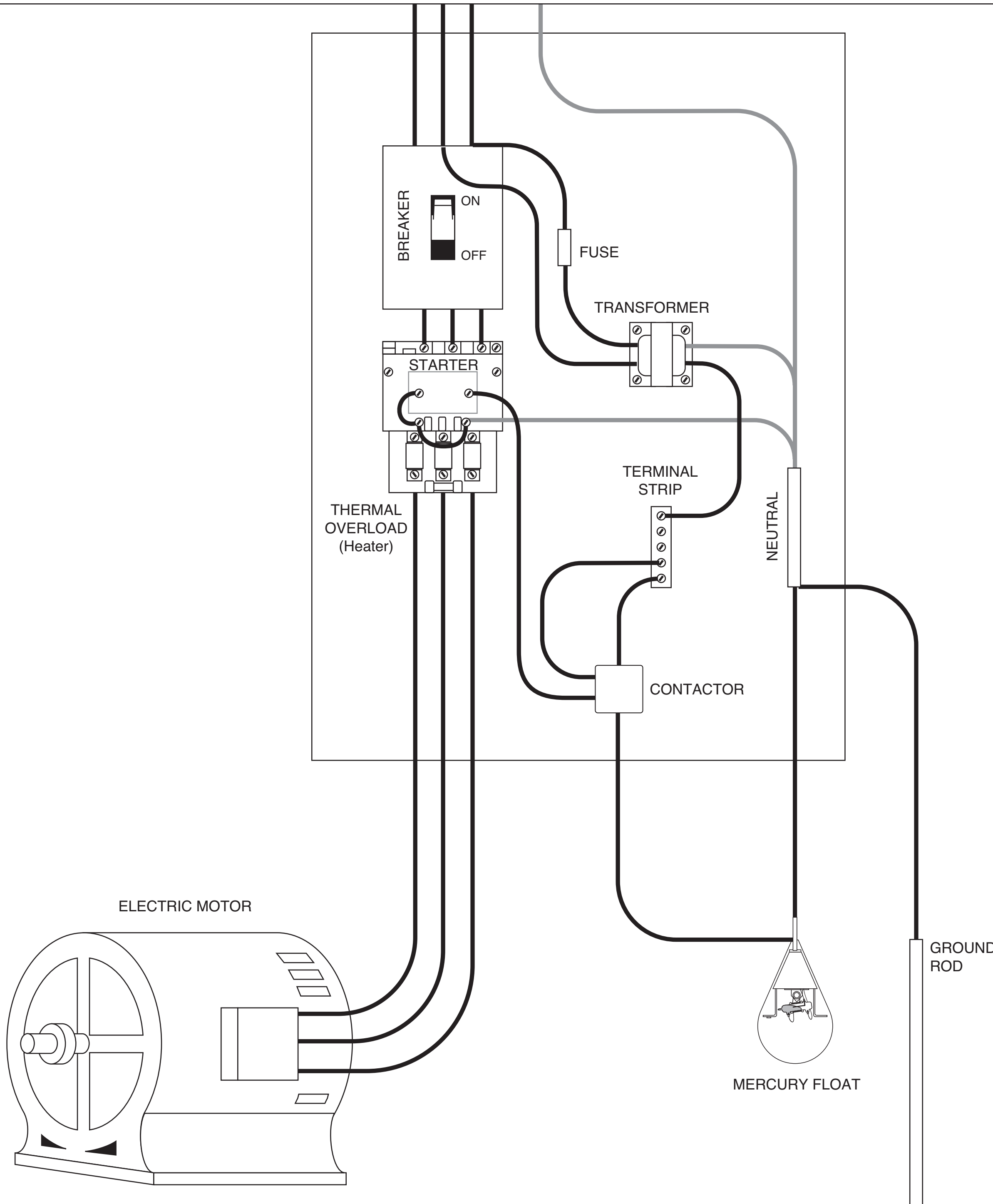


Contactors

Contactors are placed in the control circuit and are used for a number of actions. Included would be to control the floats or electrodes, turn status lights on or off, send a high water alarm and turn on the hour meter.

Panel Switches

From the transformer in the panel, the power leads to a switch or switches. Most pumping stations have a hand-off-auto (H-O-A) switch. In the hand position all



Caution About this Drawing

The above drawing is not intended to be electrically complete or correct. This is not a wiring diagram. The diagram is intended to show the relationship and position of the components.

of the remote sensing system is disconnected. From the H-O-A switch power goes to the control switch in the heater assembly.

Status

The control panel may also contain lights that indicate the status of the pumps, various alarm conditions and hour meters.

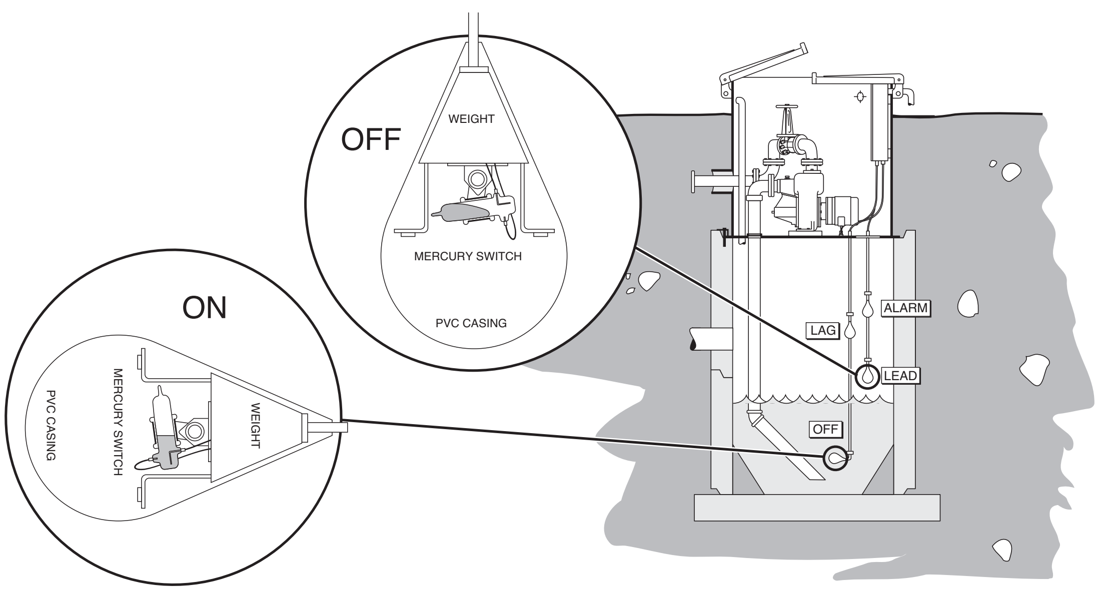
Control Switches

Introduction

The control circuit includes various control switches, including pressure sensing switches, flow switches, level sensing switches and float switches. These switches are primarily used to turn pumps on and off and send a high water alarm.

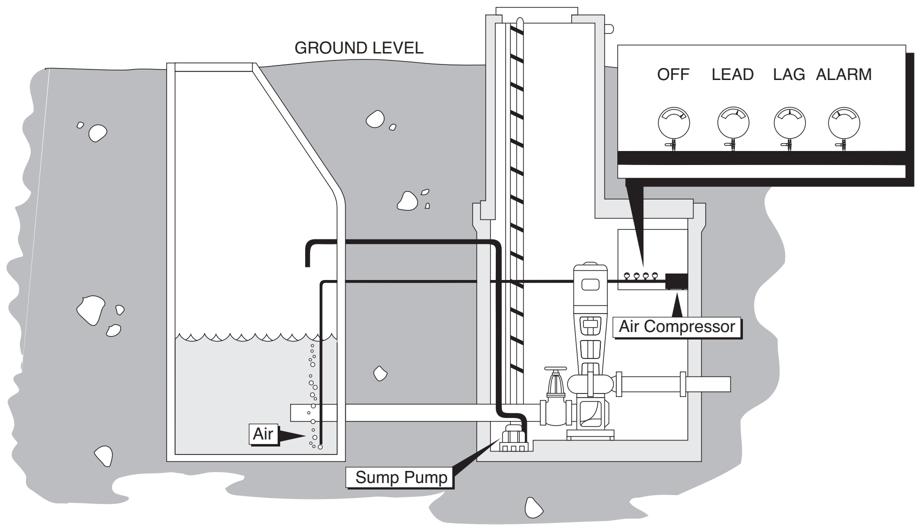
Float Switches

The most common float switch is the mercury float. The float contains a glass vial with two electrodes and a puddle of mercury. When the float is tripped the mercury runs across the electrodes and the circuit is closed. This could be used to start or stop a pump. The float switch is the most common switch used to turn lift station pumps on and off and to send a high water alarm.



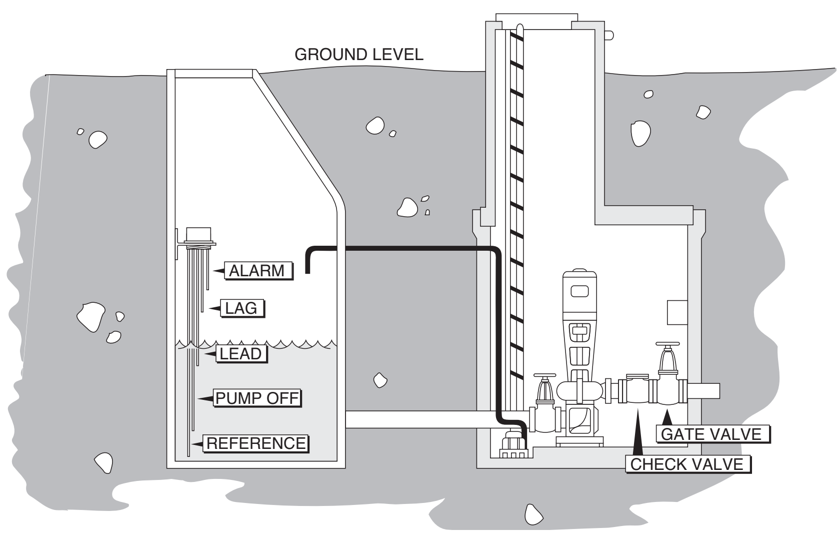
Pressure Switch

Pressure switches are often used in conjunction with a small air compressor and bubbler tube to determine the water level in a lift station wet well. Air is pumped through a line into the wet well. As the water level in wet well increases the pressure in the bubbler tube is increased. (1 foot of water will provide 0.433 psi of pressure). Pressure switches are mounted on a header and are set to turn the pumps on, off or send an alarm based on the pressure in the header. The most common of these pressure switches uses a hollow tube and a mercury vial. As pressure is increased the hollow tube straightens. The movement of this tube is used to mechanically tip a glass vial that contains two electrodes and a pool of mercury. When the vial is tipped sufficiently the mercury runs across the electrodes and thus sends a signal that can be used to start or stop a pump.



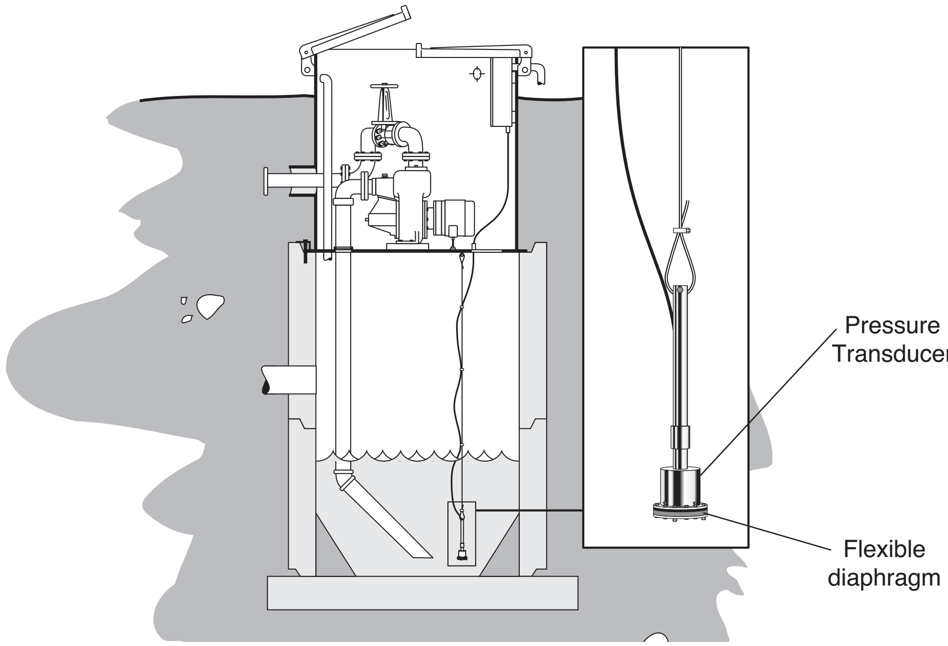
Electrodes

There are several types of electrodes used to determine water depth. The most common is the direct connecting probe. When the water level raises an electrical connection is made between the reference electrode and the “on” electrode, starting the pump.



Pressure Transducer

A pressure transducer is a device that will provide a varying electrical output based on pressure. This device is placed in a water tight housing. A flexible diaphragm is fastened to the bottom of the housing. The transducer is secured to the flexible diaphragm. As the water level in the wet well rises the signal from the transducer changes. This signal is sent to an electrical control panel and used to turn pumps on and off. The major advantage to this type of control system is that the electrical components are kept dry and the level used to turn pumps on and off can be varied easily from the control panel.



Maintenance Consideration

Basic Routines

The maintenance requirements associated with each pumping installation are unique to the installation. However, there are general considerations that can be applied to most pumping installations. These include performing the following activities and gathering the following data.

- Suction and discharge pressure - daily
- Check alarms on panels - daily
- Hours from hour meter - daily
- Inspect stuffing box for leakage - daily
- Replace packing - annually
- Amperage and voltage measurements - Quarterly
- Maintain a good inventory of spare parts. This should include, impellers, packing, mechanical seals, shaft sleeve, contact relays, motor starter and floats.
- Communicate with the power generations personnel or electric company so when a power shut down is anticipated or has occurred the wastewater department is notified.

Electrical Basics & Electrical System **Worksheet**

1. _________ is the electrical unit that is related to pressure, _________ is the electrical unit that is related to flow and _____________ is the electrical unit that is related to headloss.

2. The symbol for voltage is ________ or _______, the symbol for amperage is _______ or ______, the symbol for resistance is _________ or _________.

3. The item that rotates around the nucleus of an atom is the ____________. The ___________ and the ________________ can be found in the nucleus of an atom.

4. EMF stands for ______________________________________ force, and is the same as ___________.

5. The frequency of alternating current is measured in what units?

6. Three phase power is like having ____.

7. Work in wastewater is measured as horsepower. In electricity this same work is measured as _____________.

8. The device used to operate a magnetic starter is the _______________ __________________.

9. What is the name used to identify magnetic starters, contact relays, motor starters and relays?

10. The _______________ is used to protect the motor from excessive current draw and the ________________________ or ___________________ is used to protect the building and wiring from a short circuit.

11. The input side of a transformer is called the ________________ side and the output side is called the ___________________ side.

12. The initials for the device used by an operator to measure voltage and resistance in a control panel are _____________________. These initials stand for ______________________________________.

13. The electric meter used to measure the maximum amount of power consumed in the month is called a _____________________ meter.

14. Identify the components indicated in the drawing below. Compare the numbers on the drawing to the list provided.

    ______ a. Magnetic starter

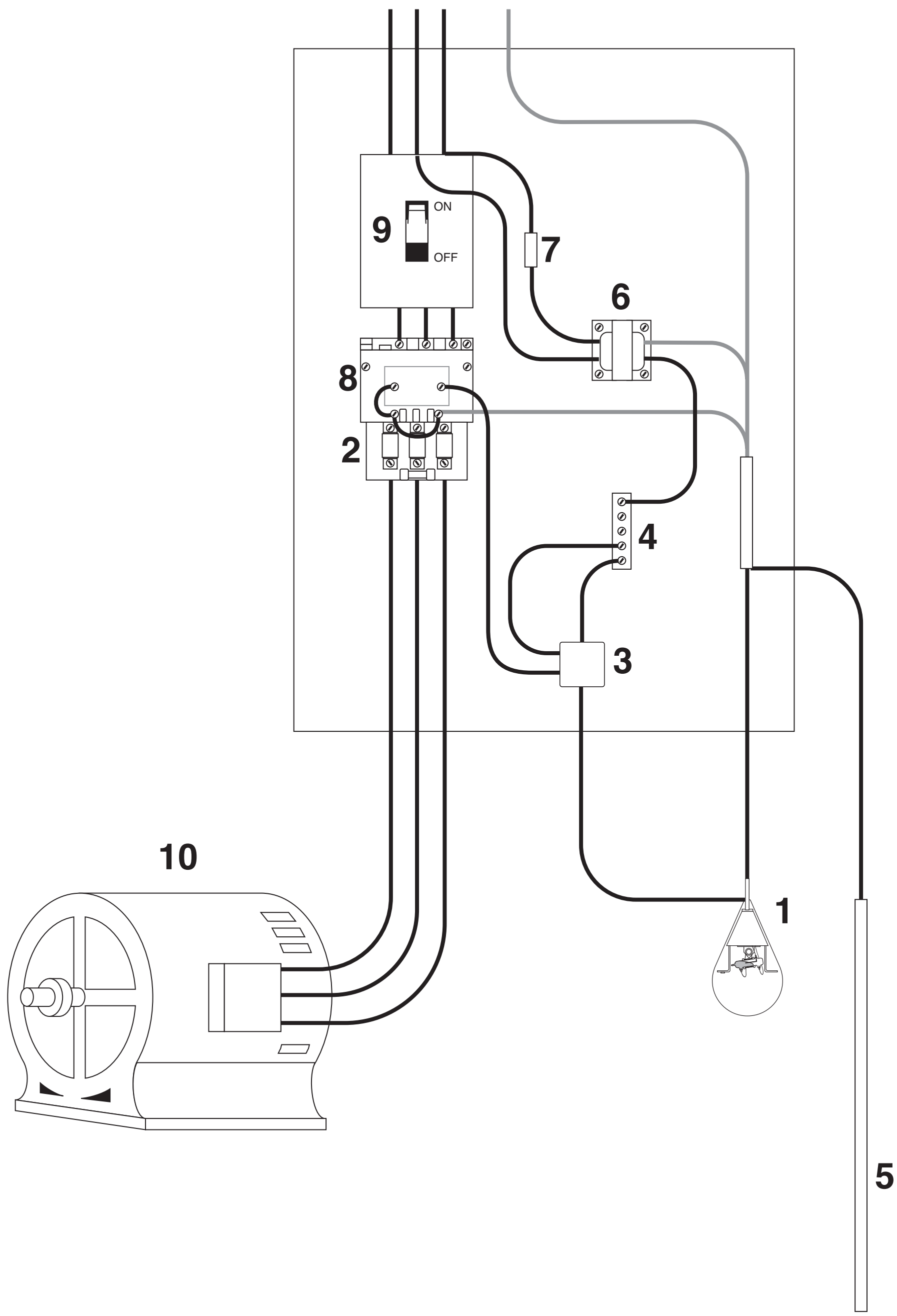
    ______ b. Magnetic breaker

    ______ c. Heater - thermal overload

    ______ d. Mercury float switch

    ______ e. Contact relay

    ______ f. Transformer



Wastewater System Safety

What is in this Lesson?

1. Problems with BBP and other infectious diseases
2. Cave-in protection equipment
3. The process of sloping to prevent cave-ins
4. What conditions require cave-in protection
5. The proper location of spoils
6. Three cave-in protection systems
7. How to determine the proper method of controlling a spill of a specific chemical
8. The problem associated with indiscriminately mixing chemicals
9. The purpose of MSDS
10. The first aid for a chlorine gas burn
11. The first aid requirements for chlorine exposure
12. The proper location of SCBA in a chlorine room
13. The common frequency of accidents in wastewater systems
14. The common safety hazards associated with entry into lift station drywells and wetwells
15. The process, sequence and equipment used in forced draft ventilation of lift stations & manholes
16. The problems associated with gasoline or volatile organic solvents in sewers
17. The process of monitoring a manhole for dangerous gases
18. Examples of confined spaces
19. The three basic components of hazardous atmospheres in collection systems
20. The dangerous gases found in wastewater
21. The level at which hydrogen sulfide is dangerous to humans
22. The percent oxygen where it is fatal
23. The hazards associated with entering confined spaces
24. The number of people and the sequence of events required for entry into a permit entry confined space
25. The hazards associated with painting in a tank
26. The safety considerations associated with handling a chlorine cylinder
27. The amperage danger level for humans
28. The personal protection required when making an electrical measurement
29. The safety equipment necessary for working with live electrical circuits
30. The type of fire extinguisher used to put out an electrical fire and why
31. The immediate first aid for burns

32. The sequence in responding to an injured person for purposes of administering first aid
33. What conditions must exist before artificial respiration is administered
34. The major components of a safety program
35. The purpose of a safety meeting
36. The importance of good housekeeping in wastewater system operations
37. The health risk associated with smoking while handling wastewater
38. The personal hygiene necessary to prevent infection from infectious disease found in sewers
39. The personal safety precautions that a worker should use after leaving a sewer manhole
40. The classification of the most common accidents in wastewater treatment
41. The location of the majority of the wastewater treatment worker accidents
42. The proper technique for lifting
43. The function of the lock/out process
44. The safety problems associated with manhole steps
45. The sequence for safely removing a manhole cover
46. The two goals of proper traffic control

Key Words

- Acceptable Entry Conditions
- Bloodborne Pathogens
- Cave-in
- Competent person
- Confined space
- Decibel
- Lockout/Tagout
- MSDS
- OSHA
- Permit-Required Confined Space
- Shield
- Shoring
- Sloping
- Trench

Wastewater System Safety

Introduction

Accidents don't just happen. They are caused. Most accidents are caused by an unsafe act and/or an unsafe condition. The following information is a brief discussion of the major components of a wastewater utility safety program. This material is not intended as a comprehensive review of safety but as an introduction to the more important aspects of a wastewater utility safety program. There are numerous publications and videos available that deal with specific safety topic. Every operator is encouraged to find out more about how they can perform their jobs safely.

Responsibility

Everyone

Everyone is responsible for providing safe working conditions, including the operator, superintendent and management. The following list of responsibilities is based on a three level management system. In many small communities there is no superintendent level. In this case, the responsibilities described here must then be divided between the manager and the operator.

Management Responsibility

The management has the responsibility to:

- develop a safety program,
- set policy,
- provide rewards and
- provide safety equipment.
- keep current on new safety practices and regulations

Superintendent Responsibility

The superintendent has the responsibility to:

- see that the safety program is carried out,
- see that operators use safety equipment, and
- see that unsafe conditions are identified and corrected.

Operator Responsibility

The operator has the responsibility to:

- use safety equipment properly,
- follow safety policies and procedures and
- provide information to the management when an unsafe condition is identified.

Regulations Federal

The Williams-Steiger Occupational Safety and Health Act of 1970 (**OSHA**[1]) required the federal government to establish minimum health and safety standards for

[1] **OSHA** - Occupational Safety and Health Act - The 1970 federal act requiring the federal government to establish minimum health and safety standards. Also called the Williams-Steiger Act.

workers. The standards and regulations developed under this act require that the employer furnish employees a place of employment that is free from recognized hazards that are likely to cause death or serious physical harm. The act provides for up to one year of prison and up to $70,000 penalty on conviction of the regulations associated with this act.

State of Alaska

The State of Alaska Department of Labor (DOL) is responsible for implementing most, but not all, of these regulations. For instance, DOL does not have regulatory authority with the new (1993) confined space regulations. In some cases the Alaska regulations are more stringent than the federal regulations. These regulations pertain to private and public employers alike.

Safety Program

Requirement

Every wastewater utility is required to have a formal safety program. The development of the program including hazard analysis, writing the program and associated procedures is a management responsibility.

Program Elements

This program should have the following minimum components:

- A written policy approved by the governing body
- A written and documented analysis of the safety hazards of the job and written procedures for dealing effectively with each hazard
- Required monthly safety meetings; the attendance and content of each safety meeting must be recorded and filed
- A routine inspection process; where management inspects each work area for possible safety hazards
- Safety solution process; a process must be in place to address each safety concern identified by an employee.
- Discipline procedure; violation of safety standards must be dealt with in a documented, fair, and reasonable manner.
- Reward system; a process of rewarding people who work safely.

Written Documents

A quality safety program would contain the following written documents:

Employee Handbook

Employee handbook containing specific information associated with each of the written policies and those procedures that are appropriate

Policies

Written policies must be developed for the following:

- General safety policies - including a description of responsibilities. General safety should address personal safety equipment use (hard hats, eye protection, hearing protection, etc.).
- Safety committee
- Safety meetings
- Confined space program
- Competent person - shoring program
- Traffic control program
- Bloodborne pathogen program
- Lockout/Tagout program
- Emergency response plan
- Hazardous material communication program

Content

The development of these policies and their written procedures should not be taken lightly. In most cases these policies and their written procedures must be site specific. That means that a general program borrowed from another community with minor changes will, in most cases not meet the requirements. The failure to develop adequate programs exposes the operator, manager and governing body to personal liability.

Safety Meetings/Training

Why?

The employer is responsible to conduct safety training (safety meetings) for the purpose of training the employees in the **recognition, avoidance and prevention of unsafe conditions**.

Major Safety Concerns

Introduction

The following is a brief discussion of major safety concerns in small wastewater utilities. This discussion is not intended to be all inclusive and does not include all of the information needed to develop written policies and procedures.

Safety Record

At the present time the frequency of accidents in wastewater treatment and collection systems indicates that each worker will have a major injury every six years. Part of this has to do with the nature of the business and part of it is due to the lack of effective safe work practices.

Common Accidents

The most common classification of injuries to wastewater operators includes sprains and strains caused by striking or being struck by objects or falls. The most common injuries are to the back, hands and legs.

Location of Accidents

For treatment plant operators the majority of the accidents occur away from the job site; manholes, sludge hauling and motor vehicles.

Hazards

The hazards that are faced by a wastewater treatment plant and/or collection system operator include:

- Falls
- Infections
- Cave-ins
- Drowning
- Fire
- Electrical shock
- Noise
- Falling objects
- Bites from insects
- Scrapes or cuts
- Explosion
- Toxic gas
- Suffocation
- Strains

Operators

The following descriptions are general in nature and operator focused. In some cases the community may have specific procedures that are more stringent than the general procedures provided here.

Reason for Description

These descriptions are intended for entry level wastewater operators and are intended to provide a general overview of typical safety problems faced by operators in small communities.

Basic Programs

Every aspect of safety as it relates to wastewater collection and wastewater treatment **are not** addressed in this lesson. Instead, the lesson is limited to those areas of safety that the authors believed to be the most important to wastewater collection and treatment in a small community. The following areas are included:

- Confined space entry
- Electrical safety
- Lockout/Tagout
- Hazard material communication
- Handling chemicals - including chlorine
- Traffic control
- Cave-in protection
- General safety including; lifting, first aid, general hygiene, fire protection, fall protection, manhole entry
- Infectious diseases

Confined Space

The Concern

Confined spaces[2] are one of the major safety concerns in wastewater collection and treatment systems. They are of concern because each year several hundred people die in confined spaces due to the lack of oxygen, the presence of toxic gases or being engulfed with water or a fine substance.

What is a Confined Space?

A confined space is any work space that meets three important criteria:

1. The space is large enough to allow a person to perform work in the space.

2. The entrance and exit from the space is restricted.

3. The space was not designed for continuous human habitation.

Examples of Confined Spaces

Common confined spaces found in a wastewater system would include:

- Manholes
- Lift station wet wells
- Lift station dry wells
- Empty clarifier or other basins (tanks) at a treatment plant
- Utilidors

Hazards

The confined space regulations address four specific types of hazards, all of which can be found in a wastewater system. The four categories are:

- Atmospheric hazards such as: oxygen depletion, toxic or explosive gases.
- Engulfment with water.
- Entrapment or asphyxiation.
- Other recognized serious safety or health hazards.

Atmospheric Hazards

Introduction

There are three common types of atmospheric hazards found in wastewater systems: oxygen depletion, presence of toxic or hazardous gases and explosive gases.

Oxygen

One of the most common hazardous atmospheric conditions is the depletion of oxygen. When the oxygen level is below 19.5% the area is considered unsafe for human habitation. Normally, air will contain 21% oxygen.

2 **Confined Space** - A space that: Is large enough and so configured that an employee can bodily enter and perform assigned work; and has limited or restricted means for entry and exit; and is NOT designed for continuous employee occupancy.

Toxic or Hazardous Gases

While there are many toxic and hazardous gases there are two that are commonly found in wastewater systems, hydrogen sulfide and methane.

- Hydrogen sulfide (H_2S) is explosive when the concentration is between 4.0% and 44%. Hydrogen sulfide concentrations above 0.2% are considered toxic when inhaled. One of the major problems with hydrogen sulfide is it gives off an offensive “rotten egg” odor at low concentrations but the odor is not detectable at high concentrations. **When the hydrogen sulfide level is above 10 ppm the space should not be entered without a proper air supply.**
- Methane (CH_4) can collect in a manhole or empty tank. When the methane level is between 5 and 15% it is explosive. **When the methane concentration is above 0.5% the space should not be entered.**

Explosive Gases

Explosive and/or hazardous chemicals such as gasoline or volatile organic solvents can be dumped or washed down a sewer and collect in a manhole or lift station wet well creating a hazardous condition, including an explosion that could destroy a portion of the collection system.

Other Gas Problems

One of the hazardous atmosphere problems that is often overlooked are chemicals and paint used in the performance of maintenance in lift stations and at the treatment plant. When painting or cleaning inside of an open tank, such as a clarifier or aeration basin, toxic vapors can accumulate near the floor. Working in this environment would require the use of some type of ventilation system and/or breathing protection.

Engulfment

Engulfment can occur in trenches, manholes, lift station wet wells and in tanks. In manholes and wet wells engulfment can occur when you are downstream of a lift station and the station comes on line. In a wastewater plant this could occur because a pump accidentally comes on or a valve is opened.

Asphyxiation/Entrapment

Asphyxiation or entrapment could occur anytime there is an inwardly converging wall or a floor which slopes downward and tapers to a smaller cross-section. This can occur in the bottom of some lift station wet wells.

Other Hazards

Other serious health hazards could occur when entering a manhole downstream of a hospital, clinic or chemical factory. A serious safety hazard could occur when entering a space that contains high voltage.

Permit System

Permit Required

When any one of the above four hazards exist or has the potential to exist in a confined space, the space must be designated as a **Permit-Required Confined Space**[3]. Permit-required confined spaces can only be entered when utilizing a specific set of procedures and obtaining a written permit. This permit process is part of an overall confined space program

Confined Space Program

Program Requirements

Each employer is required to evaluate all work spaces to determine if confined spaces exist. If they exist they must be classified as permit entry or non-permit entry. When permit entry confined spaces exist an employer has the option to prevent entry or develop a written permit entry system.

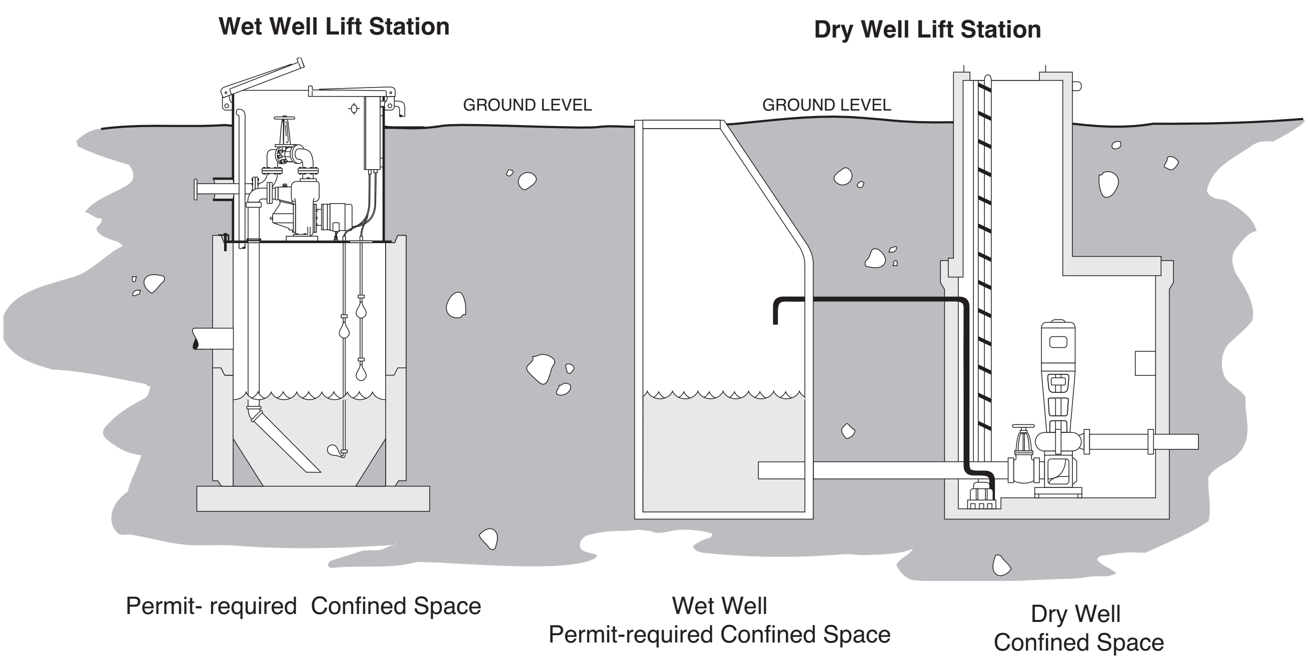
Program Elements

This program and permit system includes the following components:

Confined Space Entry

Common Spaces

There are three common permit-required confined spaces found in wastewater systems, they are; manholes, lift stations and empty basins. Each has its own special hazards. Before discussing general entry procedures a review of the associated hazards is provided.



[3] **Permit-Required Confined Space** - A confined space that has one or more of the following characteristics. Contains or has the potential to contain a hazardous atmosphere. Contains material(s) which have the potential to engulf an entrant. Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor which slopes downward and tapers to a smaller cross-section. Contains any other recognized serious safety or health hazards.

Typical Hazards

Lift Stations - General

The type of hazards or potential hazards associated with lift stations depends on which portion of the lift station is being entered. Most of the conditions can be divided into two categories; wet well and dry well considerations.

Wet Well Considerations

A wet well of a lift station is a permit-required confined space.

Dry Well Considerations

The dry well of a dry well station is a confined space. In most instances it is not considered a permit-required confined space. However, the following hazards should be considered.

- Entry into this portion of the station is usually down a ladder. Protection from falls and the condition of the ladder must be considered.
- The dry well contains the pumps, motors, electrical control panel and a sump pump. There is the potential for electrical hazards associated with these devices.
- In some older stations, consideration should be given to the potential for flooding of the dry well from a failure of the tank wall or a pipe.

Manholes

Safety considerations in a manhole include:

- The floor of most manholes will have a slight slope to the flow channel and the exposed concrete is commonly slippery.
- If there is a built-in ladder there is danger of a failure of the rungs from corrosion.
- There is always the potential for low oxygen, the presence of hydrogen sulfide, methane and other toxic or explosive gases.
- Scrapes or cuts when entering and exiting the manhole.
- Engulfment from water.

Tanks

Empty tanks provide the following safety considerations:

- Low oxygen content.
- Accumulation of toxic gases.
- Accumulation of carbon monoxide if a gas powered pump is being used to dewater the tank.
- Explosion from methane.
- Fumes associated with chemicals and products used to perform cleaning and other maintenance.
- Engulfment from water.

Safety Equipment

When entering a manhole the following safety equipment should be utilized.

- Hard hats with chin straps for all workers.
- At least two personnel, one having training as the confined space entrant, and the other trained as the attendant and confined space supervisor. These are three jobs, and it has been determined that two workers can perform the three job tasks if properly trained.
- Light weight aluminum ladder.
- Oxygen and gas meter that has been calibrated.
- Retrieval harness and tripod.
- Traffic control devices.
- Barricades to prevent pedestrian entry into the manhole.
- Manhole lifting device.
- Three to five pound hammer.
- Screw driver.
- Light.
- Bucket with rope for lowering tools into the manhole.
- Fresh air ventilator.
- Rubber boots.
- Disposable gloves.
- Coveralls.
- Communication equipment so that the attendant and entrant can be in constant communication with one another.

Preventing Problems

There are at least four methods used to prevent injury when entering a confined space. They include; testing the air to assure that **acceptable entry conditions**[4] exist, using a ventilation system, following proper entry procedures and using appropriate personal safety equipment. In most cases proper and safe entry will require using a combination of these techniques.

Oxygen & Hazardous gas detector

4 **Acceptable Entry Conditions** - The conditions that must exist in a permit space to allow entry and to ensure that employees involved with a permit-required confined space entry can safely enter into and work within the space. Acceptable conditions within a permit space must be maintained throughout the period that workers are inside the permit space.

Air Monitoring

The quality of the air must be monitored in a permit required confined space, prior to entry and continuously during the time that a worker is in the space. This monitoring must be done with an approved and certified device. It is critical that the device be calibrated at a frequency recommended by the manufacturer. (This could be daily or each time it is turned on.)

Order of Testing

Atmospheric testing must be performed in the following sequence:

- A test for oxygen level is performed first because most combustible gas meters are dependent on the presence of oxygen in order to provide an accurate reading.
- Combustible gases are tested for next because the threat of fire or explosion is more life threatening than an exposure to toxic gases and vapors.
- Toxic gases and vapors are tested for last.

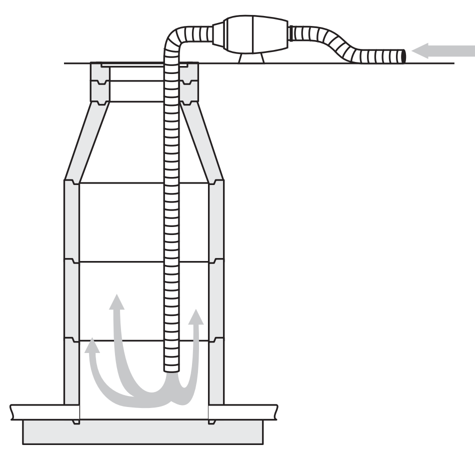
Ventilation

Purpose

A mechanical ventilation system is an excellent method of solving hazardous atmosphere problems. This device will remove hazardous and toxic gases as well as maintain the oxygen level above 19.5%.

Equipment

A typical mechanical ventilator is a gas or electric blower that is placed so that quality fresh air can be collected and blown into the manhole or wet well.



Installation

The following general sequence should be followed for installing and operating a ventilation system.

- Prior to installation the air quality must be tested as described above.
- The air input tube should be placed below the level of a persons face that may be in the space.
- There must be adequate space for the air to escape the manhole or wet well. Care must be taken to make sure that the air exiting the manhole is not sucked into the ventilator.

- Care must be taken to make sure no other hazardous gases are forced into the manhole. One of the most common problems is "sucking" automobile exhaust fumes into the manhole.

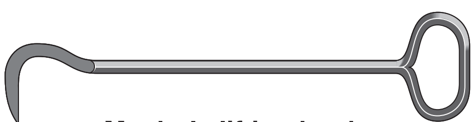
Entry Procedures

Types of Procedures

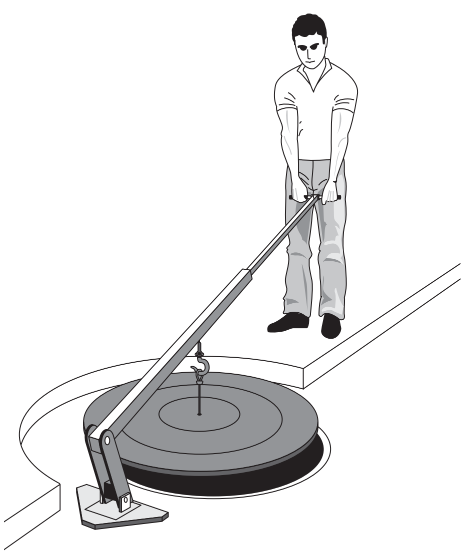
Entry into any permit-required confined space must be accomplished utilizing a written procedure. There are two types of procedures, Permit-Required Entry and Alternate Entry. A typical permit-required entry procedure could contain 20 to 30 steps. The regulations allow an alternate entry procedure into a permit required confined space if the only hazard is atmospheric and if this hazard can be controlled by mechanical ventilation.

Manhole Entry Sequence

Because manhole entry is a very common wastewater operator task and represents a high degree of hazard we provide the following general sequence for entering a manhole. This sequence should **not** be substituted for proper permit-required confined space entry procedures. Is is assumed that a proper permit for entry has been obtained.



Manhole lifting hook



Manhole lifting device

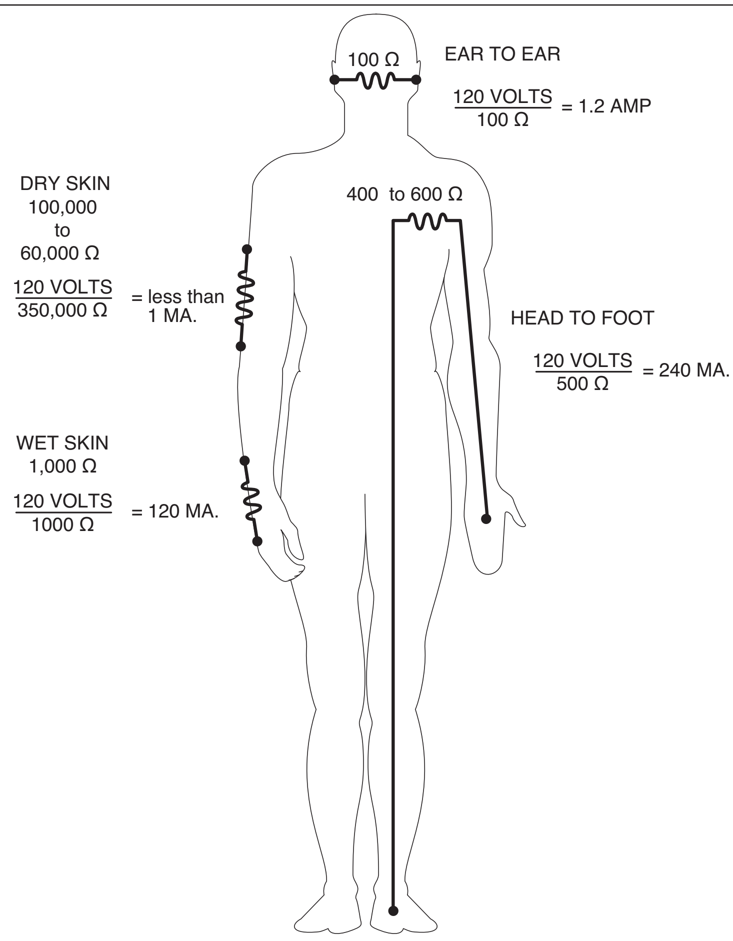
- Use the atmospheric test meter to determine if there are any explosive gases in and around the manhole. This may be accomplished by inserting the air input tube down through the manhole vent hole.
- If no explosive gases are present, strike the lid on the edge once or twice to loosen dirt and rocks that may be holding the lid in place.
- Use a screwdriver or manhole hook to remove the debris from between the manhole lid and the lid ring.
- Using proper lifting technique and a manhole hook to remove the Lid. Slide the lid away from the manhole entrance. *Keep the lid upright.*
- Clean dirt from the manhole lid ring and cover.
- Perform proper atmospheric testing.
- Install the ventilation system.
- Put on personal protective equipment. Retrieval harness, hard hat, gloves and safety glasses.
- Enter and perform work. Test atmosphere continuously.
- After exiting, remove gloves, disinfect gloves if necessary.
- Replace the manhole cover by sliding it into the ring.

Electrical Measurements

Electrical measurements should be taken by a licensed electrician. The following general safety precautions should be followed;

- Remove all jewelry; including ear rings, rings, watches, necklaces, metal rimmed glasses and large belt buckles.
- Wear shirts with tight fitting sleeves.
- Fasten the panel door open.
- Wear safety goggles.
- Wear electrical safety gloves.
- Have a second person standing by when making the measurements.
- Make the measurements with one hand, keep the second hand in your pocket.

Amperage flow through various portions of the body with 120 volts



Effects of 60 Hz current on an Average Human

	Current Values through Body Trunk	Effect
Safe Current Values	1 Milliamp, or less	Causes no sensation - not felt. Is at threshold of perception.
	1 to 8 Milliamps	Sensation of shock. Not painful. Individual can let go at will, as muscular control is not lost. (5ma is accepted as maximum harmless current intensity.)
	8 to 15 Milliamps	Painful shock. Individual **can let go** at will, as muscular control is not lost.
Unsafe Current Values	15 to 20 Milliamps	Painful shock. Muscular control of adjacent muscles lost. **Cannot let go.**
	20 to 50 Milliamps	Painful. Severe muscular contractions. Breathing is difficult.
	100 to 200 Milliamps	Ventricular Fibrillation (A heart condition that results in death - **no known remedy.**)
	200 and over Milliamps	Severe burns. Severe muscular contractions, so severe that chest muscles clamp heart and stop it during duration of shock. (This prevents Ventricular Fibrillation.)

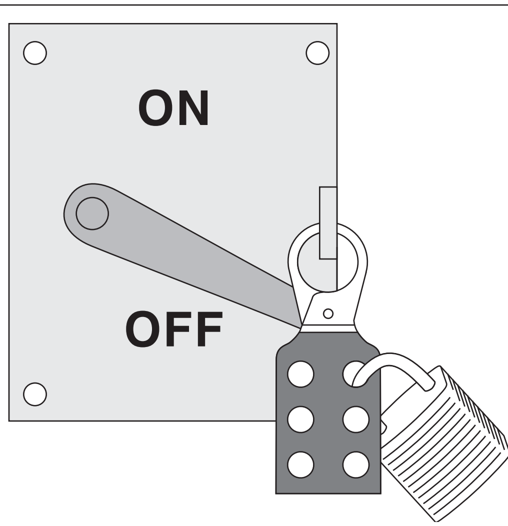
Lockout/Tagout

Requirement

All energy devices, such a motors and valves, that need to be shut down must be locked-out and tagged-out. A **lockout/tagout**[5] program must be established which includes written procedures and other components.

Removal of Device

The only person who can remove the lockout device is the one that put it in place.



Padlock and lockout device

Tag for lockout

[5] **Lockout/Tagout** - A process of physically locking and tagging hazardous energy sources to prevent energizing during maintenance.

Hazardous Material Communication

Introduction

OSHA has developed a hazardous communication standard to make sure that the proper information on handling hazardous materials reaches each worker required to handle the material. This program addresses five main areas:

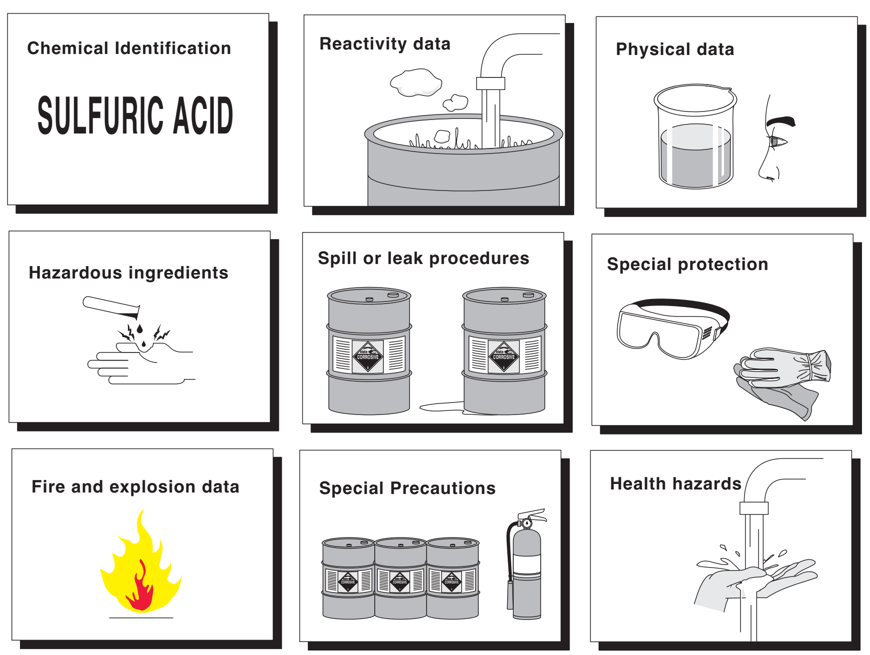
- The identification of hazardous chemicals
- A product warning label system
- The development of Material Safety Data Sheets (**MSDS**[6])
- The development by each organization of a hazardous communication program
- Employee training program on how to handle hazardous materials and how to read the hazardous material labels and MSDS.

MSDS Components

A MSDS is a written document provided by the manufacturer and supplier of the chemical. Each chemical (alum, chlorine, paint, cleaners, etc.) must have an MSDS. Each organization is required to have available copies of the MSDS for the chemicals handled by the workers. Each MSDS has information concerning nine specific areas. They are:

- Chemical identification information
- Hazardous ingredients and safe exposure levels
- Physical data

Nine Components of a MSDS



[6] **MSDS** - Material Safety Data Sheet - Written material produced by the chemical manufacturer describing properties and safe handling procedures.

- Fire and explosion data, including flash point and how to extinguish a fire.
- Health hazards, including first aid requirements
- Reactivity data - The incompatibility and instability of the material with other chemicals
- How to handle a spill or leak
- What special protective equipment is required for handling
- Special precautions concerning posting, handling and clean-up.

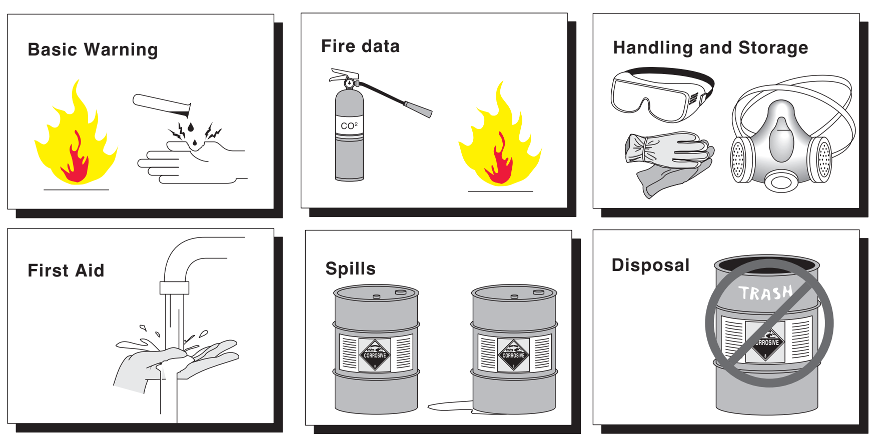
Label Components

Each manufacturer of a chemical is required to place a label on the container of that chemical. The label contains information on six specific areas:

- Basic Warning; includes chemical name, hazardous ingredients and name and address of manufacturer.
- First aid for exposure to the chemical
- How to handle a fire involving the chemical
- How to handle a spill of the chemical
- Equipment necessary for proper handling and storage of the chemical
- Cautions regarding proper disposal of the container

In addition, a placard indicating special precautions is commonly included. Typical placards are for flammable, corrosive, oxidizer, poison, irritant, explosive, and combustible.

Lable Components Example



Written Program Content

Each organization is required to have a written program that contains the following elements:

- A listing of all hazardous chemicals in the workplace
- How any needed labels will be provided
- The location of MSDS's
- How employee training will be provided

- How employees will be informed of hazards found in unlabeled pipes
- How workers will be told the hazards of non-routine tasks.

Training Requirements

The training program must contain the following elements:

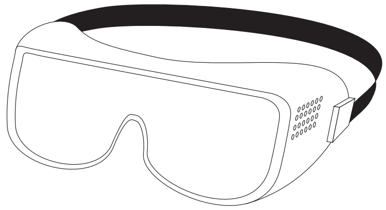
- How to detect the release of a hazardous chemical
- The hazards of all chemicals in your work area and the dangers associated of any job
- How to protect yourself from these dangers
- The details of the hazardous communication program developed by the employer

Examples of common placards

Handling Chemicals

The most common chemicals handled by small wastewater system operators include:

- Gas chlorine
- Lime
- Calcium hypochlorite
- Sodium hypochlorite



Chemical Safety Goggles

The chemicals should be stored and marked in accordance with the MSDS's.

The following are general guidelines for personal protective equipment for these common chemicals. For more specific information see the MSDS for the specific chemical.

Safety Equipment	Chemical
Chemical Safety Goggles	Required for all but gas chlorine.
Cartridge Respirator	Calcium hypochlorite, sodium hypochlorite
Dust Mask	Lime
Rubberized gloves	Calcium and sodium hypochlorite
Self Contained Breathing Apparatus	Gas Chlorine

Respirator Program

Requirements

When an operator is required to wear a respirator it is an OSHA requirement that the employer develop a respirator program that includes the following items:

- A fit test of the respirator in order to make sure that the face piece fits the individual operator.
- A training program that teaches the operator how and when to use the respirator.
- A monthly respirator inspection program to determine the condition of the respirator.

Full face cartridge respirator - for calcium hypochlorite.

Handling Gas Chlorine

Classification

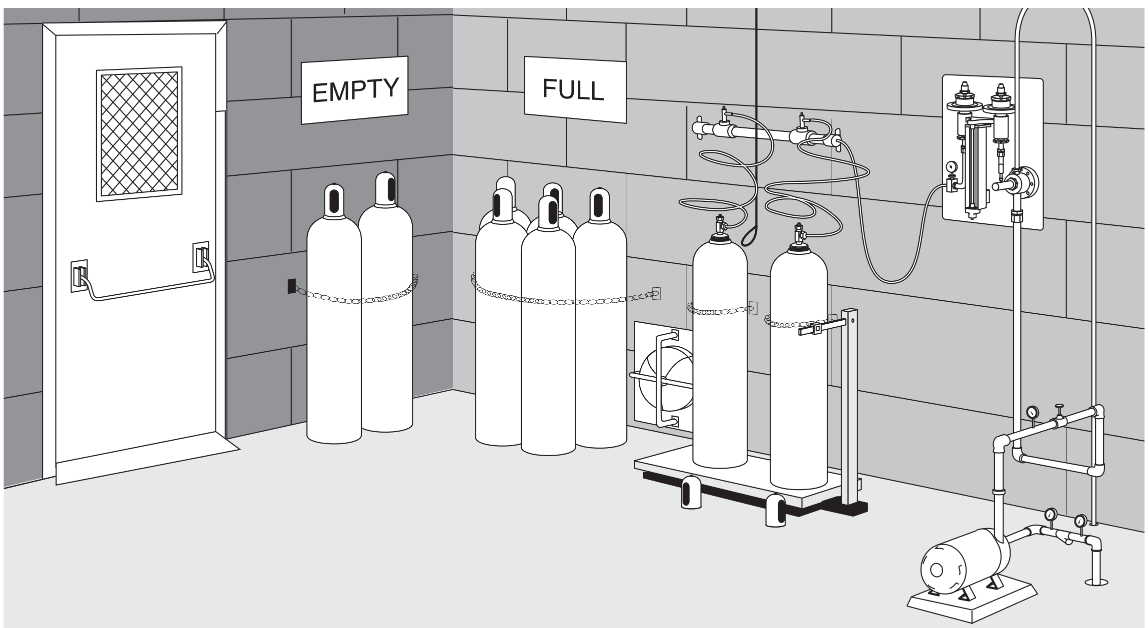
Gas chlorine is classified by OSHA, DOT and EPA as a poison and an inhalation hazard. This classification places a special emphasis on transportation and handling of chlorine cylinders.

Handling, Storage & Use

When chlorine cylinders are stored, handled or used the employer is obligated to develop a written policy and set of procedures detailing the safe procedures for storage, handling and changing the containers. These procedures will address the following:

- Container should never be moved without their bonnet being in place.

- The storage room should be maintained at 70°.
- All 100 and 150 pound cylinders should be chained up 2/3 from the bottom under normal circumstances and an additional chain or containment device should be placed at the bottom when the containers are stored in an earthquake area. This security must be maintained on all cylinders, during handling, storage or use.
- Two people should be present when changing the cylinders.
- Written procedures must be developed to handle normal O & M releases of chlorine that might occur during a cylinder exchange as well as procedures for a chlorine emergency.



Emergency Equipment

Three protection devices are required in order to handle a chlorine emergency:

- 2 - SCBA - Self contained breathing apparatus
- Full body protection suit
- Chlorine emergency repair kit

Location of SCBA's

If the SCBA's and other emergency equipment is to be stored at the wastewater treatment plant, then it must be stored within easy access of the gas chlorine installation but not in the same room with the chlorine containers or the chlorinator.

Emergency Response

The only personnel who should respond to a chlorine emergency response are those with specific training in how to respond to a hazardous material spill. This minimum training has often been called the 40 hour hazmat training. Often the members of the community's fire department have this training.

Chemical Spills

Information

When a chemical spill occurs the method of properly and safely controlling the spill is described in one of two places. Small in-house spill containment is described in the MSDS for the chemical. Methods and safety precautions for handling large spills is found in the DOT Emergency Response Guidebook.

Safety Concerns

If no information is available on how to safely handle a spill, complete respirator, face and skin protection systems should be utilized. It is either use full protection or avoid the response. Any other action could cause serious injury.

Mixing Chemicals

Indiscriminately Mixing

Some chemicals, when mixed together can react violently with the evolution of heat and/or toxic fumes. If you are unsure of the proper proportions or the sequence of mixing two or more chemicals then mixing should be stopped.

Calcium Hypochlorite

When mixing calcium hypochlorite in water the container should be filled to about one-half full of water and then the hypochlorite mixed with the water. *Never pour the water directly onto dry calcium hypochlorite. It could explode and burn.*

Acid and Water

When mixing acid and water together the acid is added to the water. If the water is placed into the acid there will be a violent reaction with the evolution of heat.

Chlorine and Ammonia

Under no circumstances should a chlorine solution (calcium or sodium) be mixed with ammonia. The result can be a violent reaction. In any case ammonia chloride, a deadly gas will be produced.

Hydrated Lime

The preferred lime for the treatment of sludge or honey buckets is $Ca(OH)_2$ calcium hydroxide, also called hydrated lime. This material is a very strong base and will burn the skin or mucous membranes of the nose and mouth. When added to water heat is generated. If the quantity of lime is too high for the volume of water an explosion can occur.

Honey Buckets & Lime

If dry lime is mixed directly with honey bucket waste containing urine an extremely violent explosion can occur. This is a result of the reaction between the lime and ammonia.

Gluing PVC

The cleaning solvent used to prepare PVC for gluing contains MEK (Methyl Ethyl Ketone). This solvent can enter the bloodstream by passing directly through the skin or by breathing the fumes. It is recommended that you use butyl rubber gloves and an organic vapor cartridge respirator when using this material.

Traffic Control

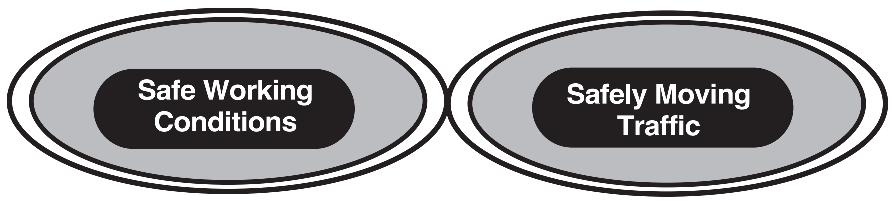
Introduction

Traffic control includes protection for vehicles, snow machines, ATV's and pedestrians. When work is being performed in a street or sidewalk the proper number of signs and cones should be in place. The number of signs and cones needed is dependent on the speed of the traffic.

Goals of Traffic Control

There are two goals of traffic control:

- Make the work site safe
- Keep the traffic moving safely



Elements of Traffic Control

In order to accomplish these goals traffic control engineers have determined that there are two elements to proper traffic control. These elements are:

- Give adequate warning to the drivers and
- Keep the traffic controls simple.

People driving into a construction or work zone need the warning to be far enough in advance to give them time to react. In addition the warnings and controls must be simple enough to allow the driver to make the required changes without becoming confused.

Zones

When setting up traffic control there are four zones that must be considered.

Advanced Warning

The Advance Warning Zone is the zone prior to the work site. Here signs such as UTILITY WORK AHEAD, RIGHT LANE CLOSED, AND CONSTRUCTION AHEAD are used.

Transition Zone

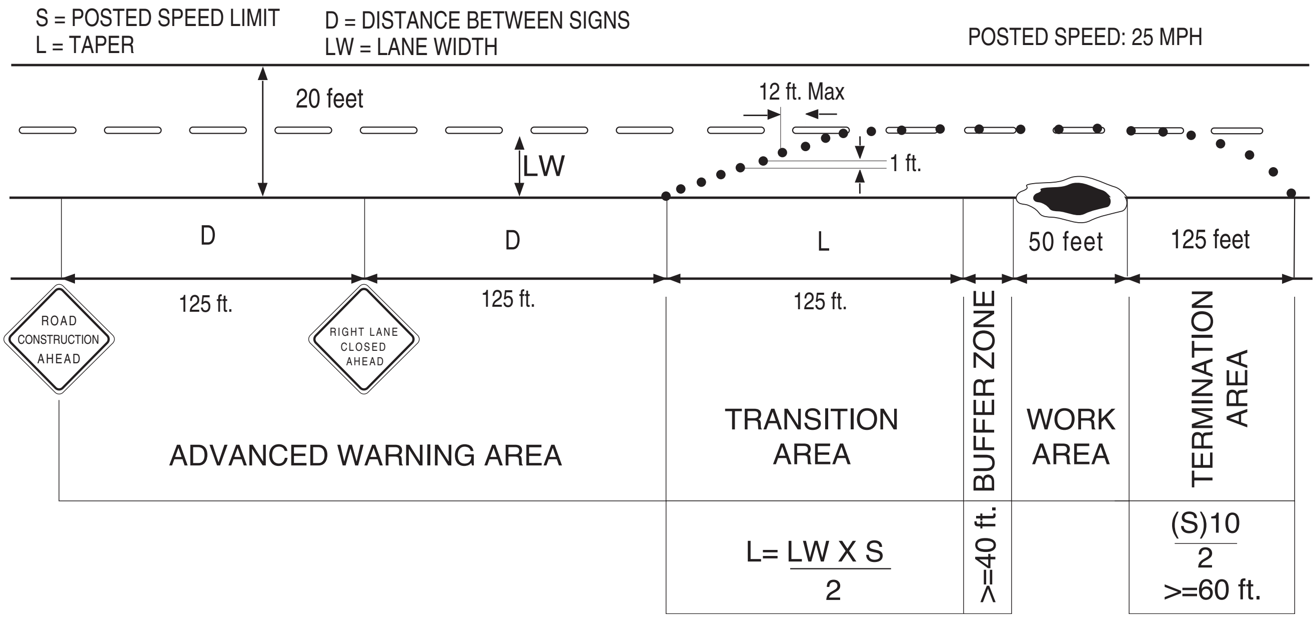
The transition zone is used to move the traffic away from the work area and into a selected lane. Cones are often used to define the transition zone.

Buffer And Work Area

A buffer area of 40 to 50 feet is desirable in front of the work area. This allows the placement of equipment without being in the traffic area.

Termination Zone

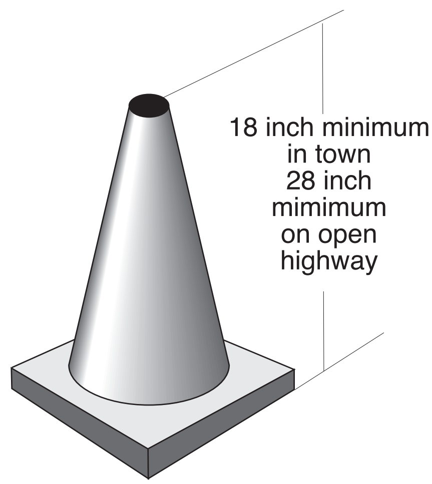
This is the area after the work area where traffic is allowed to come back into its normal flow pattern.



Sign Placement

When the traffic speed is 25 mph or less a typical traffic control setup would include:

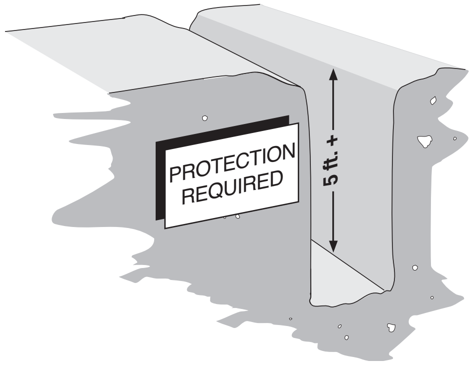
- At least two advanced warning signs 125 feet apart
- Cone taper would need to be 125 to 150 feet
- 12 cones would be needed
- The cones would be spaced 12 feet apart.



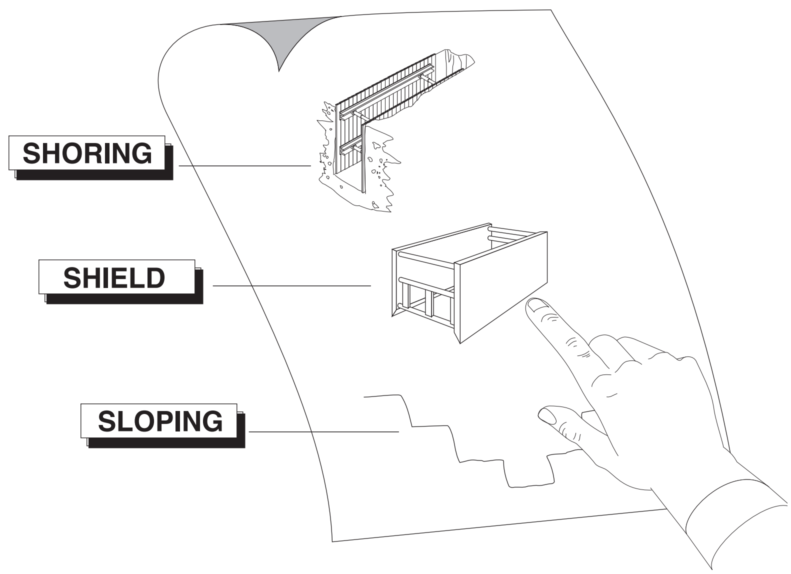
Competent Person/Shoring

Competent Person

When a **trench**[7] is dug for construction or repair. A person with the proper training to be considered a "**competent person**[8]" must be on hand to do the following:



- Inspect the site for potential hazards.
- Test the soil to determine its classification
- Determine the proper method of preventing a **cave-in**[9]**.** While the federal regulations require cave-in protection when a trench is greater than 5 feet in depth, some states, such as Alaska have set a the maximum depth 4 feet deep. There are three methods of protecting and/or preventing cave-ins. They are **sloping**[10] the banks, using a **shield**[11], or **shoring**[12]



- Assure that there are no materials on the surface adjacent to the trench that can present a hazard to those in the trench.

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[7] **Trench -** A narrow excavation made below the surface of the ground. In general, the depth is greater than the width, but the width of a trench is not greater than 15 feet.

[8] **Competent Person** - One who is capable of identifying existing and predictable hazards in the surroundings, or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them.

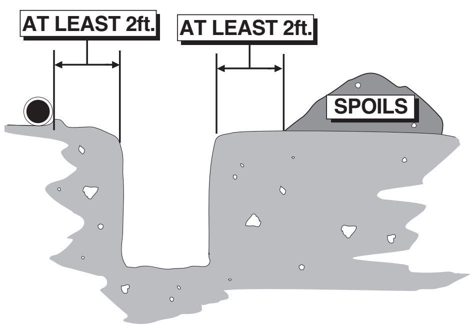
[9] **Cave-in -** The separation of a mass of soil or rock material from the side of an excavation, or the loss of soil from under a trench shield or support system, and its sudden movement into the excavation, either by falling or sliding, in sufficient quantity so that it could entrap, bury, or otherwise injure and immobilize a person.

[10] **Sloping -** A method of protecting employees from cave-ins by excavating to form sides of an excavation that are inclined away from the excavation so as to prevent cave-ins.

[11] **Shield -** A structure that is able to withstand the forces imposed on it by a cave-in and thereby protect employees within the structures.

[12] **Shoring** - A structure such as metal hydraulic, mechanical or timber shoring system that supports the sides of an excavation and which is designed to prevent cave-ins.

- Determine that all other underground utilities in the vicinity of the excavation are located.
- Determine that proper access and egress is available for workers to enter and exit the trench. A ladder must be within 25 feet of any person working in a trench that is 4 feet deep or deeper.
- Determine that all traffic control is properly installed.
- Assure that no load can fall on those working in the trench.
- Make sure that back-up warning systems are in place and working on all equipment at the work site.
- Make sure that the workers are protected from the accumulation of water.
- Make sure that all adjacent structures are stable and do not represent a hazard to the workers.
- Make sure that the spoils are placed at least 2 feet back of the trench wall.
- Assure that adequate protection to prevent persons from falling into the excavation is in place.
- Assure that proper procedures are used to test the trench for the presence of oxygen and the absence of explosive gases. The oxygen level must remain above 19.5%.
- Assure that proper emergency rescue equipment is on the job site.



The "competent person" should inspect the excavation at least once a day and record the findings of that inspection.

General Safety

Personal Protective Equipment

Use of Equipment

In order to provide the highest level of protection from accidental injury it is important to wear proper safety equipment.

Employer Responsibility

In nearly every case the employer is responsible for the purchase of all required safety equipment.

Employee Responsibility

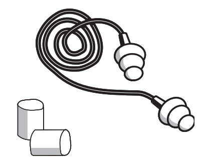
The wastewater operator has the responsibility to wear and use the safety equipment in a proper manner. The operator is also responsible for the care and cleanliness of the equipment.

Overview

Throughout this lesson we have identified general and specific safety equipment that is either suggested or required by one of the many safety regulations. The following is a brief general discussion of those pieces of personal safety equipment that we do not believe have been emphasized in other portions of this lesson.

Hearing Protection

In order to protect your hearing, acceptable noise levels have been established. The levels vary depending on the length of the exposure. The following is a table that shows this relationship. As a rule of thumb, any time the noise level exceeds 85 **decibels**[13] (dBA) hearing protection should be worn.

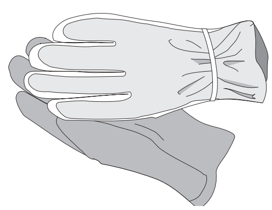


Permissible Noise Exposures

Hours	dBA
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

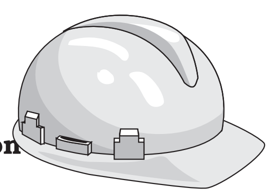
Impact/Impulse Noise Should Not Exceed 140 dBA

Gloves



There are three types of gloves that are commonly used by wastewater operators; leather or rubberized gloves for protection when doing heavy work, disposable latex gloves worn when performing laboratory analysis and working in raw sewage and special gloves used for protection when gluing PVC pipe.

Hard hats



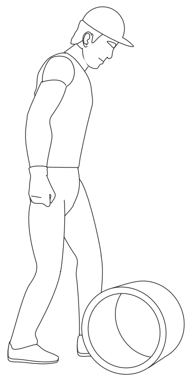
Hard hats should be worn around all construction sites and anytime an entrant is in a manhole, wet well or other confined space.

Dust Protection

When working in an area where dust will be inhaled into the lungs a dust mask is required. This same type of mask should be worn when handling lime.

[13]**Decibel** - A unit for measuring relative loudness of sounds, equal to the smallest difference of loudness detectable by the human ear. (The range of sensitivity of the human ear based on this unit is 130 decibels, the average pain threshold, where 1 decibel is the faintest audible sound.)

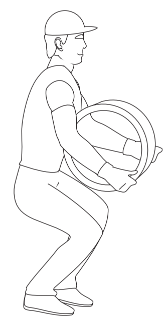
Lifting



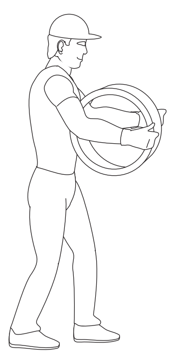
Working in a wastewater system, by its nature, requires lifting. We all have a tendency to lift too much and to ignore the proper techniques of lifting. The result is a high rate of back injuries in people who perform construction work. Here are a few simple steps that, if followed, will reduce the possibility of a back injury.

1. First get on firm flat footing. Keep your knees apart and your toes pointed slightly out.
2. Bend at the knees, not at the hips

3. Tighten your stomach muscles - This will help to support your back



4. Lift with your legs - This puts less pressure on your back.
5. Keep the load close to your body
6. Think before your start the lift - Here are a few basic questions to ask.



- What is the size of the load?
- Can I safely lift this load?
- Can I get help if the load is beyond by capabilities? A "He-Man" is of very little value with a bad back!
- Is there a better way?
- Can I use a hand truck, backhoe or other device to do this job?
- Is the pathway clear? - Most accidents in this industry are slips, trips and falls.

7. Keep in shape. Exercising at least three times a week will keep both the back and stomach muscles in tone and thus will reduce the possibility of back injury.

Housekeeping

Cause of Accidents

One of the major causes of accidents to wastewater treatment plant and collection system operators is poor housekeeping. This one item is the major cause of most slips, trips and fall accidents.

The Solution

The easiest solution is to promote good housekeeping practices. In general this would include:

- Cleaning up spills of grease, oil and chemicals as soon as the spill occurs.
- Placing chemicals in proper storage containers. Not mixing incompatible chemicals in the same storage area.
- Keep tools and spare parts in their proper storage area.
- At a work site, place tools in some type of container. This could be a bucket or other simple container.
- Do not lay shovels and other devices with long handles on the ground around a work site. Stand them up.
- Keep the interior of the work vehicle clean and remove old and broken parts, tools and debris left from previous jobs.

First Aid

Introduction

The following is a brief review of common first aid practices for accidents likely to occur in the wastewater industry.

Initial Actions

Before applying first aid one must be properly trained. Without training the actions that a person takes may cause more problems that they prevent. One of the items that is taught in first aid training is the sequence of observation and treatment of an injured person. Generally this sequence is:

- Observe for pulse first
- Second is breathing
- If they have a pulse and are breathing, handling any bleeding problems
- Treat for shock, broken bones and other conditions only after you are sure they have a pulse, are breathing and bleeding has been controlled.

Chlorine on Skin

For exposure of your skin to sodium hypochlorite, calcium hypochlorite solution or gas chlorine, flush the area for 15 minutes with clean fresh water. If burning persists, see a doctor.

Chlorine in Eye

If sodium hypochlorite, calcium hypochlorite solution or gas chlorine enters the eye, flush the eye for 15 minutes with clean, warm, fresh water. See a doctor.

Overcome with Chlorine Gas

If overcome by gas chlorine remove the person from the contaminated area and treat for shock. If the victim is not breathing give mouth-to-mouth resuscitation. If the heart has stopped, give CPR (if trained).

Treating for Shock

In the case of shock due to injury, illness or poison: the symptoms will be pale, mottled face, cold sweat, fast breathing and weak pulse.

Treatment - Keep warm, lying down, feet raised. Do not give fluids or food.

Frost Bite

The symptoms of frost bite are; skin flushed, then changing to white or grayish yellow. Blisters may appear. Skin is cold and numb. Victim will experience pain.

Treatment - Do not rub the area. Quickly warm by immersing in warm water (102° F to 105°F).

Burns

The symptoms of burns are; redness & pain. Moderate burn will blister. A severe burn shows tissue destruction.

Treatment; Ice for small burns. Use cool (not ice) water for big burns. Wash with cool water and soap. Apply sterile dressing but, **No** ointment. Do not remove clothing stuck to a burn. Seek medical help if there is extensive blistering, or skin is white, dry and painless.

Electric Shock

The symptoms of electric shock are: unconsciousness and pale, blushed skin that is clammy and mottled in appearance.

Treatment: If the victim is not breathing, give mouth-to-mouth. If there is no pulse, give CPR (only if you are trained). Elevate feet and keep warm.

General Hygiene

Disease Potential

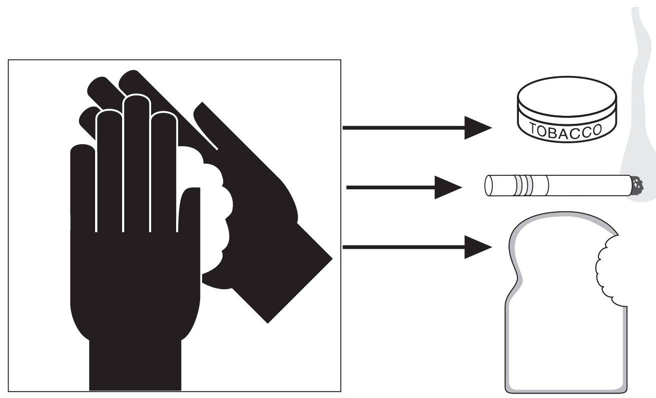
In the process of operating wastewater treatment plants and collection systems operators come in contact with piping, soil, pumping components and water that is contaminated with human waste. People are one of the most significant carriers of diseases. Most of the waterborne diseases discussed in this text are carried by people.

Protection

There are several precautions that an operator can take to maintain a level of protection from diseases such as hepatitis and gastroenteritis;

- When possible use rubberized gloves to handle contaminated material.
- Never smoke while working in a contaminated area.
- Never eat food in a contaminated area.
- Keep your hands away from your face when working in a contaminated area.

- Wear rubber boots, rubberized gloves and coveralls when working in a manhole. Remove this clothing and keep it at the treatment plant.
- Wash your hands after exiting a manhole. If you received a cut, scratch or bite from an insect while in the manhole, disinfect the affected area with hydrogen peroxide, sodium hypochlorite, rubbing alcohol or some other disinfectant.
- Wash with soap and water after handling contaminated material.



- Always wash your hands with soap and water after using the restroom.
- If possible, shower and change clothes before going home.

Bloodborne Pathogens

Diseases

While the wastewater worker does not come in contact with blood they do come in contact with other body fluids that can contain disease-causing viruses called **bloodborne pathogens**[14]. Typical bloodborne diseases include non-A hepatitis, non-B hepatitis, hepatitis B, delta hepatitis, syphilis, malaria, and human immunodeficiency virus. The two most common bloodborne pathogens are Hepatitis B (HBV) and human immunodeficiency virus (HIV). The HBV is the one virus that is of greatest concern to the wastewater operator.

Hepatitis A

In addition the wastewater operator is exposed to Hepatitis A virus (HAV)which is found in human waste from individuals infected by the virus.

Prevention

The simplest way to avoid becoming infected with the Hepatitis A or B virus is to practice good personal hygiene. Using “rubber” gloves, washing your hands and disinfecting any cuts obtained when working are the most important actions an operator can take.

[14] **Bloodborne Pathogens** - Pathogens carried in the blood of a human.

Fire Safety

Classification of Fires

There are four classifications of fires based on the type of material involved in the fire;

CLASS A - A class A fire is ordinary combustibles or fibrous material, such as wood, paper, cloth, paper and some plastics.

CLASS B - A Class B fire is flammable or combustible liquids such as gasoline, diesel, kerosene, paint, paint thinners and propane.

CLASS C - A Class C fire is energized electrical equipment, such as motors, motor controls, switches panel boxes and power tools.

CLASS D - A Class D fire is certain combustible metals, such as magnesium, titanium, potassium and sodium. These metals burn at high temperatures and give off sufficient oxygen to support combustion. They may react violently with water or other chemicals, and must be handled with care.

Extinguishing Small Fires

Class A Fires

Extinguish with pressurized water, foam or multipurpose dry chemical extinguishers. **Do no use** carbon dioxide or ordinary dry chemical extinguishers on Class A fires.

Class B Fires

Extinguish Class B fires by removing oxygen, by preventing vapors from reaching ignition sources, or by inhibiting the chemical chain reaction. Use foam, carbon dioxide, ordinary dry chemicals, multipurpose dry chemicals and halon extinguishers.

Class C Fires

Extinguish Class C fires by using carbon dioxide, ordinary dry chemical, multipurpose dry chemicals and halon fire extinguishers.

Class D Fires

Extinguish Class D fires by using dry powder extinguishers made specially for this type of fire.

Special Note

Halon fire extinguishers will no longer be allowed after 1995.

WasteWater System Safety

Worksheet

1. The department in Alaska responsible for the implementation of the OSHA regulations is ______.

2. List the major components to a safety program
   a. Written _____________
   b. An ________________ of the safety hazards
   c. Monthly _______________ meeting
   d. Routine ___________________ process
   e. __________________ solution process
   f. ___________________ procedures for violation of safety standards
   g. ___________________ system

3. Safety meetings and safety training are provided in order for the employer to train the employee in the _____________, ____________ and ____________ of unsafe conditions.

4. The most common accidents in a wastewater treatment plant fall into what classification?

5. Most of the accidents that occur to a wastewater operator occur in what general location?

6. A wastewater operator has a chance of becoming seriously injured every _____ years.

7. What is a confined space?

8. Which of the following are considered permit-required confined spaces?
   a. ____ Empty water tank
   b. ____ 55 gallon drum
   c. ____ Dry well of a sewage lift station
   d. ____ Wet well of a sewage lift station
   e. ____ Manhole

9. When performing an atmospheric test on a manhole which should be tested first?
    a. ____ Combustible gases
    b. ____ Oxygen
    c. ____ Toxic gases and vapor

10. There are four types of confined space hazards associated with entry into a manhole. They are:
    a. ____________________ hazards
    b. ____________________ with water
    c. _____________________ or ________________
    d. Other recognized __________________ safety or ______________ hazards.

11. When forced air ventilation is used in a manhole, what precaution should be taken concerning the source air?

12. Why should the collection system worker be concerned about gasoline being dumped into the collection system?

13. A confined space should not be entered unless the oxygen level is above ___________%

14. The two most common hazardous gases found in a manhole are:
    a. ________________________
    b. ________________________

15. A space should not be entered if the concentration of hydrogen sulfide is above _______ ppm.

16. In order to respond to a chlorine release, what is the minimum training requirement?

17. When painting the inside of a basin, what are the safety considerations?

18. What is the safety problem associated with the steps found in a manhole?

19. Describe the sequence for safely removing a manhole cover.

20. An amperage above ____________ MA is considered not safe.

21. When making electrical measurements what personal protection actions should be taken?

22. What special safety equipment should be used when making electrical measurements?

23. What does it mean to lockout and tagout a control panel?

24. What is the function of the MSDS?

25. The tool that can be used to determine how to handle a chemical spill is the ________________.

26. What is the function of the hazardous material communication program?

27. If an SCBA is to be available for the in-house chlorine emergency response team, where should it be stored?

28. A chlorine cylinder should be chained up _________ from the bottom.

29. There are three pieces of safety equipment that must be worn when responding to a chlorine release. They are:
    - a. 2 ____________________
    - b. Full body __________________ ___________________
    - c. An emergency _________________ _________________

30. Kit ______ is the emergency repair kit for 150 pound cylinders.

31. What are the two goals of traffic control?
    - a. ______________________________________
    - b. ______________________________________

32. There are three ways to protect against a trench cave-in. They are:
    - a. ____________________________
    - b. ____________________________
    - c. ____________________________

33. To prevent spoils from falling on a worker in a trench they should be placed at least ________ feet from the wall of the trench.

34. In Alaska the soils associated with any trench must be tested by a ____________ ___________ and if the trench is more than _______ deep, protection must be provided.

35. In order to protect your back you should always lift with your ____________.

36. Why is it a good practice to practice good housekeeping?

37. What is the first aid for a spill of chlorine on your skin?

38. If a wastewater operator smokes on the job. What special safety precaution (associated with the job) should be completed before lighting a cigarette?

39. After working in a sewer manhole the operator should always _________________________________ before eating lunch.

40. What is the most common BBP related disease that a wastewater operator is likely to be exposed to?

____

41. An electrical fire is a Class ______ fire and can be extinguished using. ....

42. A diesel fire is a Class ______ fire and can be extinguished using…..

Utility Management Considerations

What is in this Lesson?

1. Roles of utility personnel
2. Components of a customer service/public relations program
3. The basic responsibilities of management, operations and customers
4. The reason for maintaining daily records at a water system
5. Definition of utility management
6. The major components of a MM system
7. The purpose of preventive maintenance
8. The components of an emergency plan
9. The five major components of utility management
10. The five resources under the direction of the utility manager
11. The major elements and function of each of the five utility management components

Key Words

- Cash
- Chart of Accounts
- Disbursements
- Maintenance Management
- Non-code ordinance
- Resources
- Visioning
- Capital construction
- Consumable inventory
- Force Account
- Master plan
- R & R
- Resolutions

Utility Management Considerations

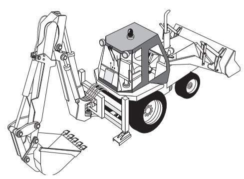
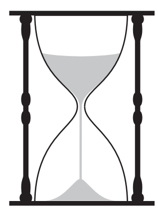
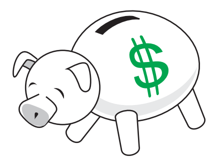
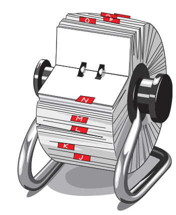
Formal Definition

Utility management is a method of obtaining results by planning, organizing, staffing, directing and controlling the use of the available **resources**[1]. It is a process of getting work done through the cooperation of others.

Application

From a practical approach, management can be defined as the process used to direct the use of resources to achieve desired results. It is working with others. The emphasis is on the effective use of resources. What resources are considered? Resources include:

- people
- materials, equipment and facilities
- time
- money
- information

Of all of these resources, people are the most important. Without people to perform the work, there are no results.

Application of Management to Utilities

Component Groupings

This lesson was designed around the application of the basic management principles (planning, organizing, staffing, directing and controlling) to five basic management components:

- Organizational Management
- Planning Management
- Personnel Management
- Operational Management
- Financial Management

These five components were selected because they closely represent the grouping of activities in a typical utility. The following is a brief introduction to the elements of each of these components.

[1] **Resources -** The people, time, money, information and physical facilities necessary to accomplish the goal of providing safe potable water to the community.

Organizational Management

Definition

Organizational management is the process of managing the structure and information flow of the organization and contains the following elements:

- Organizational structures
- Organizing the organization

Organizational Structures

Although utilities may be privatly owned the vast majority of small utilities are publicly owned. While this text may be of value to privatly owned utilities it was designed around the public utility thus only public utility practices are described. There are different types of public organizations that may own, operate, maintain and manage water and wastewater utilities. Some of the more common are:

- Municipalities (Cities and Boroughs)
- Tribal Governments (IRA & Traditional)
- Nonprofit corporations
- Service districts and service areas
- Authorities

Municipalities

City

There are three common types of municipalities: cities, counties, and boroughs. Cities may be organized using a strong mayor or city manager form of government. With a strong mayor form of government, the mayor is the chief administrative and executive officer of the city. The mayor may appoint a city administrator to whom administrative duties are delegated. In the city manager form of government, a city manager is hired by an elected council to provide administrative duties. The mayor serves as ceremonial leader of the council. In both forms of city government, an elected council sets city policy and approves the city budget.

Counties & Boroughs

Counties and boroughs typically have the general powers granted to cities, plus they may have area-wide powers of education, land-use regulation, and assessment and collection of taxes.

Utility Boards

In some jurisdictions, a utility board is appointed by the policy-making body to provide policy oversight and review of the operation of the utility. Typically this board has no formal jurisdiction. The board and its chair may report directly to the policy-making body, mayor, or administrator.

Tribal Governments

Tribal governments can take many forms. The most common tribal governments include an elected tribal council. There are two recognized forms of tribal governments: IRA and traditional.

Most tribal and Alaskan native goverments conform to the Indian Reorganization Act (IRA), a federal statute adopted by Congress in 1934 which was applied to Alaska in 1936 All IRA governments have constitutions that have gone through a federal review process and Secretarial Election.

Most traditional tribal governments have adopted written constitutions.

Both traditional and IRA Councils have equal federal recognition and ultimately derive their powers from inherent sovereignty.

Non-Profit Corporations

Definition

Nonprofit corporations can be formed to provide any lawful purpose including operation and management of utilities. Examples of purposes for which nonprofit corporations are organized include: religious organizations, education, civic, cemetery, political, cultural, scientific, professional, commercial and trade unions, and trade associations. Excluded from using this designation are cooperative corporations such as electric and telephone cooperatives and organizations subject to state insurance or banking laws.

Organization

Non-profit corporations are usually governed by a Board of Directors that contains at least three members of the corporation. The specifics of the governing methods of the organization are described in the Articles of Incorporation and the organization's bylaws.

Service Districts and Services Areas

Service Districts

Special service districts are formed to provide specific services, such as drinking water, wastewater, fire, police and schools. The district is operated by an elected board. The leader of the board is usually called the chairperson. State statues restrict the board authority to providing one specific service. The board may hire an administrator, usually called the superintendent, to provide administrative duties.

Service Areas

A service area may be established by a county or borough and must be within the county or borough. Special service areas have taxing jurisdiction and can be established to provide a special service such as road maintenance, fire protection or water supply. In some states these service areas are called service districts.

Authorities

Definition

Service authorities have been established in many of the US Territories and island nations of the Pacific. These authorities may be called an authority, corporation or company. The territory, state or national government owns the assets. The authority is typically governed by a board of directors appointed by the governor, president, or legislature. The manager of the utility may be hired by the board of directors or by the governor or president. It is very common for these authorities to have the responsibility over many of the utilities. Typical combinations include power generation, power distribution, water, wastewater, and in some cases solid waste.

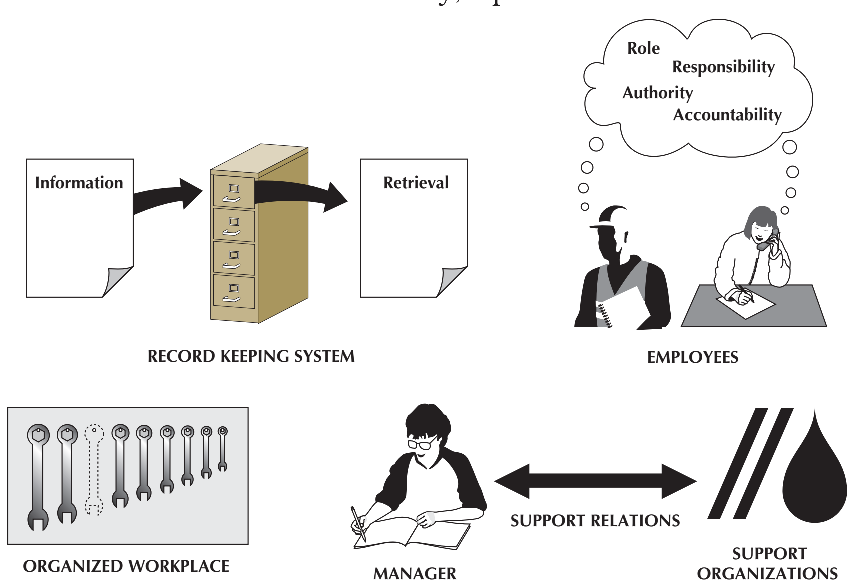
Organizing the Organization

Being Effective

In order for a utility to be effective, there must be an organizational structure. There are several key components to an effective organization. One of the first is the establishment of clear understanding of the responsibilities and authority of each employee and how they will be held accountable for their behavior. This should be committed to writing in job descriptions. Responsibilities for some key positions may be clarified in the utility ordinance. Establishing responsibilities, authority and accountability is the duty of the utility manager.

Information Management

Every organization requires information in order to be effective. One of the responsibilities of utility management is to establish a method of management and control of the utility record-keeping system. This includes personnel records, accounting records, customer information, construction and project information, asset data, operation information, maintenance history, Operation and Maintenance



manuals, safety information, **consumable inventory**[2], and other documents and records required by various state and federal agencies.

The Workplace

In order to be effective and efficient, the workplace must be organized. The shop, office and other utility facilities must be organized. The work spaces must be kept clean and all equipment in working order. Adequate space must be provided for the storage of supplies, equipment, tools, and old records. When these work spaces are neat and orderly, each job will proceed more smoothly than if the work space is disorganized.

Support Entities

In addition to all of the above actions, the utility must establish and maintain lines of communication and interaction between cooperating agencies and professional organizations that can assist in the operation, maintenance, and management of the utility. These organizations can be extremely helpful in providing guidance in working with limited resources and the constraints provided by state and federal regulations. These organizations include state health agencies, USEPA, US Public Health Service, American Water Works Association, Water Environment Federation, and American Public Works Association.

Roles and Responsibilities

Customers

The customer is the end user of the product and is responsible for paying for the service provided and using the water in a wise manner.

Federal and State Agencies

Federal, state, and territorial agencies are responsible for establishing regulations to assure that water provided by public water systems is safe to drink.

Policy-Making Body

The policy-making body may be a city council, board of directors or traditional council. The policy-making body sets policy and rates and is responsible for overseeing the entire water utility. The policy-making body as a group, and sometimes as individuals, is responsible and liable for the quality of the service, the fair treatment of customers, employees and vendors, including contractors, safety of employees and for the financial solvency and physical well being of the water utility.

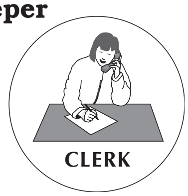
Utility Management

Each utility, regardless of ownership or size, should have an individual identified as the utility manager. This is the individual responsible for the administrative duties of the utility and oversight of the day-to-day operations. The utility manager reports

[2] **Consumable inventory** - Supplies and materials which will be used up or converted within a year to provide a service. Consumables include chemicals, office supplies, and repair parts.

directly to the policy-making body. The responsibilities and duties of the utility manager may be delegated to a managers, department heads, and supervisors

Utility Clerk - Bookkeeper



The utility must also have individuals designated to manage all of the business, personnel, financial records, and transactions of the utility. This may be one or more people, full or part-time. The tasks are usually divided into two categories. The administrative tasks are the responsibility of a utility clerk and the financial tasks (accounting) are the responsibility of a bookkeeper or comptroller.

Utility Operator

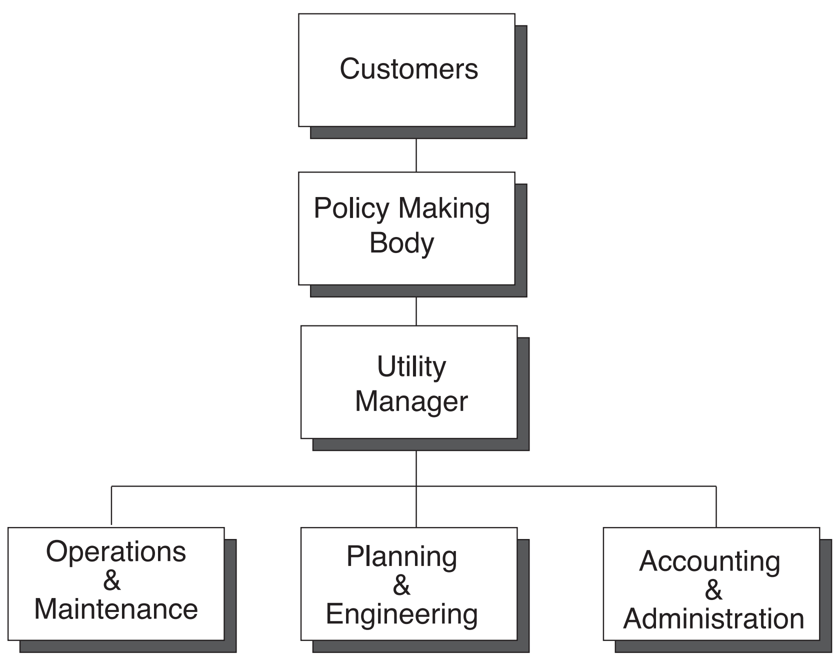
The utility must have an individual designated as the operator. The operator is responsible for the day-to-day operation and maintenance of the utility. The operator may be full or part-time and in a small utility normally reports to the utility manager. When this occurs the person is usually called the superintendent. In larger utilities the operations and maintenance of the water system is divided among one or more crews.

Planning & Engineering

Design of new facilities, replacement of older facilities, system expansion, and construction are assigned to the planning and engineering function. In small systems these tasks are performed by contracts or agreements with agencies, such as the Indian Health Service, or private firms. In larger utilities these tasks are a support staff function.

Organizational Chart

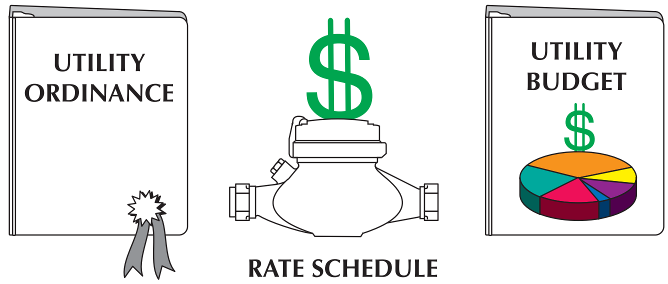
Organizational charts are designed to provide a clear view of the authority, lines of communication, and organization of the utility. They also identify the supervisor for each position.



Authorization Documents

Three Documents

The organization and operation of the utility is authorized in three separate but related documents: the utility ordinance, the utility rate schedule, and the utility budget.



Utility Ordinance

The key utility organization document is the utility ordinance. The utility ordinance is the legal document that establishes the utility. It clearly identifies areas of responsibility and authority for key positions and establishes methods of accountability.

Ordinance as a Guide

The utility ordinance provides guidance on how the utility is to be operated and managed. It includes guidelines requiring specific accounting practices and establishes the criteria for establishing utility rates and other charges. It documents the service to be provided and as well as the area to be served.

Ordinance and Customer

In addition to the other provisions, the utility ordinance provides the rules governing customers, new connections, billing process, and the handling of past-due accounts.

Rates & Rate Schedule

The rate-making process is described in the utility ordinance. However, the rates should be contained in a separate **resolution**[3] or **non-code ordinance**[4] that describes all rates and customer charges. A summary of the rate structure and rate making process should be placed in a document that is given to the customer.

Customer Agreement

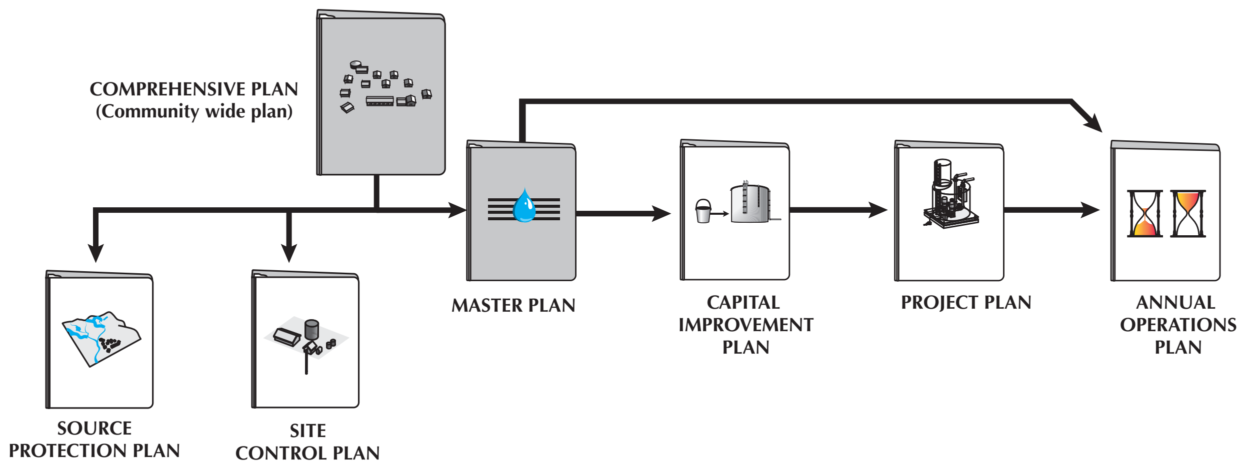
A document frequently called the Customer Agreement is a customer service document containing information describing the billing process, emergency response by the utility, service connection process, how to contest a bill, the customer's rights and responsibilities, and the utilities responsibilities. The contents of this document are obtained from the utility ordinance and the utility construction standards.

3 **Resolutions** - An official opinion or statement of the policy-making body on a particular subject. A resolution is a formal, written expression adopted by the policy-making body at a public meeting. Common uses of a resolution are to voice support for a project or issue, call attention to a problem affecting the community, or direct the administration to do something.

4 **Non-code ordinance** - An ordinance which is not part of the permanent code of ordinances. Examples of non-code ordinances include budget ordinances and emergency ordinances.

Planning Management

Planning management is a process used by the utility to set the direction of the utility, provide a means of responding to customers needs, and preventing crises.



Planning Components

There are two categories of plans that impact a utility: community wide plans and utility plans.

Community Wide Plans

Comprehensive Plan

The heart of planning documents is the comprehensive plan. This is a document developed by the community that sets the direction of the use of lands and major activities in the community. This document reflects the values of the community and is the guide to all other planning documents.

Contents

The comprehensive plan contains a description of the physical, social, and economic characteristics of the community. In addition, the plan describes the needs of the community and provides guidance on what will need to be done to meet those needs, who will do it, when and how the major portions will be accomplished and financed.

Utility Plans

Introduction

Utility plans include:

- Site control
- Source protection
- Master plan - sometimes called a Facility Plan
- Capital improvement plan
- Project plan
- Operations plan

These plans are all developed by authority of the policy-making body and must be consistent with the comprehensive plan.

Site Control

The site control plan identifies existing utility land ownership, existing utility land use, future utility land use needs, and how land should be acquired for utility use. Because site control requires land-use planning, it must be developed in cooperation with the comprehensive plan.

Source Protection

The source of water for a utility can become contaminated or the volume altered by human and natural actions. To protect the recharge area of groundwater supplies and the source of surface water supplies, special land use programs are developed. The groundwater protection program is called a well head protection program and the surface water program is called a watershed protection program. Like site control, source protection plans involve land use planning, and must be developed in cooperation with the comprehensive plan.

Master Plans/Facility Plans

The major short-term and long-term steps required to reach the goals of the utility are described in a document called the utility **master plan**[5]. Included in this document is a discussion of the options considered and the criteria used to reach the conclusions. In addition, this master plan sets up time lines and projects costs, identification of roadblocks, and implementation considerations.

Capital Improvement Plan

Capital improvement plans are used by utilities to plan for the construction of new water and wastewater facilities as well as replacement of existing facilities. These plans are designed to meet needs described in the comprehensive plan and the utility master plan. The capital improvement plan document includes a description of what facilities need to be built, when they should be built, and how the construction is to be financed. Typical finance methods are grants and bonds. In addition, a decision on how to most effectively get construction done using either a contractor or **force account**[6] labor.

Project Plan

Utilities are constantly involved in planning and organizing projects. These projects may be small or large and financed by state, federal, or local funds.

They may be for **capital construction**[7] improvements or major repairs and/or rehabilitation. The utility

[5] **Master plan** - long-range plan for a municipal service, facility or utility which 1) Identifies the municipality's growth management, development and financing policies and outlines the communities needs and desired service levels; 2) Identifies the constraints and advantages presented by the physical environment and existing patterns of development; 3) Details all federal, state and local design standards for the service, facility or utility; 4) Assesses the condition of any relevant physical plant, the quality of operations and maintenance and the current financial position ; and 5) Develops a strategy tying together needs, constraints, local government policies and design standards, state and federal standards, operational improvements, long-term capital improvements and long-term financing.

[6] **Force Account** - The use of municipal staff and equipment for the construction, alteration or rehabilitation of buildings and system improvements rather than an outside contractor.

[7] **Capital construction** - Projects which consist of the purchase, construction or major rehabilitation/renewal of capital assets.

manager is responsible for organizing these projects. Besides the obvious requirements for development of engineering plans, cost estimates and personnel requirements, the manager must develop a method to control the inventory of project materials, develop cost controls, identify personnel and equipment requirements, and establish a record-keeping system.

Operation Plan

Once each year, in conjunction with the budget development process, the manager and operator develop the annual operating plan for the utility. This plan describes the expected level of service for the next year, special projects and actions plans. This plan is a simple document that includes capital construction, repair, and replacement considerations for the upcoming year. This document is often called the budget message.

Planning Process

Working Together

At the heart of planning management is working with the staff and customers in the development of clear visions and goals for the utility. They also work together to commit the utility to attaining the vision and meeting the goals. The elements of the process are discussed in the following paragraphs.

Setting Goals

The development of community-wide-supported goals for the utility determines the level of service desired by the community. For new systems this includes the selection of the type of system. For existing utilities this includes the frequency of performing tasks, the quality of product, and the service provided.

Constraints

In the development of the above vision, the goals and priorities of the federal and state regulatory agencies must be considered.

Community Input

Utility planning in a community may require making decisions that impact the entire community. The most effective process for making these decisions is through community involvement. One effective tool for obtaining community involvement is the **visioning**[8] process. Most projects in small communities are difficult to complete without community support. In addition, the lack of community support may be reflected in low collection of service fees.

[8] **Visioning** - A formal process of identifying community and economic development concerns using a community forum technique.

Personnel Management

Introduction

The key to any organization is the effectiveness of the manager in the management of the people resource. This requires managers, supervisors, and foreman to develop leadership skills, provide motivation, and delegate work.

Communication

A key to effective leadership and management is the manager's ability to develop a vision of the utility and effectively communicate the vision to the staff. This requires maintaining lines of communication, developing communication techniques, and designing communication processes within the utility.

Management Function

In addition to the development and use of leadership and communication skills, an effective manager must implement policies and procedures that are used to direct personnel and resolve personnel issues. These include employee polices and procedures and the employee safety program.

Personnel Policies

Clearly written personnel policies are one of the key methods used to communicate responsibility, authority, and accountability to the staff. Included in these policies are

- Hiring and firing procedures, including the utility's application of federal and state EEO and AA regulations
- A description of the performance appraisal process, frequency and functions
- Job descriptions and written list of job responsibilities;
- A description of the discipline procedure, how it is applied, and the employee's rights to contest the action
- A description of training requirements, how training is funded, what is expected of the employee, and the results of the utility's expectations
- A description of the operator certification requirements for the utility

These policies should be placed in an employee handbook that is distributed to each employee. The manager is responsible for updating the procedures and handbooks as regulations and conditions change.

Safety Program

In order to properly protect workers and meet the requirements of state and federal regulations, the utility must develop an appropriate safety program for all workers. This safety program must be based on an assessment of the hazards faced by the workers. In addition to the development of the safety program, the utility must implement and maintain appropriate records. The utility is responsible for furnishing all required safety equipment and training at no cost to the employee.

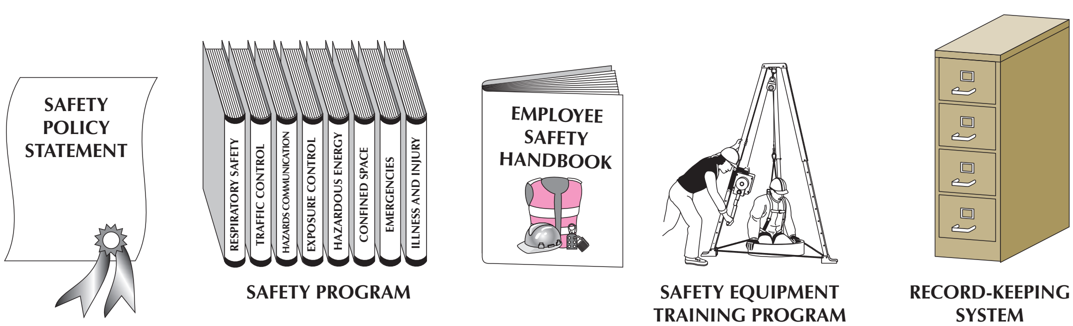
Safety Program Elements

A properly designed program would include a written policy and written programs and procedures based on the hazard assessment. Common safety program elements for a utility include:

- Injury and illness prevention program - This is the umbrella program and includes safety committees, personal protective equipment requirements (PPE), first aid, and record keeping.
- Hazard Communication Program
- Control of Hazardous Energy (Lockout\Tagout)
- Confined Space Entry program
- Traffic Control program
- Excavation Safety program
- Control of Occupational Diseases program - includes safe handling of AC pipe
- Respiratory Protection program
- Heavy equipment operation - incudes backhoes, cranes, forklifts and boom trucks.

Training & Equipment

In nearly every case, each safety program component has a training requirement, as well as specific requirements for selection and use of safety equipment. Current federal safety regulations require the employer to supply all required safety equipment.



Staff Training Program

Why?

Training costs money. Why then do successful organizations require and support personnel training? These organizations have found that training is can:

- Provide personnel with the proper information to allow them to properly operate and maintain the system.
- Reduce operating cost.
- Be a motivator for all personnel.
- Is required in order to meet certification and safety requirements. Providing this training reduces the organizations liability exposure, improves operations and reduces accidents.
- Prevent costly system failures.
- In critical environments such as cold climates, properly trained personnel can prevent costly system failures.

Certification and Training

Besides the training requirements associated with the safety program, each organization has the responsibility to see that the operators and office staff are properly trained, and where appropriate, certified. While operator certification may not be required for some systems, it is an excellent way to motivate employees and at the same time reduce the organizations' liability exposure.

Advanced Training

Research indicates that the best results are acheived by people who are trained at least one level above their work requirements. Therefore, it is the responsibility of management to see that each worker is involved in a regular training program. If the budget allows, at least two training and/or conference sessions per year are suggested. Both American Water Works Association and the Water Environment Federation have suggested that the personnel training budget be equal to at least five percent of the amount paid for salary.

Operational Management

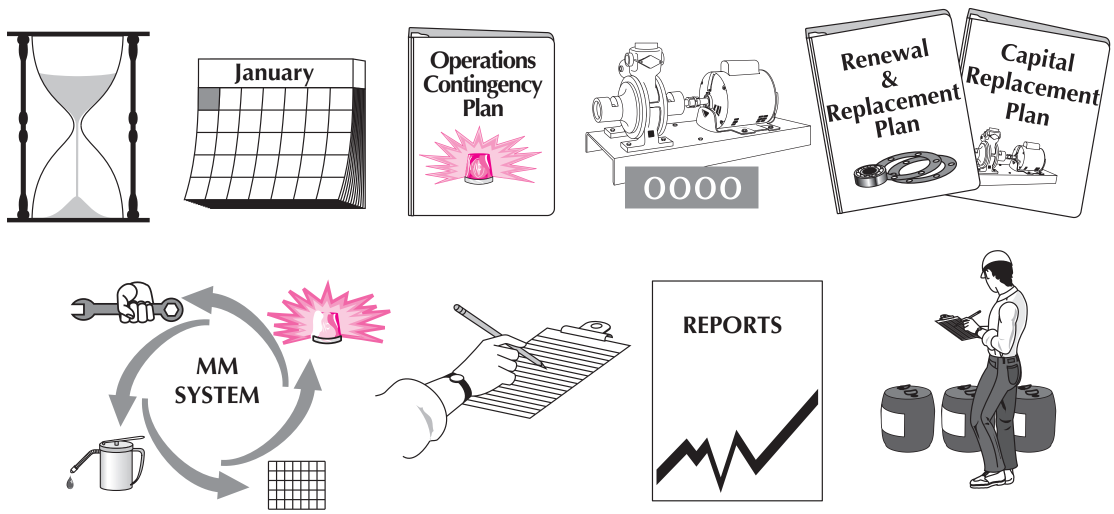
Components

Effective and efficient utilities develop processes designed to manage the operational function of the utility. These include:

- Asset management system
- Routine Operations & Preventive Maintenance
- Sampling schedule
- Repair work order system
- Work scheduling
- Contingency plan
- Consumable inventory control
- Data collection and reporting
- Information management
- Renewal and replacement schedule

Maintenance Management

The term **maintenance management**[9] is used to describe all of the operational management components described above.



Asset Management System

The asset management system is a method of numbering and tracking the use, condition, and value of the assets that belong to the utility. The identification and documentation of the brand, model, size, and condition of the assets is the key to proper development of routine operations and preventive maintenance systems. It is from the asset management system that we can determine the required spare parts and equipment replacement schedule.

Operations and PM

An operations and preventive maintenance system is the method for determining the labor, tools, and spare

9 **Maintenance Management -** A systematic process of planning, organizing, scheduling and controlling preventive and repair maintenance in order to provide a defined level of service at a specific cost.

parts requirements for the utility. This system includes all routine operations and preventive maintenance tasks required to maintain the adequacy and reliability of the system, the frequency of each task, number of people required to do the tasks, parts and special materials needed to complete each task.

Sampling Schedule

To be assured that the proper water quality samples are collected from the correct location at the correct time, a sampling schedule is developed. This schedule lists all sampling requirements, locations, frequency, laboratory requirements, reporting requirements, and any special provisions. The sampling sites are noted on a system map.

Repair Work

The use of a formal or informal repair Work Order system will allow the manager to determine and control the cost of most repairs. This system would include a formal request for work, estimating the cost of the work, determining if finances allowed the work to be completed, and documenting material, labor and equipment cost.

Work Scheduling

Scheduling is the key to collecting samples at the proper time, effectively performing preventive and repair work and controlling labor cost. Scheduling provides a means of completing the most important jobs first, ordering parts and equipment on time, and controlling item cost.

Contingency Plan

To maintain the reliability of the utility facilities, a contingency plan (also called an emergency plan) is developed. This plan describes in detail how to handle common utility problems. These would include raw sewage spills, broken water or sewer lines, loss of the water source, and contamination of the system. In addition, non-routine tasks such as how to take the reservoir off line, by-pass a lift station, as well as switch pumps or wells should be described in this plan. Critical spare parts required to implement these plans should be purchased and on-hand.

Consumable Inventory

In order to maintain an adequate and reliable utility, it essential that an inventory of critical spare parts be maintained. This inventory is called a consumable inventory. A system of verifying inventory needs, purchasing, verifying receipt of the items, documenting use, and reordering in a timely manner is all part of an inventory control system.

Data Collection and Reporting

In order to effectively manage a utility, key operational and water quality data must be collected and analyzed. Some data elements such as production, chemical usage, chlorine residuals, and system pressures must be obtained and recoded daily. Other data elements such as pump and motor efficiency can be collected and analyzed quarterly or annually. The most important part of data collection is the routine collection and analysis of the data. A well operated data collection system includes data collection forms and formal reports.

Information Management

A major portion of managing the operation of the utility is an effective information control system. This system must include a method of filing and retrieving reports, plans, O & M manuals, water-quality testing results, as well as communication with state and federal agencies. In addition, there must be a method for storage and retrieval of maps and drawings.

Renewal and Replacement

The **R & R**[10] (Renewal and Replacement plan) allows the utility to determine the estimated cost and develop a schedule for the replacement of assets at or prior to the end of their estimated life.The information for the R & R plan comes from the asset management system.

[10] **R & R** - Renewal and Replacement. A systematic process or budgeting for the repair and replacement of equipment that either requires a significant annual repair cost or has a life expectancy of less than ten years.

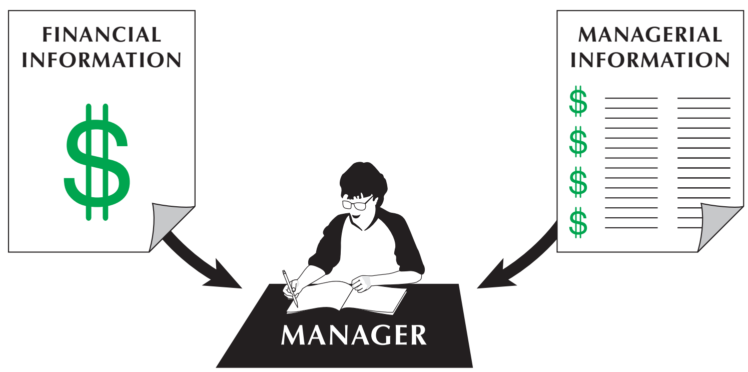
Financial Management

Purpose

Financial management provides two basic functions: financial information and management information. Both functions use financial data to provide management with different views of the financial health of the utility. Financial information includes the relationship between the amount of money received or spent and the amount budgeted. Management information includes the cost of providing a specific service or quantity of service.

Key

The key to effective financial management is the development of a system that allows the manager to easily compare the budget with the rate model and the accounting system.

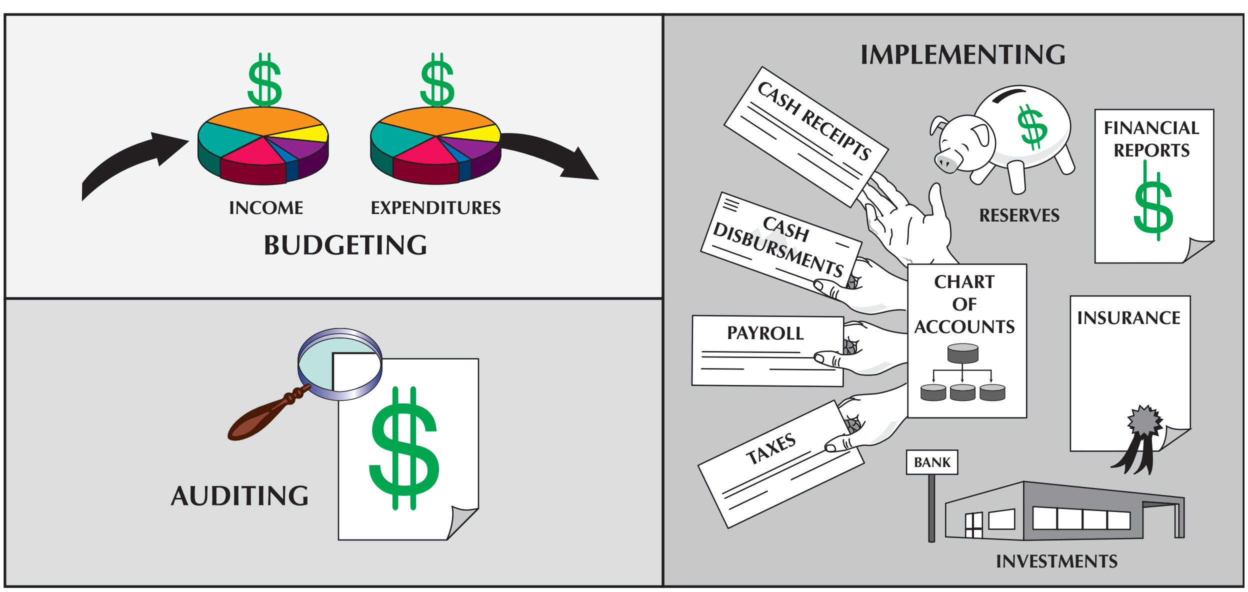


Authorization

Financial management practices used by the utility are authorized by the utility ordinance and the accounting policy and procedures manual.

Three Phases

There are three phases to the proprietary financial management of a utility described in this text. These phases are budgeting, implementing and auditing.



Budgeting

Functions

The budgeting serves three basic functions. First, it is a method of projecting operating cost and income requirements. Second, it is a planning tool reflecting the master plan and annual operating plan. Third, it provides the authorization to spend money.

Three Budgets

There are three segments to the annual budget prepared by utilities. Each of these segments is called a budget: operating budgets, capital budgets, and cash flow budgets. The finished product is called a combined budget.

Two Areas

There are two parts to each budget: income and expenditures. For example, the operating budget details labor and material cost for the annual operation and maintenance of the utility. This budget also details that portion of the utility income allocated to O&M and R&R.

Budgets & Rates

With the exception of grants for capital construction, most income to a utility is obtained from the customers. The rate a customer is charged should be based on the true operating cost of the utility. The most effective rates are those projected five years into the future along with the five year budgets.

Fair and Explainable

In order for the rate-making process to be effective, the rate-making method must be easily explainable to the customer. In addition, the rates must be equitable, that is, they must be fairly applied to all customers.

Implementing

Chart of Accounts

To correctly determine rates and track income and expenditures, a **chart of accounts**[11] (COA) is needed in the accounting system. This is simply a hierarchical system of numbered accounts that allows the manager to determine how much money has been spent and for what. In addition, the chart of accounts allows the manager to determine the amount of income from each major source. The major categories in the COA must reflect major areas of the budget and the rate model.

Cash

Money received by the utility is called **cash**[12] receipts and payments by the utility are called cash **disbursements**[13]. The receipts and disbursements details are tracked in the receipts and disbursements journals.

Financial Reports

Financial reports provide the manager, operator and policy-making body with the financial status of the utility. These reports are the key to understanding the

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[11] **Chart of Accounts** - A listing of account numbers and titles used in an accounting system.
[12] **Cash** - Money in the form of currency or checks.
[13] **Disbursements** - The actual outlay of cash to make payment on an operating expenditure or capital expenditure or to retire debt. Note that the expenditure is the creation of the obligation to pay and the disbursement is the actual payment.

financial health of the utility and preventing financial crises. These reports can be placed into two categories: financial information and management information.

- Financial information provides a summary of income and expenditure by COA categories. This report shows a comparison of actual income and expenses budgeted for the month and year-to-date. The report is used by the manager to maintain the expenses in balance with the budget. In addition, unexpected increases or reductions in income are shown allowing time to make appropriate changes.
- Management information provides additional information on the cost of operating the utility, for example, the cost of producing each 1,000 gallons of water, or the number of gallons produced or treated per kilowatt hour of power consumed. In addition, management reports would contain information on outstanding payables and receivables as well as the percentage of past-due customer accounts.

Payroll and Taxes

The utility must have an effective and accurate payroll process. The Internal Revenue Service requires that the process and reports produced for payroll and payroll taxes be precise, filed on time and maintained up-to-date. The utility is required to pay the taxes withheld from payroll, the utilitie's portion of FICA and unemployment taxes promptly. Failure to pay these taxes can result in extensive fines.

Customer Accounts

A customer accounts system is used to determine when the customer was billed, when they paid and any outstanding balance. In addition, customer files are established that contain the original of the user agreement signed by the user at the time of the connection. This file also contains the past history of customer complaints and billing problems.

Reserves

To pay for emergencies, capital projects, and equipment that is expected to wear out, the utility should maintain a cash reserve. A major portion of the requirements of this reserve can be obtained from the R & R budget. In addition, it is desirable to accumulate an amount of cash equal to ten percent of the value of assets with an expected life expectancy greater than ten years, This will allow the utility to pay for pre-engineering and legal cost for replacement of the asset.

Investments

Investments can provide an additional source of revenue. Cash reserves should be invested in CDs or in some other secure form of investment such as managed money-market accounts. Many investments can be made for very short term and provide a reasonable return. Investments must be handled by a reputable firm.

Risk Management

The process of protecting the utility assets, customers and utility personnel is called risk management. This process allows the utility to determine the best method of managing a specific risk. The utility has four options in managing risk. They can eliminate the risk, reduce the risk, assume the risk, or transfer the risk to an insurance company.

Insurance

The three categories of insurance that a utility should consider are casualty, liability, and employee insurance.

Casualty insurance includes inland marine, earthquake, wind, flood, fire, theft and, perhaps, malicious vandalism.

Liability insurance covers product liability, property liability, possible errors or omissions of the policy-making body and bonds on staff members who handle cash.

The third category is employee insurance. This includes mandatory workers compensation insurance and health insurance.

Auditing

Auditing is the last component of the financial management circle. Auditing is a formal process of reviewing the financial practices and procedures, determining that funds were properly used and that there has been no theft of funds or assets.

Management Considerations **Worksheet**

1. For each of the following, provide one major responsibility in association with water systems.

   a. Customers____

   b. Policy Making Body ____

   c. Management____

   d. Operations ____

2. The five resources available to a utility manager are

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

   e. ______________________________

3. A utility manager's area of responsibility is defined by the ________-_________ ________________.

4. What are the five basic management components discussed in this lesson?

   a. ______________________________

   b. ______________________________

c. ______________________________________

d. ______________________________________

e. ______________________________________

5. _________________ ___________________ is the process of managing the structure and information flow of the organization.

6. _________________________ ______________ are designed to provide a clear view of the authority, lines of communication and organization of the utility.

7. __________________ ________________ is a process by the utility to set the direction of the utility, provide a means of responding to customers needs and prevent crises.

8. The two levels of plans that impact the operation of a utility, are:

   a. ______________________________________

   b. ______________________________________

9. Two key written documents that guide the management of the personnel of the utility are:

   a. ______________________________________

   b. ______________________________________

10. The tool used to identify the labor requirements of the utility is the ________________ _____________________program.

11. What are the three phases of financial management?

    a. ____

    b. ____

    c. ____

12. In order for the customer to accept utility rates they must be ___________ and _______________________.

13. Who has the responsibility for setting customer rates?

14. Who has the responsibility for the development of the water operations and maintenance budget?

15. Identify three of the safety programs that must be developed by management.

    a. ____

    b. ____

    c. ____

Math - The Basics

What is in this Lesson?

1. The principles of working with fractions
2. The principles of working with decimals
3. How to round numbers
4. How to determine significant digits
5. How to read powers
6. Conversions using standard conversion factors
7. The weight of one cubic foot of wastewater
8. The volume in gallons of one cubic foot of wastewater
9. The number of square feet in an acre
10. How to average a set of numbers
11. How to determine area of rectangles and circles
12. How to determine volume of rectangular, circular and cone shaped objects
13. How to convert whole numbers to percent
14. How to calculate percent
15. How to make common wastewater conversions
16. Common abbreviations found in wastewater math
17. How to convert pressure to feet of head
18. The number of gpm that equals one cfs
19. How to calculate the radius and circumference of a circle
20. How to calculate the perimeter of a rectangle
21. How to calculate flow
22. How to calculate detention time
23. How to work with simple equations to solve wastewater problems
24. How to calculate BOD and TSS removal
25. How to calculate pump efficiency
26. How to use ratio and proportions
26. How to calculate flow
27. How to use the pounds formula
28. How to make common metric conversions found in the wastewater field

Key Words

- Area
- Averages
- cfs
- Circumference
- Cross sectional area
- Cubic feet
- Cylinder
- Detention time
- Flow
- Head
- MGD
- mg/L
- pi
- Pressure
- Radius
- Rectangle
- Velocity
- Volume

Math - The Basics

Introduction

Lesson Intent

This lesson on math basics is intended as a review and introduction to those math concepts believed to be critical and minimal for operators who are working at the OIT and/or level I in rural Alaskan communities. This does not mean that these are the only math concepts that a competent operator would need to solve routine operation and maintenance problems. Several books are available that deal exclusively with math for operators. Contact DEC's Operator Certification Program to borrow a math book from the Operator Lending Library.

Lesson Content

This lesson on basic math is a review of the principles needed for working with fractions, working with decimals, rounding numbers, determining the correct number of significant digits, raising numbers to powers, using basic formulas, calculating percent, making simple conversions, calculating **flow**[1], calculating volume, calculating **detention time**[2], making metric conversions, and using the pounds formula.

[1] **Flow** - To be in constant movement, typically in a single direction. In wastewater this term typically relates to a volume per unit of time-gallons per minute, cubic feet per second, etc.

[2] **Detention time** - The theoretical time required to displace the contents of a tank or unit at a give rate of discharge or flow.

Abbreviations

Limitations

The following is a listing of common abbreviations that are used in math problems in the wastewater field. With a few exceptions, this listing is limited to those abbreviations that are associated with the English units of measurement. Abbreviations associated with the SI (metric) system of measurements are found in the section of this lesson on metric units.

ac	acre	ac-ft	acre-feet
af	acre-feet	amp	ampere
BHp	Brake horsepower		
°C	degrees Celsius	cfm	cubic feet per minute
cfs	cubic feet per second	cu-ft	cubic feet (ft^3)
cu-in	cubic inch	EHp	electrical horsepower
°F	degrees Fahrenheit	ft	feet or foot
ft^2	square feet		
ft-lb/min	foot pounds per minute	gal	gallon
gpd	gallons per day	gpcpd	gallons per capita per day
gpm	gallons per minute	hr	hour
Hp	horsepower	in	inch
in^2	square inches	in^3	cubic inches
KW	Kilowatt	KWh	Kilowatt-hour
lb	pound	M	Million
MGD	million gallons per day	mg/L	milligrams per liter
min	minute	psi	pounds per square inch
ppm	parts per million	sq ft	square feet (ft^2)
W	watt	WHp	Water horsepower
yd^3	cubic yard		

Some Common Conversions

Area
1 acre = 43,560 ft^2
1 ft^2 = 144 in^2

Linear Measurements
1" = 2.54 cm
1' = 30.5 cm
1 meter = 100 cm = 3.281 feet = 39.4"
1 yard = 3 feet

Volume
1 gal = 3.78 liters
1 ft^3 = 7.48 gal
1 ft^3 = 62.4 lbs
1 gal = 8.34 lbs
1 Liter = 1000 mL
1 acre foot = 43,560 cubic feet
1 gal = 8 pint
1 gal = 16 cups
1 pint = 2 cups
1 pound = 16 oz dry wt
1 yd^3= 27 ft^3
1gpm = 1440 gpd

Weight
1 ft^3 of water= 62.4 lbs
1 gal = 8.34 lbs
1 lb = 453.6 grams
1 kg = 1000 g = 2.2 lbs
1 % = 10,000 mg/L

Pressure
1 ft of head = 0.433 psi
1 psi = 2.31 ft of head

Flow
1 cfs = 448 gpm
1 cfs = 0.6463 MGD
1 MGD = 694.5 gpm

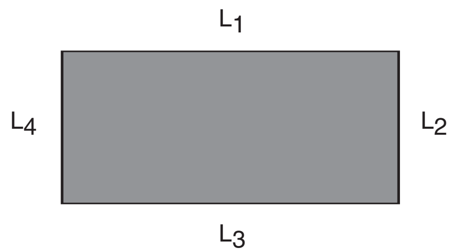
Equation Examples

The following is a listing of the basic formulas found in the math section of this text. They have been compiled here for your convenience.

Perimeter/Circumference

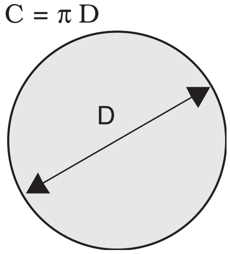
Square or Rectangle

$P = L_1 + L_2 + L_3 + L_4$



Circle

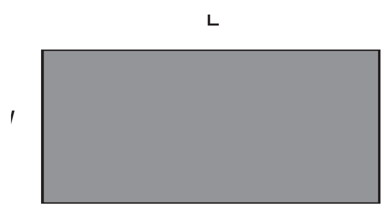
$C = \pi D$



Area

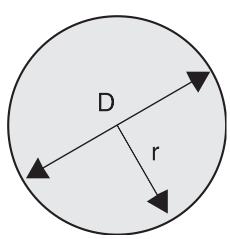
Rectangle or Square

$A = L X W$



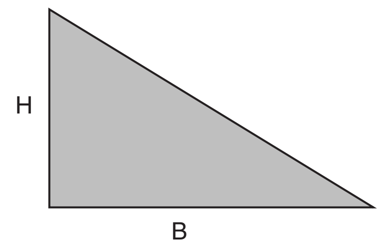
Circle

$A = \pi\pi r^2$



Triangle

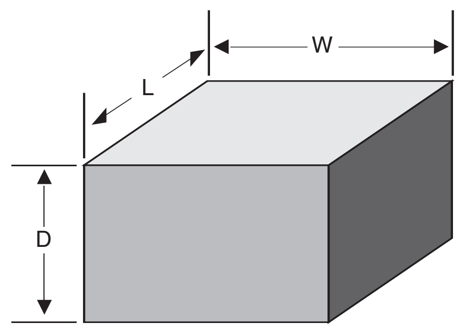
$$A = \frac{B X H}{2}$$

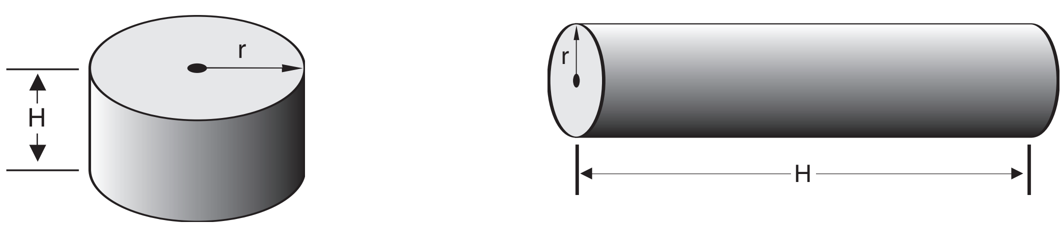


Volume

Rectangle or Square

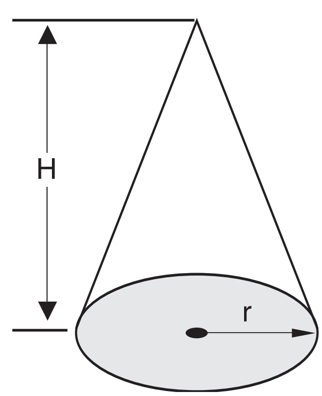
V = L X W X D





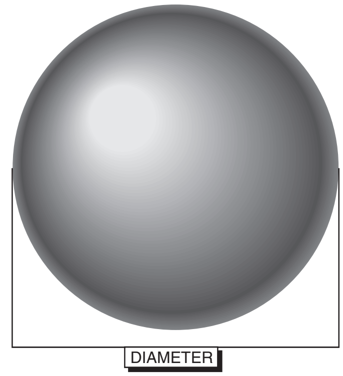
Cylinder

$V = \pi r^2 X H$ or L



Cone

$$V = \frac{r^2 H}{3}$$



Sphere

$$V = \frac{4\ r^3}{3}$$

Other Equations

Pounds

$Lbs = V,_{MG}\ X\ 8.34_{lbs/gal}\ X\ Conc,_{mg/L}$

Where:

Lbs = pounds

V = flow or volume in millions of gallons

Conc = concentration or dosage in mg/L

Removal Efficiency

$$\frac{(\text{Input - Output})}{\text{Input}}\ X\ 100 = \%\ \text{Removal}$$

Pump Efficiency

$$\frac{\text{Output Horsepower}}{\text{Input Horsepower}}\ X\ 100 = \%\ \text{Efficiency}$$

Weir Overflow Rate

$$WO = \frac{\text{flow rate in gpm}}{\text{weir length in feet}}$$

Temperature

°C = 5/9 (°F - 32°)

°F = (9/5 X°C) + 32

Detention Time

$$DT = \frac{\text{Volume}}{\text{flow}}$$

Working with Math

Steps in Solving Problems

Introduction

There is often more than one way to solve wastewater problems. We have a tendency to select and adapt problem solving styles that fit our individual preferences. If you have selected one or more methods that are beneficial to your style we suggest that you continue to use what has worked in the past. However, if wastewater problems have frustrated you then we suggest that you consider some version of the following procedure.

Procedure

1. When appropriate make a drawing of the information in the problem.
2. Place the data that is given on the drawing.
3. Ask, "What is the question?" - Write down what you are to find. Sometimes the answer has more than one piece. For instance, you may need to find "X" and from there find "Y".
4. Write down any equation that you are going to need.
5. Fill in the data in the equation.
6. Rearrange the equation, if necessary.
7. Pick up the calculator and make the calculation.
8. Write down the answer.
9. Check your answer. Does it make sense?

Word Problems

Words to Symbols

In word problems, certain words can be used to determine the correct math function or meaning. Here are a few of the basic word meaning examples:

Word	Meaning
of	multiply
and	add
per	divide
less than	subtract

Symbols to Words

In writing mathematical formulas or expressions, symbols are used to indicate an mathematical operation. Here are a few examples:

Math Operation	Symbol	Example
Multiplication	X	Q = V X A
Multiplication	•	Q = V • A
Multiplication	No space	Q = VA
Multiplication	( ) ( )	Q = (V)(A)
Division	÷	r = D ÷ 2
Division	──	$r = \frac{D}{2}$
Division	/	r = D/2

Help with the Calculator

Introduction

The calculator has made the solution of wastewater problems much easier and improved accuracy. At the same time the calculator has its own problems. The following are a few hints that may make using the calculator less stressful.

Hint #1 - Type of Calculator

A scientific calculator is more appropriate and useful than a business calculator. A quality scientific calculator used by a wastewater operator should have:

- Keys large enough to allow the fingers to be easily placed on them.
- The calculator should have a pi[3] (π) key. This will make calculating pipe and circular tank volumes much easier.
- Solar calculators do not offer the freedom of use that battery calculators offer.
- A protective case will add life to the calculator.
- The display should allow for 10 characters.

Hint #2 - Read the Book

The small booklet that comes with the calculator is designed to help you understand the functions of the calculator. It should be read and then stored for easy access. This allows you to use the book to help solve unique problems that only show up on occasion.

Hint #3 - Division by 2

One of the common problems confronted by operators is the proper method to solve the following:

$$\text{Dosage, mg/L} \ \frac{7 \text{ lbs}}{0.25 \text{ MG X } 8.34 \text{ lbs/ga}}$$

- One incorrect method that is used is to divide 7 by 0.25 and then multiply that answer by 8.34. The display on the calculator will show 233.52, which is an incorrect answer.
- A second less serious mistake is to multiply 0.25 X 8.34 and write the answer down on a piece of scratch paper (2.085). Typically the answer is rounded off to 2. The rounding reduces the accuracy and writing the number down is a step that is not necessary.
- The CORRECT APPROACH would be to place 7 in the calculator, press the divide key (÷), then enter in the number 0.25 and press the divide key (÷) again, now enter the number 8.34 and press the equal key (=). The correct answer of 3.357 should be displayed. This can be rounded off to 3.4 mg/L[4].

[3] **pi** - Greek letter (π) used as a symbol denoting the ratio of the circumference of a circle to its diameter
[4] **mg/L- milligrams per Liter** - A unit of the concentration of a constituent in water. It is 0.001g of the constituent in 1,000 ml of water. mg/L has replaced the PPM (parts per million) in reporting results in water.

Math Principles

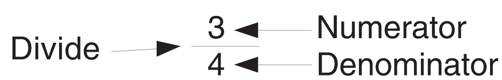
Fractions

Use

With today's calculators working with fractions is easier than it once was. However, the operator often faces routine situations that require thinking in fractions and on occasion actually working with fractions. One of the common uses for the rules governing the use of fractions in a math problem is dealing with units. Units like gpm are actually a fraction gal/min, and **cfs**[5] is actually ft^3/sec. Understanding fractions may help you solve other problems.

Components of a Fraction

A fraction is composed of three items, two numbers and a line. The number on the top is called the **numerator**, the number on the bottom is called the **denominator** and the line in between them means to divide. Just remember that the "D" in **D**enominator means down; the number "down" below the line



Principles of Working With Fractions

Introduction

Like all other math functions, how we deal with fractions is governed by rules or principles. The following is a discussion of 11 principles associated with using fractions.

Same Numerator & Denominator

When the numerator and denominator of a fraction are the same number the fraction can be reduced to 1. For example:

$$\frac{4}{4} = 1,\ \frac{24}{24} = 1,\ \frac{8}{8} = 1,\ \frac{12}{12} = 1,\ \frac{125}{125} = 1$$

Whole Numbers to Fractions

Any whole number can be expressed as a fraction by placing a "1" in the denominator. For example:

$$2 \text{ is the same as } \frac{2}{1}, \text{ and } 45 \text{ is the same as } \frac{45}{1}$$

Adding Fractions

Only fractions with the same denominator can be added and only the numerators are added. For example:

$$\frac{1}{8} + \frac{3}{8} = \frac{4}{8}, \quad \text{and } \frac{6}{32} + \frac{12}{32} = \frac{18}{32}$$

Subtracting Fractions

Only fractions with the same denominator can be subtracted, and only the numerators are subtracted. The denominator remains the same. For example:

$$\frac{7}{8} - \frac{3}{8} = \frac{4}{8}, \text{ and } \frac{18}{25} - \frac{6}{25} = \frac{12}{25}$$

[5] **cfs** - Cubic Feet per Second - A measurement of flow. 1 cfs is equal to 448 gpm.

Mixed Numbers

A fraction combined with a whole number is called a mixed number. For example:

$4\frac{1}{8}$, $16\frac{2}{3}$, $8\frac{3}{4}$, $45\frac{1}{2}$, and $12\frac{17}{32}$

These numbers are read, four *and* one eighth, sixteen *and* two thirds, eight *and* three fourths, forty-five and one half, and twelve *and* seventeen thirty seconds.

Changing a Fraction

A fraction is changed by multiplying the numerator and the denominator by the same number; this does not change the value of the fraction. For instance:

$\frac{1}{2}$ is the same as $\frac{1 X 2}{2 X 2}$ which is $\frac{2}{4}$ or $\frac{1 X 4}{2 X 4}$ which is $\frac{4}{8}$

Simplest Terms

Fractions should be reduced to their simplest terms. This is accomplished by dividing the numerator and denominator by the same number. The result of this division must leave both the numerator and the denominator as whole numbers. For instance:

$\frac{2}{4}$ is not in its simplest terms, by dividing both the top and bottom numbers by 2 we obtain $\frac{1}{2}$

The number 2/3 cannot be reduced any further since there is no number that can be divided evenly into the 2 and the 3.

Practice

Reduce the following to their simplest terms.

4/8 =

12/18 =

3/4 =

6/8 =

24/32 =

9/18 =

15/27 =

Solutions

1/2 - both were divided by 2

2/3 - both were divided by 6

3/4 - is in its simplest terms

3/4 - both were divided by 2

3/4 - both were divided by 8

1/2 - both were divided by 9

5/9 - both were divided by 3

Key to Reducing, Even Numbers

When the starting point is not obvious, do the following: if the numerator and denominator are both even numbers (2, 4, 6, 8, 10, etc) divide them both by 2, continue dividing by 2 until a division will no longer yield a whole number with the numerator and denominator.

Key to Reducing, Odd Number

When the numerator and denominator are both odd numbers, (3, 5, 7, 9, 11, 13, 15) attempt to divide by three, continue dividing by 3 until a division will no longer yield a whole number with the numerator and denominator. It is obvious that some numbers such as 5, 7 and 11 cannot be divided by 3 and are in their simplest terms.

Different Denominators

To add and/or subtract fractions with different denominators, the denominators must be changed to a common denominator. That is the denominators must be the same before adding or subtracting the fraction. One of the simplest methods of obtaining a common denominator is to multiply the denominators together. Each fraction must then be converted to a fraction expressing the new denominator.

For instance to add 1/8 and 2/3 together;

- Start by multiplying the denominators 8 X 3 = 24
- Change 1/8 to a fraction with 24 as the denominator

$$\frac{24}{8} = 3, 3 \text{ X } 1 = 3 \text{ (the numerator), new fraction is } \frac{3}{24}$$

Notice that this is the same as 1/8 except 3/24 is not reduced to its simplest terms.

- Change 2/3 to a fraction with 24 as the denominator

$$\frac{24}{3} = 8, 8 \text{ X } 2 = 16 \text{ (the numerator), new fraction is } \frac{16}{24}$$

- Complete the addition

$$\frac{3}{24} + \frac{16}{24} = \frac{19}{24}$$

Numerator Larger

Anytime the numerator is larger than the denominator the fraction should be turned into a mixed number. This is accomplished by the following procedure;

- Determine the number of times the denominator can be divided evenly into the numerator. This will be the whole number portion of the mixed number.
- Multiply the whole number times the denominator and subtract from the numerator. This value, the remainder, becomes the numerator of the fraction portion of the mixed number.

$\frac{28}{12}$, 28 is divisible by 12 twice - 2 is the whole number

$2 \text{ X } 12 = 24$

$\frac{28}{12} - \frac{24}{12} = \frac{4}{12}$, dividing top and bottom by $4 = \frac{1}{3}$

New mixed number is $2\frac{1}{3}$

Multiplying Fractions

In order to multiply fractions, simply multiply the numerators together, then multiply the denominators together, and reduce to the simplest terms. For instance:

Find the result of multiplying 1/8 X 2/3

$$\frac{1}{8} \text{ X } \frac{2}{3} = \frac{1 \text{ X } 2 = 2}{8 \text{ X } 3 = 24} = \frac{2}{24} = \frac{1}{12}$$

Dividing Fractions

In order to divide fractions, simply invert the fraction on the bottom (turn it upside down), multiply and reduce to simplest terms. For example:

Divide 1/8 by 2/3

$$\frac{\frac{1}{8}}{\frac{2}{3}} = \frac{1}{8} \text{ X } \frac{3}{2} = \frac{1 \text{ X } 3 = 3}{8 \text{ X } 2 = 16} = \frac{3}{16}$$

Invert

Divide Symbols

The divide symbol can be ÷ or / or ———.

Fractions to Decimals

In order to convert a fraction to a decimal, simply divide the numerator by the denominator. For example:

$\frac{1}{2} = 0.5$, $\frac{7}{8} = 0.875$, $\frac{7}{16} = 0.4375$, $\frac{1}{4} = 0.25$ and $\frac{2}{3} = 0.667$

Changing Inches to Feet

To change inches to feet divide the number of inches by 12. For example:

Change 3 inches to feet

$\frac{3}{12} = 0.25$ feet

Practice

Change the following to feet:

2 inches, 4 inches, 6 inches, 8 inches

$\frac{2}{12} = 0.167$ feet

$\frac{4}{12} = 0.333$ feet

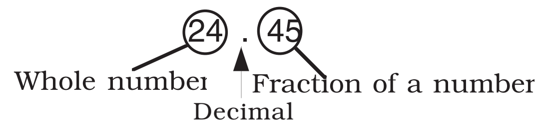
$\frac{6}{12} = 0.5$ feet

$\frac{8}{12} = 0.667$

Decimals

The Components

A decimal is composed of two sets of numbers, the numbers to the left of the decimal are whole numbers and numbers to the right of the decimal are parts of whole numbers, or a fraction of a whole number.



Fraction Component

The terms used to express the fraction component is dependent on the number of characters to the right of the decimal.

The first character to the right of the decimal point is tenths

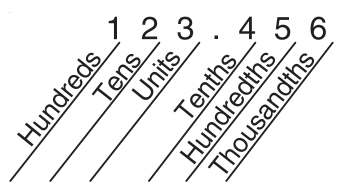
The second character is hundredths

The third character is thousandths

• 0.1 - tenths

• 0.01 - hundredths

• 0.001 - thousandths



Principles

Calculators

With todays use of calculators we seldom need the rules for handling decimals. As a result when we need to make a computation manually we often cannot remember the basic rules. Therefore, this brief review is provided.

Number Less Than One

When a number is less than one and is expressed as a decimal, place a "0" (zero) to the left of the decimal. This makes it clear that the number is less than one. For instance 0.25 is much clearer than .25.

Subtraction

When subtracting decimals, simply line up the numbers at the decimal and subtract. For example:

$$\begin{array}{r} 28.65 \\ \underline{-\ 12.25} \\ 16.40 \end{array}$$

$$\begin{array}{r} 145.600 \\ \underline{-\ 13.212} \\ 132.388 \end{array}$$

Addition

To add numbers with a decimal, use the same rules as subtraction, line up the numbers on the decimal and add.

$$\begin{array}{r} 28.65 \\ \underline{+12.25} \\ 40.90 \end{array}$$

$$\begin{array}{r} 145.600 \\ \underline{+\ 13.212} \\ 158.812 \end{array}$$

Multiplication

In order to multiply two or more numbers containing decimals follow these few basic steps:

- Multiply the numbers as whole numbers, do not worry about the decimals
- Write down the answer
- Count the total number of digits (numbers) to the right of the decimal in all of the numbers being multiplied
- To place the decimal in the answer, count from the right to the left the number of digits counted in the previous step. For example:
- Multiplying 3.04 X 8.6 yields the number 26144
- There are a total of three digits to the right of the decimal point (2 for the number 3.04 and 1 for the number 8.6). Therefore, the decimal point would be placed three places to the left of the last 4.

26.144

Division

In order to divide a number by a number containing a decimal, the divisor must be made into a whole number by moving the decimal point to the right until you have a whole number.

- Count the number of places the decimal needed to be moved.
- Move the decimal in the dividend by the same number of places.

$$\text{Divisor} \quad 45.6 \,\overline{)\,346.2} \quad \text{Dividend}$$

$$\begin{array}{r} 7.59 \\ 456 \,\overline{)\,3462.00} \end{array}$$

Using the Calculator

With today's calculators this problem would simply be set up as follows: Enter 346.2, press ÷, and enter 45.6, press = and the answer 7.59 should be displayed.

Rounding

Why Round

Numbers are rounded to reduce the number of digits to the right of the decimal point. This is for convenience, not accuracy.

Process of Rounding

Start by deciding how many places you want to the right of the decimal. Remember this is done for convenience.

- If the number to the right of the last number that you wish to report is 5 or greater than 5, increase the size of the last number by 1.
- If the number to the right of the last number that you wish to report is less than 5, the size of the last number remains the same.

Example #1

A calculation has just been completed and the answer is 24.55836. A decision is made to have two places to the right of the decimal. Two places takes you to 25.55. The next number is "8." Therefore, the last five is rounded up to a six. The number is 24.56.

Example #2

A calculation has just been completed and the answer is 24.55436. A decision is made to have two places to the right of the decimal. Two places takes you to 25.55. The next number is "4". Therefore, all of the numbers to the right of the .55 are dropped. The reported number is 24.55.

Practice Problems

(Answers on page 489)

Round the following to the nearest hundredths. (Second place after the decimal)

2.4568

27.2534

128.2111

364.8762

354.777777

34.666666

67.33333

Round the following to the nearest tenths. (1st place after the decimal)

2.4568

27.2534

128.2111

364.8762

354.777777

34.666666

67.33333

Determining Significant Digits

The Concept

The concept of significant digits is related to rounding. It can be used to determine where to round off. The basic idea is that no answer can be more accurate than the least accurate piece of data used to calculate the answer.

Process

The process involves two steps:

- First, determine the number of decimal places in the least accurate piece of data.
- Second, round off the answer to this position.

Example

The following calculation was made:

25.456 X 4.6 = 117.0976

The least accurate piece of data is number 4.6. This piece of data has only one digit to the right of the decimal. Therefore, the answer can have only one digit to the right of the decimal. The answer should be rounded off to 117.1.

Practice Problems

(Answers on page 489)

Round the following answers off to the most significant digit.

26.34 X 124.34567 = 3,275.26495

25.1 + 26.43 = 51.53

128.456 - 121.4 = 7.056

23.5 ft X 34.25 ft = 804.875 ft^2

12,457.92 X 3 = 37,373.76

Working with Powers

Principle

Powers are used to indicate that a number should be square or cubed or etc. This means the number of times a number must be multiplied times itself. Powers are used to identify **area**[6], as in square feet, and volume as in **cubic feet**[7].

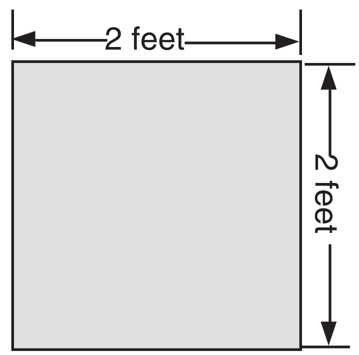
Examples

For example we could find these two numbers;

4^2 or 4 ft^2

The number 4^2 means 4 x 4 = 16

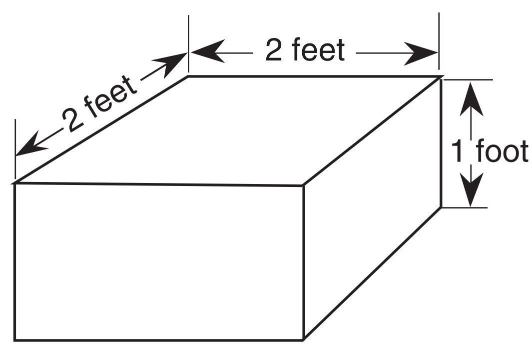
The number 4 ft^2 means four square feet, an area 2 ft X 2 ft (ft X ft = ft^2).



Or we might see these two numbers 4^3 or 4 ft^3

The number 4^3 means 4 x 4 x 4 = 64

The number 4 ft^3 means 4 cubic feet,
a block 2 ft X 2 ft X 1 foot deep (ft X ft X ft = ft^3).



6 **Area -** The extent of a surface, measured by the number of squares of equal size it contains.
7 **Cubic Feet** - A measurement of volume in the number of cubes that are 1 foot on a side.

Finding Averages

Use

Finding an **average**[8] of a series of values is accomplished by adding the values and dividing by the number of values in the group. The average for the month is commonly figured on all chemicals added and on most test results.

Example

Find the average of the following series: 12, 8, 6, 21, 4, 5, 9, and 12. Adding the numbers together we get, 77. There are 8 values in this set. Divide 77 by 8.

$$\frac{77}{8} = 9.6 \text{ is the average of the set}$$

Example

Here is a series of daily flows in MGD. Obtain the average for them.

0.3
0.4
0.3
0.1
<u>0.8</u>
1.9 is the total. There are 5 numbers in the set. Therefore:

$$\frac{1.9}{5} = 0.38, \text{ rounding off we get } 0.4 \text{ MGD}$$

Practice

Find the average of the following set of numbers:
0.2
0.2
0.1
0.3
0.2
0.4
0.6
0.1
0.3

Answer

The total is 2.4, there are 9 numbers in the set. Therefore
2.4 ÷ 9 = 0.2667, rounding to 0.3

[8] **Average** - An arithmetic mean. The value is arrived at by adding the quantities in a series and dividing the total by the number in the series.

Equations

Description

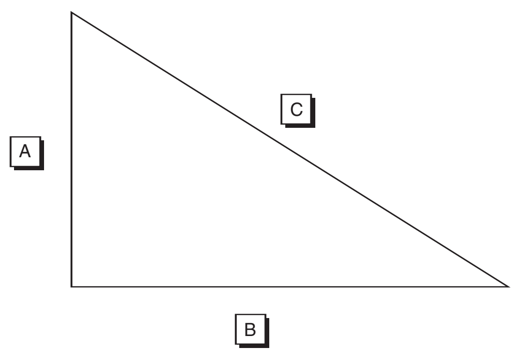
An equation is a symbolic representation of how to combine certain information in order to obtain the proper result. Equations are written using letters and symbols to represent unknown or standard values.

Use

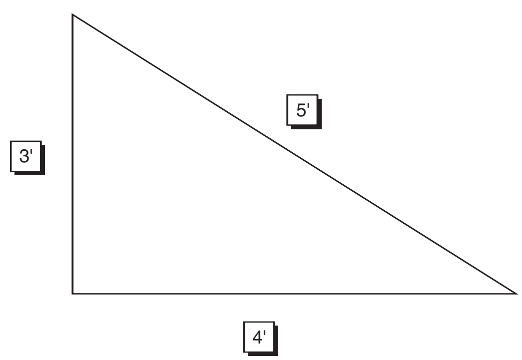
Equations (also called formulas) are used by operators to solve a wide variety of problems associated with treatment and collection. In fact, most operators use formulas without thinking about them to solve routine problems. For instance, to determine the perimeter or distance around a building requires using a formula.

Example

The equation for determining the perimeter of a triangle is $P = a + b + c$. P is the letter used to designate the perimeter and a, b, c are used to identify the lengths of the sides. The mathematical symbol = and + tell the user what math functions are to be carried out. This formula says to add the lengths of all of the sides to obtain the perimeter.



In the example below the numbers 3', 4' and 5' have been substituted for the letters a, b and c. In order to solve the equation substitute the numbers for the appropriate letters, a = 3', b=4' and c=5'. Now add the three together to obtain a perimeter of 12'. The distance around this triangle is 12 feet.



Works on All Triangles

This equation will work for all triangles regardless of the lengths of their sides.

Formulas With Symbols

Some equations such as the one for the area of a circle, $A = \pi r^2$, use symbols. The symbol π (pi) is used to represent a constant, 3.14. This is done in equations to simplify the writing of the equation.

Listing of Formulas

A listing of common equations used in wastewater can be found at the beginning of this lesson. In addition, equations are used in most of the other sections of this lesson.

Rearranging Equations

Types of Equations

The equations that are commonly used in wastewater math are called linear equations (follow a straight line). In order to be successful in solving wastewater math problems, an operator must be able to solve a linear equation with one unknown (perimeter of a triangle, pounds formula, area of a circle are all examples of this type of equation).

Why Rearrange

In order to solve a problem an operator is often required to solve the equation for a component that is not normally part of the solution. For instance, The perimeter and the length of two sides of a triangle may be known and you wish to solve for the length of the third side.

Two Sides

Equations have two sides that are separated by the equal (=) sign. In order to solve an equation there must be only one unknown and the unknown must be on one side of the equation by itself.

Rearranging Equations with Addition and Subtraction

Rule

To move an item from one side of an equation to the other in an addition or subtraction equation change its sign (from + to - or form - to +).

Example

Solve the equation 12 = 3 + b + 5

Fist step is to rearrange the equation so that the unknown is one one side of the equation by its self. This is accomplished by subtracting 3 and 5 from both sides of the equation.

12 - 3 - 5 = 3 + b + 5 - 3 - 5

On the right side of the equation 3 - 3 = 0 and 5 - 5 = 0

The resulting new equation would look like this.

12 - 3 - 5 = b

The last step is to do the math. That is subtract 3 and 5 from 12. The result is:

4 = b

Rearranging Equations with Multiplication and Division

Process

To solve for an unknown value in an equation using multiplication or division the unknown value must be moved to one side of the equation by itself.

Top and Bottom

As stated above, an equation has two sides. A multiplication and division equation also has a top and bottom that are separated by a division line. When the equation is just multiplication the division line is not shown and all of the items are above the line.

Rule

To move an item from one side of an equation to the other in a multiplication or division equation, the item is moved from the top of one side to the bottom of the other or from the bottom of one side to the top of the other.

Summary

To state it another way, if the item that is being moved is on top of the equation then it must be placed below when moved. If an item is below in the equation then it must be placed above when it is moved.

Example #1

Solve this equation for V

254 = V X 8.34 X 35

$$\frac{254}{\phantom{8.34 \text{ X } 35}} = V \text{ X } 8.34 \text{ X } 35$$

Result

$$\frac{254}{8.34 \text{ X } 35} = V$$

V = 0.87

Example #2

Solve for X in the following equation

$$6 = \frac{X}{10}$$

Step 1 - Rearrange the equation

$$6 = \frac{X}{10}$$

(10) (6) = X

Step 2 - Solve the equation

60 = X

Special Note

Many equations are written without the use of the multiplication sign. For instance $A = \pi r^2$ and $C = \pi D$.

$\pi\, r^2$ is the same as π X r^2 , or pi, times r^2.

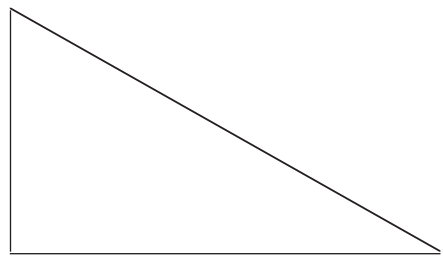
Also, $\pi\, (r^2)$ is the same as π X (r^2) or pi, times r^2.

Equation Problems

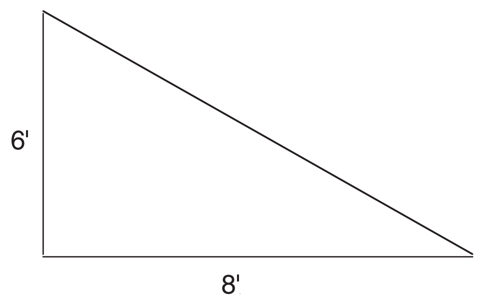
Example #1

A triangle has a perimeter of 24’, the length of the bottom is 8’ and the length of the left side is 6’. What is the length of the long side?

Step 1 - Draw a diagram of the triangle



Step 2 - Place the known values on the diagram



Step 3 - Write the equation

P = a + b+ c

Step 4 - Fill in the known values in the equation

24’ = 6’ + 8’ + c

Step 4 - Rearrange the equation

24’- 6’ - 8’ = c

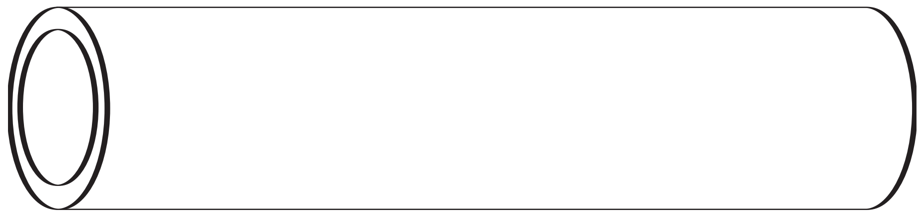
Step 5 - Solve the equation

10’ = c

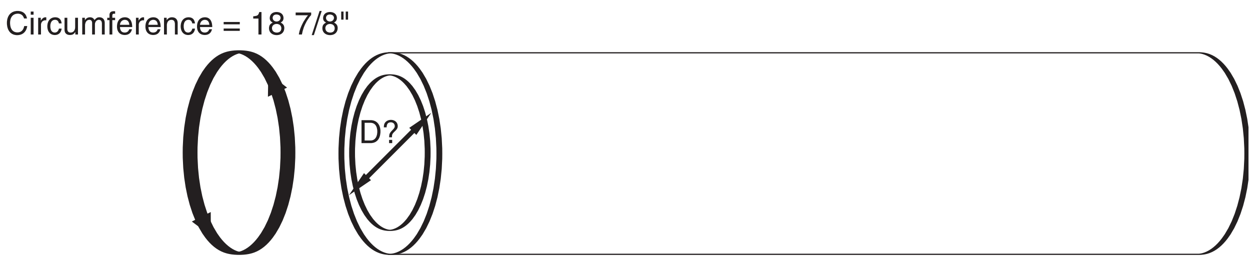
Example #2

Find the diameter of a pipe with a circumference of 18 7/8 inches.

Step 1 - Draw a diagram of the pipe



Step 2 - Place the known values on the diagram



Step 3 - Make any obvious conversions

The circumference is given in inches and fractions of inches. This must be converted to a decimal before proceeding.

18 7/8” = 18.875”

Step 4 - Select an equation

$C = \pi D$

Step 5 - Fill in the known values

18.75” = π D

Step 6 - Rearrange the equation

$$\frac{18.75''}{\pi} = D$$

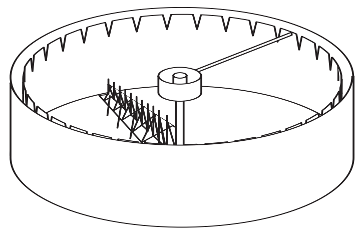
Step 7 - Solve the equation

6” = D

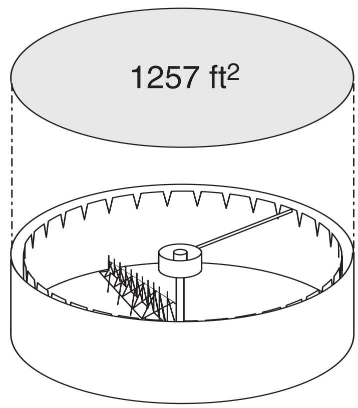
Example #3

Find the diameter of a clarifier with a surface area of 1257 ft^2.

Step 1 - Draw a diagram of the clarifier



Step 2 - Place the known values on the diagram



Step 3 - Select an equation

$A = \pi r^2$

Step 4 - Fill in the known values

$1257\ ft^2 = \pi\pi\ r^2$

Step 5 - Rearrange the equation

$$\frac{1257\ ft^2}{\pi} = r^2$$

This rearrangement will require two steps. The second step is to change the r^2 to r. This is accomplished by finding the square root of all of the values on the left side of the equation.

$$\sqrt{\frac{1257\,ft^2}{\pi}} = r$$

20 feet = r

Step 6 - Determine the diameter from the radius

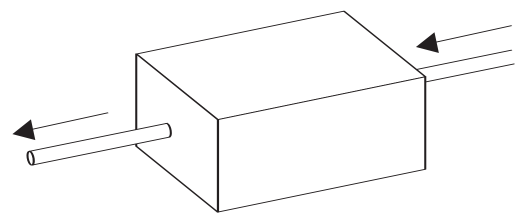
Since the radius is one half of the diameter this value must be multiplied by 2.

2 X 20 ft = 40 ft - the diameter of the clarifier

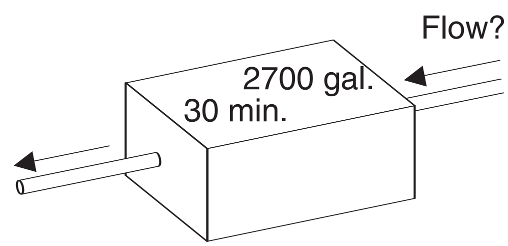
Example #4

A chlorine contact chamber holds 2700 gallons. It is desired to have a contact time of 30 minutes in the chamber. What is the maximum flow rate that can pass through this chamber at this detention time.

Step 1 - Draw a diagram of the situation



Step 2 - Place the unknown values on the diagram



Step 3 - Select an equation

$$DT = \frac{\text{Volume}}{\text{flow}}$$

Step 4 - Place the known values in the equation

$$30\,\text{min} = \frac{2{,}700\,\text{gal}}{\text{gpm}}$$

Step 5 - Rearrange the equation

$$\text{gpm} = \frac{2{,}700\,\text{gal}}{30\,\text{min}}$$

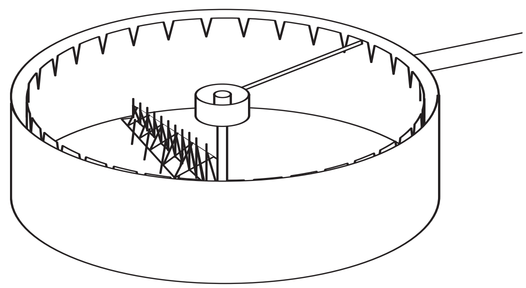
Step 6 - Solve the equation

gpm = 90 gpm

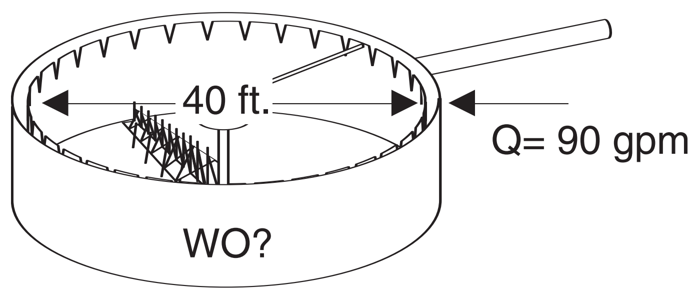
Example #5

Find the weir overflow rate of a clarifier that is 40 feet in diameter when the plant flow is 90 gpm. The weir is placed on the circumference of the clarifier.

Step 1 - Draw a diagram of the situation



Step 2 - Place the known values on the diagram



Step 3 - Select an equation

$$WO = \frac{\text{flow rate in gpm}}{\text{weir length in feet}}$$

Step 4 - Determine the length of the weir

C = π D

C = π X 40 ft

C = 126 ft

Step 6 - Place the known values in the equation

$$WO = \frac{90 \text{ gpm}}{126 \text{ ft}}$$

Step 7 - Solve the equation

WO = 0.72 gpm/ft

Equations - Practice Problems

(Answers on page 490)

a. Find the diameter of a clarifier that has a circumference of 126 feet.

b. Find the diameter of a pipe that has a circumference of 12 9/16".

c. Find the diameter of a clarifier that has a surface area of 113 ft^2.

d. Find the diameter of a clarifier that has a surface area of 314 ft^2.

e. The detention time in a chlorine contact chamber is 42 minutes. If the chamber holds 3200 gallons, what is the flow rate in gpm?

f. A primary clarifier has a detention time of 2 hours. What is the flow rate in gpm if the clarifier holds 8000 gallons?

g. A rectangular clarifier has a weir length of 10 feet. What is the weir overflow rate when the flow is 80,000 gpd?

h. A circular clarifier is 18 feet in diameter. What is the weir overflow rate when the flow is 450 gpm?

Finding Perimeter/Circumference

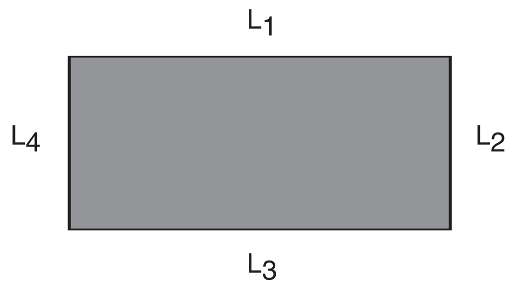
Units

The perimeter is how far it is around an object, like a plot of ground, a building or a box. **Circumference**[9] is the distance around a circle. Distance is a linear measurement and therefore the standard units for linear measurements are used. Typical samples would be inches, feet, miles, etc.

Formula - Rectangle

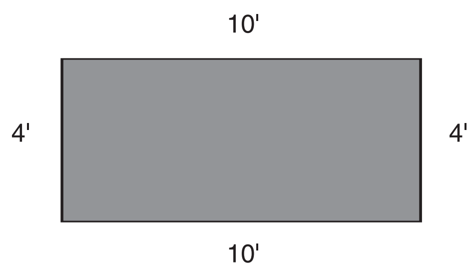
The perimeter of a **rectangle**[10] is obtained by adding together the lengths of the four sides.

Perimeter = $L_1 + L_2 + L_3 + L_4$



Rectangle Example

Find the perimeter of the following rectangle:

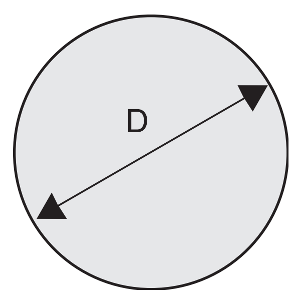


P = 10' + 4' + 10' + 4' = 28'

Formula Circle

The circumference of a circle is found by multiplying pi (π) times the **diameter**[11].

$C = \pi D$



Where:

C = circumference

π = Greek letter pi

π = 3.1416

D = diameter

Example of Circumference

Find the circumference of a circle that has a diameter of 10 feet. (pi = 3.1416)

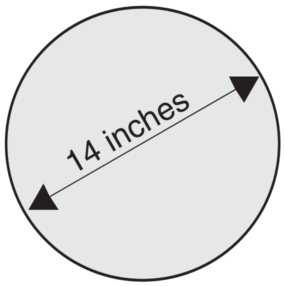
$C = \pi$ X 10' = 31.4 feet

---

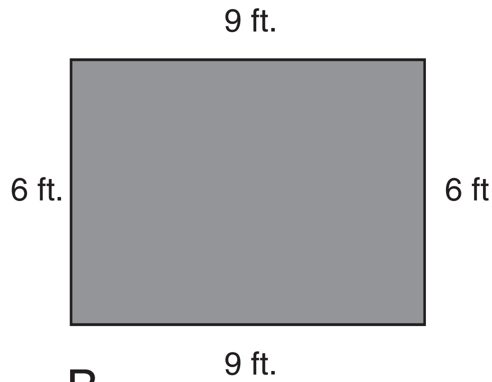
9 **Circumference** - The perimeter of a circle .
10 **Rectangle** - A 4-sided figure with 4 right angles.
11 **Diameter** - The distance across a circle - A straight line passing through the center of a circle.

Perimeter - Practice Problems

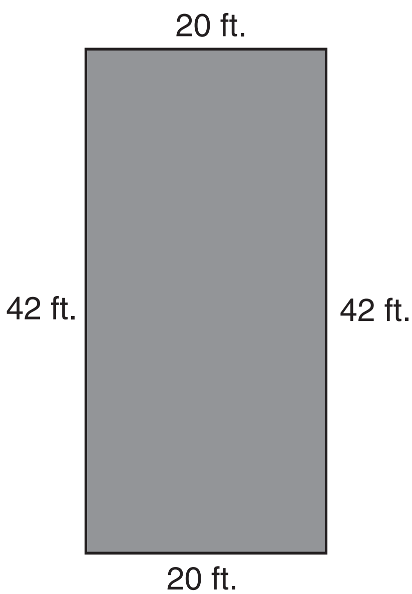
Find the perimeter or circumference of the following items. (Answers on page 492)



A



B



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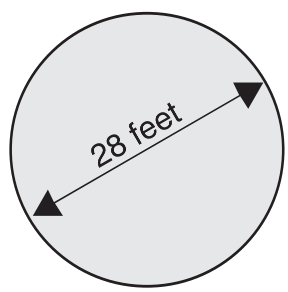


D

Finding Area

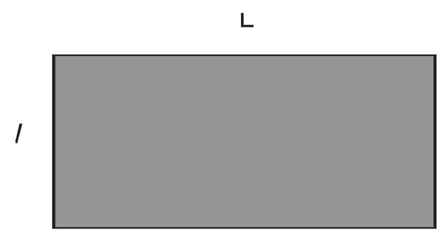
Units

Area is an expression of the square unit measurement of the surface of an item or a piece of land. The area on top of a sedimentation basin is called the surface area. The area of the end of a pipe is called the **cross sectional area**[12]. Area is usually expressed in squared terms such as square inches (in^2), or square feet (ft^2). Land may also be expressed in terms of sections (1 square mile) or acres (43,560 ft^2) or in the metric system as hectares.

Formula for a Rectangle

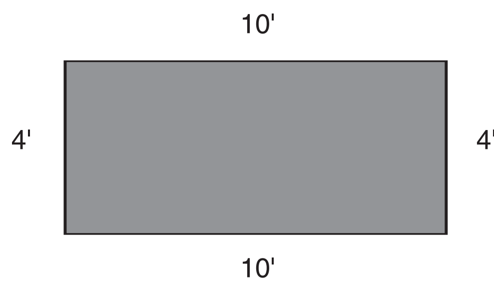
The area of a rectangle is found by multiplying the length times the width.

Area = L X W



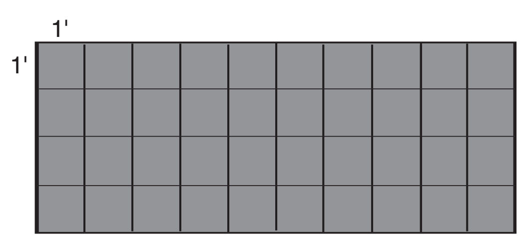
Example - Rectangle

Find the area of the following rectangle:



A = 4' X 10' = 40 ft^2

This is the same as saying that 40 individual pieces of paper one foot by one foot could be placed on this surface.



[12] **Cross Sectional Area** - The area at right angles to the length of a pipe or basin.

Formula for a Circle

The surface area of a circle is determined by multiplying pi times the radius squared.

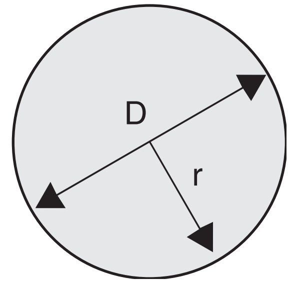
$A = \pi r^2$

Where:

A = area

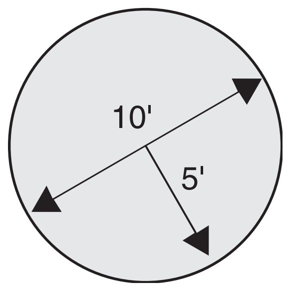
ππ = Greek letter pi - $\pi = 3.1416$

r = **radius**[13] of a circle - Radius is one half of the diameter.



Example - Circle

Find the surface area of the following circle:



$A = \pi r^2$

$A = \pi (5ft)^2$

$A = \pi X 25 ft^2$

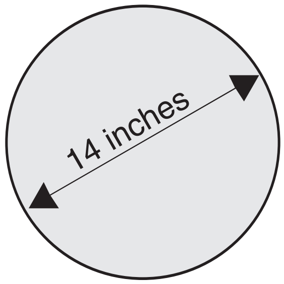
$A = 78.5 ft^2$

[13] **Radius** - A line from the center of a circle or sphere to the circumference of the circle or surface of the sphere.

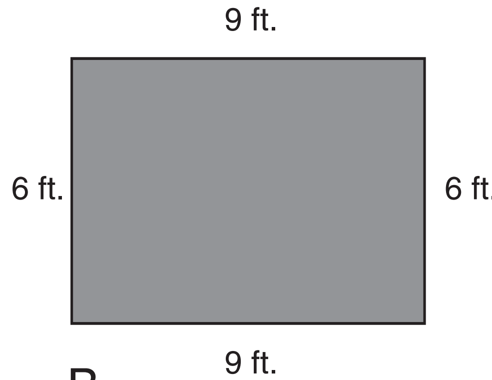
Area - Practice Problems

Find the area of the following items.

(Answers on page 493)



A



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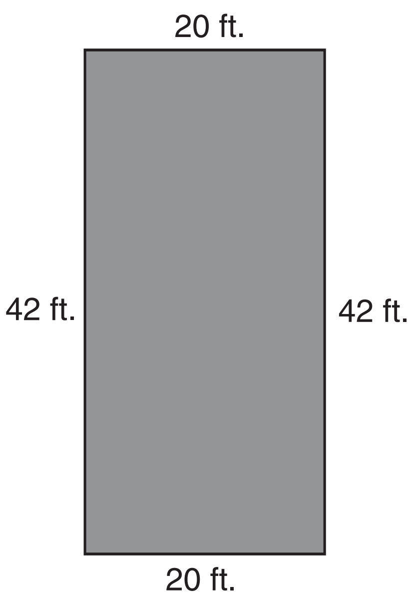

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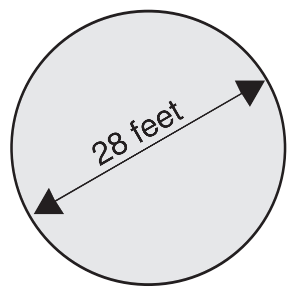


D

Finding the Volume

Units

Volume[14] is expressed in cubic units, such as cubic inches (in^3), cubic feet (ft^3), acre feet (1 Acre foot = 43,560 ft^3), and etc.

Formula for Rectangular Object

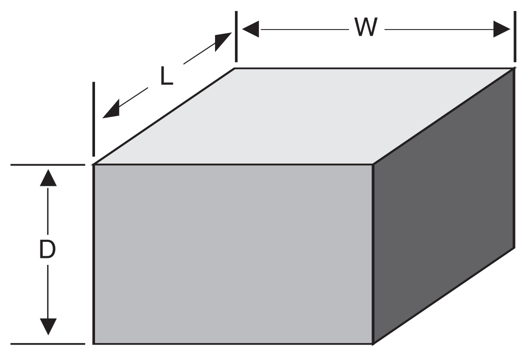
The volume of a rectangular object is obtained by multiplying the length times the width times the depth or height. V = L X W X D

Where:

L = Length

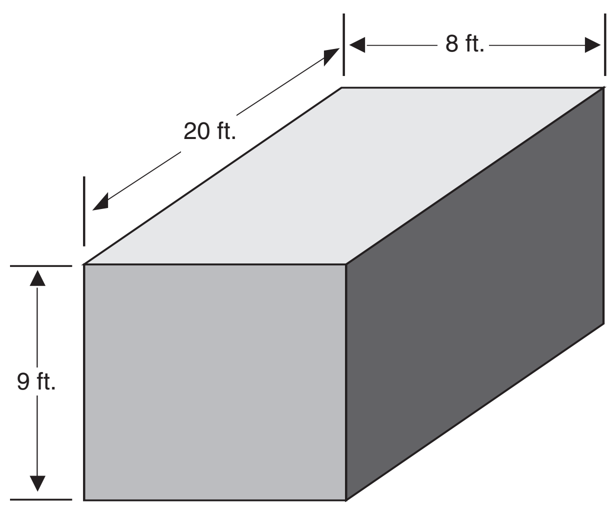
W = Width

D or H = Depth or height



Example

Find the volume in cubic feet of the sedimentation basin below



V = L X W X D

V = 20 ft X 8 ft X 9 ft

V = 1,440 ft^3

[14] **Volume** - The amount of space occupied by or contained in an object. Measured by the number of cubes, each with an edge 1 unit long that can be contained in the object.

Formula - Cylinder

The volume of a **cylinder**[15] (such as a piece of pipe or a tank) is equal to its height times pi times the radius of the cylinder squared. The length (L) and height (H) of a cylinder are the same dimension.

$V = H \times \pi r^2$

Where:

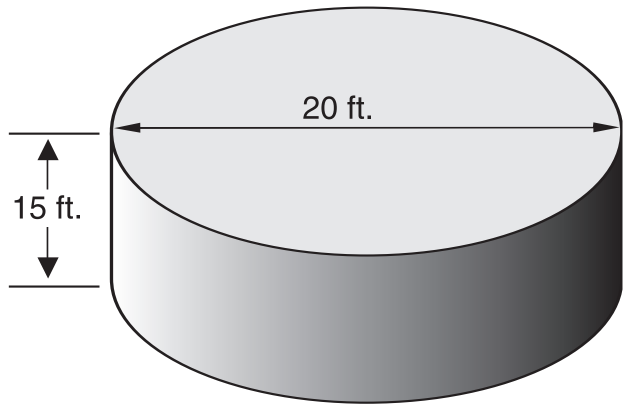
H = height or length of the cylinder

$\pi = 3.1416$

r = radius of the cylinder

Example

Find the volume of a tank, 20 feet in diameter and 15 feet tall.



$\text{Volume} = H \times \pi r^2$

The radius of a circle is one half the diameter, since the diameter is 20 feet the radius is 10 feet.

$V = 15 \text{ ft} \times \pi (10 \text{ ft})^2$

$V = 15 \text{ ft} \times \pi \times 100 \text{ ft}^2$

$V = 4{,}712 \text{ ft}^3$ (Note $\text{ft} \times \text{ft} \times \text{ft} = \text{ft}^3$)

[15] **Cylinder** - A solid or hollow figure, traced out when a rectangle rotates using one of its sides as the axis of the rotation.

Volume - Practice Problems

Find the volume of the following: (Answers on page 494)

a. A 3 inch pipe 200 feet long. (Hint, change the diameter of the pipe from inches to feet by dividing by 12)

b. Find the volume of a fuel tank 4 feet in diameter and 10 feet long.

c. Find the volume of a chlorine barrel that is 20 inches in diameter and 42 inches tall.

d. Find the volume of a trench 2.5 feet wide, 6 feet deep and 60 feet long.

Working with Percent

Definition

Percent means parts of 100 parts. The symbol for percent is %. We use percent to describe portions of the whole. For instance if a tank is 1/2 full, we say that it contains 50% of the original solution. We also use percent to describe the portion of a budget spent or a project completed. "There is only 25% of the budgeted amount remaining." "The collection system line project is 80% complete."

How Expressed

Percentage is expressed as a whole number with a % sign after it, except when it is used in a calculation. In a calculation percent is expressed as a decimal. The decimal is obtained by dividing the percent by 100. For instance, 11% is expressed as the decimal 0.11, since 11% is equal to 11/100. This decimal is obtained by dividing 11 by 100.

Finding Percentage

To determine what percentage a part is of the whole, divide the part by the whole: There are 80 manholes to be inspected, Jim has finished 24 of them. What percentage of the manholes have been inspected?

- 24 ÷ 80 = 0.30
- The 0.30 is converted to percent by multiplying the answer by 100
- 0.30 X 100 = 30%. Thus 30% of the 80 manholes have been inspected.

Formula

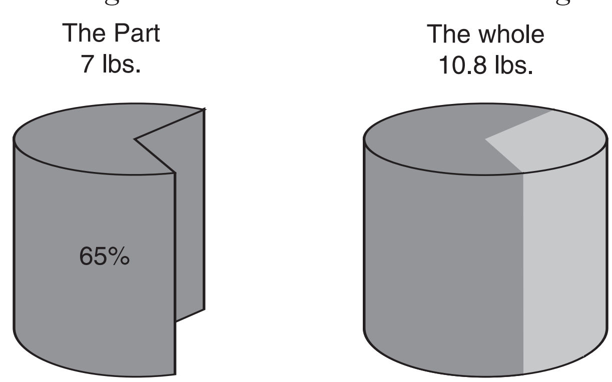
Here is the basic formula for finding percent.

$$\text{Percent} = \frac{\text{Part}}{\text{Whole}} \text{ X } 100$$

Finding the Whole

To determine the whole when the part and its percentage is given, divide the part by the percentage. Example: How much 65% calcium hypochlorite is required to obtain 7 pounds of pure chlorine? The part is the 7 pounds, which is 65% of the whole.

- Convert the percentage to a decimal by dividing by 100. 65% ÷ 100 = 0.65
- Divide the part by the decimal equivalent of the percentage. 7lbs ÷ 0.65 = 10.769 – rounding to 10.8 lbs.



Changing Decimals to Percent

To change the percent obtained above to the decimal equivalent divide the percent by 100.

Change 30% to a decimal

- 30% ÷ 100 = 0.30; 0.30 is the decimal equivalent of 30%

Percentage of a Number - The Part

To find the percentage of a number multiply the number by the decimal equivalent of the percentage given in the problem. For instance, what is 28% of 286.

- Change the 28% to a decimal equivalent - 28% ÷ 100 = 0.28
- Multiply 286 X 0.28 = 80, thus
- 28% of 286 is 80; 80 is 28% of 286.

Increase a Value by a Percent

To increase the value by a percent - add the decimal equivalent of the percent to “1” and multiply it times the number.

A filter bed will expand 25% during backwash. If the filter bed is 36 inches deep, how deep will it be during backwash.

- Change the percent to a decimal - 25% ÷100 = 0.25
- Add the whole number 1 to this value, 1 + 0.25 = 1.25
- Multiply times the value, 36 in X 1.25 = 45 inches

Percentage Concentrations

The concentration of chemicals and digester solids are commonly expressed as a percentage. For instance, a chlorine solution was made to have a 4% concentration. It is often desirable to determine this concentration in mg/L. This is relatively simple, the 4% is four percent of a million. To find the concentration in mg/L when it is expressed in percent, do the following:

- Change the percent to a decimal - 4% ÷ 100 = 0.04
- Multiply times a million -

0.04 X 1,000,000 = 40,000 mg/L

We get the million because a liter of wastewater weighs 1,000,000 mg. 1 mg in 1 liter is 1 part in a million parts (ppm).

Percentage - Practice Problems

(Answers on page 496)

a. 25% of the chlorine in a 30 gallon vat has been used. How many gallons are remaining in the vat?

b. The annual public works budget is $147,450. If 75% of the budget should be spent by the end of September, how many dollars are to be spent? How many dollars will be remaining?

c. There are 50 pounds of pure chlorine in a barrel. If the chlorine is 67% calcium hypochlorite, how much does the barrel weigh?

d. 3/4 is the same as what percentage?

e. A 2% chlorine solution is what concentration in mg/L?

f. A wastewater plant treats 84,000 gallons per day. 7,560 gallons are removed as sludge. What percentage of plant flow is removed as sludge?

g. The average day winter flow of a community is 14,500 gallons. If the summer flow is estimated to be 72% greater than the winter. What is the estimated summer flow?

h. The city manager has informed the plant operator that 36% of the $5,700.00 budget has been spent. How many dollars are left for the remaining 7 months of the budget year?

Efficiency

Use

There are two common conditions that require the operator to calculate efficiency. One is the removal capabilities of a process unit or the plant. The second is the efficiency of a pump or motor.

Removal

BOD & TSS

Each treatment process removes a certain percentage of the TSS and BOD of the system. The amount of removal is commonly expressed as a percentage of the influent into the process unit or the plant.

Process

In order to determine the efficiency of removal the value of the output is subtracted from the value of the input and the result is divided by the value of the input. This result is multiplied times 100 to convert the decimal into a percentage.

$$\frac{(\text{Input - Output})}{\text{Input}} \text{ X } 100 = \% \text{ Removal}$$

Example

The TSS of the raw influent is 290 mg/L, the final TSS is 18 mg/L. What is the efficiency of TSS removal?

Step 1- Place the data into the equation.

$$\frac{(290 \text{ mg/L} - 18 \text{ mg/L})}{290 \text{ mg/L}} \text{ X } 100 = \% \text{ Removal}$$

Step 2 - Subtract the output from the input

$$\frac{272 \text{ mg/L}}{290 \text{ mg/L}} \text{ X } 100 = \% \text{ Removal}$$

Step 3 - Complete the math

93.8% removal of TSS

Pump Efficiency

Horsepower

There are three types of horsepower associated with a pumping installation. The horsepower that is purchased from the power company is called Electrical Horsepower (EHp). The horsepower that is the output of the electric motor is called Brake horsepower (BHp). This is the input horsepower to the pump. The horsepower that is the output of the pump is called Water Horsepower (WHp).

Process - Pump or Motor

To determine the efficiency of a pump or motor, divide the output horsepower by the input horsepower. Then multiply the result by 100 to change the decimal into percent.

$$\frac{\text{Output Horsepower}}{\text{Input Horsepower}} \text{ X } 100 = \% \text{ Efficiency}$$

Process - When % is Given

If the efficiency of each unit is known and you wish to determine the efficiency of the entire pump station, then merely multiply the decimal equivalency of the two percentages together.

Efficiency of Motor X Efficiency of Pump = Station %

Example - Pump Efficiency

It has been determined that the water horsepower of a pump is 5 Hp and the brake horsepower output of the motor is 7.2 Hp. What is the efficiency of the motor?

$$\frac{5 \text{ WHp}}{7.2 \text{ BHp}} \text{ X } 100 = 69.4\%$$

Example - Pump Efficiency

If a motor is 90% efficient and the output is 7.5 BHp what is the electrical horsepower requirement?

$$\frac{7.5 \text{ BHp}}{0.90} = 8.3 \text{ EHp}$$

Example - Station Efficiency

If a pump is 70% efficient and the motor is 85% efficient, what is the efficiency of the lift station?

Step 1 - Change the efficiency into decimals by dividing each by 100.

$$\frac{70\%}{100} = 0.70, \quad \frac{90\%}{100} = 0.90$$

Step 2 - Multiply the two values

0.70 X 0.90 = 0.63

Step 3 - Multiply the value by 100 to convert the decimal to a percentage

0.63 X 100 = 63%

Practice Problems- Efficiency

(Answers on page 498)

a. The BOD of the raw influent is 260 mg/L, the final BOD of the plant is 26 mg/L. What is the percentage of BOD removal?

b. The TSS of the raw sewage is 460 mg/L. The effluent of the primary clarifier is 320 mg/L. The final effluent is 24 mg/L. What is the percent removal of TSS in the primary portion of the plant?

c. The raw influent BOD in St. Mary's is 380 mg/L. The final effluent is 31 mg/L. What is the percent removal?

d. The efficiency of a pump is determined to be 75%. The efficiency of the motor is estimated at 94%. What is the efficiency of the lift station?

e. The water horsepower of a lift station with a submersible pump has been calculated at 8.2 WHp. The Output of the electric motor is measured as 10.3 BHp. What is the efficiency of the pump?

Making Conversions

Use

Conversions are a process of changing the units of a number in order to make the number usable in a specific situation. Common conversions in wastewater are:

- gpm to cfs
- Million gallons to acre feet
- Cubic feet to acre feet
- Cubic feet of wastewater to weight
- Cubic feet of wastewater to gallons
- Gallons of wastewater to weight
- gpm to **MGD**[16]
- psi to feet of **head**[17]

Working with formulas

In order to use a formula the units of the data given must be changed to meet the requirements of the formula.

Example

The formula for finding **velocity**[18] in a pipe is $V = Q \div A$ where Q is the flow in cubic feet per second. We most often measure flow in gallons per minute. In order to use this formula we must often convert the flow from gpm to cfs.

What is a Conversion?

A conversion is a number that is used to multiply or divide into another number in order to change the units of the number.

Known Conversions

In most instances, the conversion factor cannot be derived. It must be known. Therefore, tables such as the one on page 460 are used to find the common conversions.

Committing to Memory

Most operators memorize some standard conversions, This happens as a result of using the conversions, not as a result of attempting to memorize them.

Selecting a Conversion

The key to selecting which conversion to use is to look at the units. If you wish to convert cubic feet of wastewater to pounds, then you need a conversion that has both of these units (1 ft^3 of wastewater = 62.4 lbs)

Complex Process

The process of converting units can be highly complex and require several steps. A working understanding of the processes used requires a basic understanding of algebra. Because this is outside of the scope of this material, a process that does not require the understanding of algebra is described below. This process only works if there is an existing conversion and only a single conversion is required.

---

16 **MGD** - Million gallons per day. A unit of flow and a unit of volume.
17 **Head** - The measure of the pressure of water expressed as height of water in feet - 1 psi = 2.31 feet of head.
18 **Velocity -** The speed at which water moves, expressed in feet per second.

Straight Line Conversion

The technique described below is for working with straight line conversions. A straight line conversion is one that is direct - gpm to cfs, gal to liters, gallons to pounds, etc.

Process

The best way to describe this process is with an example. Convert 865 gpm to cfs.

- The first step is to place the known value on the paper with the units as a fraction and with 1 as the denominator to that fraction
- Next, place a X (multiply) after the units
- Then Place a straight line after the X
- And then, follow the straight line with an = sign.

$$865 \frac{gpm}{1} \text{ X} \text{ -------------- } =$$

- Now, ask the following question. "What units do I want to get rid of?" - Place this unit under the straight line. In this case we want to get rid of the gpm.

$$865 \frac{gpm}{1} \text{ X ------------} \frac{?}{gpm} =$$

- Then, ask yourself "What units do we want when we get done?" - Place this unit above the straight line. The original question asks that we convert gpm to cfs. So cfs is what we want when we get done.

$$865 \frac{gpm}{1} \text{ X --------------} \frac{cfs}{gpm} =$$

- Now, find a conversion that goes between these two units. From the table above we find the following conversion.

1 cfs = 448 gpm

- Place the conversion next to the proper units above or below the line. In our example the conversion was 448 gpm, so the 448 goes below the line next to its proper units.

$$865 \frac{gpm}{1} \text{ X } \frac{1 \text{ cfs}}{448 \text{ gpm}} =$$

- Finally, solve the problem. The information above could be rewritten into a fraction.

$$cfs = \frac{865 \text{ gpm X } 1 \text{ cfs}}{1 \text{ X } 448 \text{ gpm}} = \frac{865 \text{ gpm-cfs}}{448 \text{ gpm}} = 1.92 \text{ cfs}$$

Note that the units "gpm" cancelled out.

NOTE: DON'T FORGET TO USE COMMON SENSE. DON'T GET CARRIED AWAY WITH FORMULAS AND FORGET TO THINK.

Some Common Conversions

Area

1 acre = 43,560 ft^2

1 ft^2 = 144 in^2

Linear Measurements

1” = 2.54 cm

1’ = 30.5 cm

1 meter = 100 cm = 3.281 feet = 39.4”

1 yard = 3 feet

Volume

1 gal = 3.78 liters

1 ft^3 = 7.48 gal

1 ft^3 = 62.4 lbs

1 gal = 8.34 lbs

1 L = 1000 mL

1 acre foot = 43,560 cubic feet

1 gal = 8 pint

1 gal = 16 cups

1 pint = 2 cups

1 pound = 16 oz dry wt

1 yd ^{3}= 27 ft^3

1gpm = 1440 gpd

Weight

1 ft^3 of water= 62.4 lbs

1 gal = 8.34 lbs

1 lb = 453.6 grams

1 kg = 1000 g = 2.2 lbs

1 % = 10,000 mg/L

Pressure

1 ft of head = 0.433 psi

1 psi = 2.31 ft of head

Flow

1 cfs = 448 gpm

1 cfs = 0.6463 MGD

1 MGD = 694.5 gpm

Conversion - Practice Problems

Convert the following: (Answers on page 499)

a. 750 ft^3 of wastewater to gallons

b. 50 gallons to pounds

c. 560 gpm to cfs

d. 4 lbs to ounces

e. 128 ft^3 of wastewater to weight in pounds

f. 340 in^2 to ft^2

g. 3.4 cfs to gpm

h. 65 ft^3 to yd^3

i. 3,000 gallons to ft^3

j. 250,000 gallons to MG

k. 75 gpm to MGD

l. 8 inches to feet

m. 2.4 MGD to cfs

n. 2.4 MGD to gpm

o. 65 pints to gallons

p. 2.5 ft^2 to square inches

q. 7 yards to feet

r. 36,000 gpd to gpm

s. 125 gpm to gph

Temperature Conversion

Two Scales

There are two scales used to report temperature, the English scale of Fahrenheit and the metric scale of Celsius. There are two classic equations used to convert between these two scales. The formulas are:

°C = 5/9 (°F - 32°)

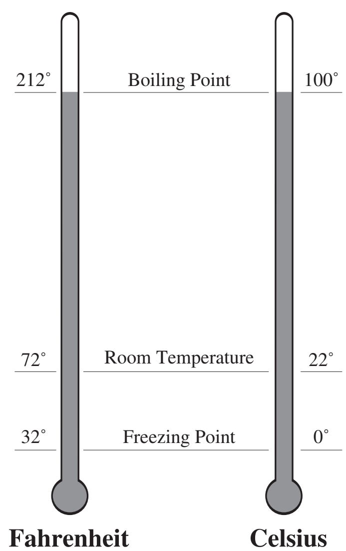
°F = (9/5 X°C) + 32

Confusion

Typically these two formulas provide more confusion than clarity. The following is our attempt at sharing a method that we find helpful in making these conversions.

The Scales

To understand how to make these conversions start with comparing the two scales. With the Fahrenheit scale, water freezes at 32° and boils at 212°. On the Celsius scale, water freezes at 0° and boils at 100°.

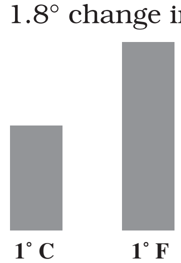


Difference of 32°

To start with then we can see that if we want to go from Fahrenheit to Celsius we must start by subtracting 32°. To go from Celsius to Fahrenheit we must add 32°.

Size of the Division

The difference between 32° and 212° is 180°. This is the difference between water freezing and boiling on the Fahrenheit scale. The difference between freezing and boiling on the Celsius scale is 100°. Therefore, we can see that each 1° change in the Celsius scale is the same as a 1.8° change in the Fahrenheit scale.



Changing Scales

As a result, to change from Celsius to Fahrenheit we must multiply the result by 1.8. To change from Fahrenheit to Celsius we must divide by 1.8

Final Confusion

The most confusing part is to determine if you should adjust for the 32° first or adjust for the size of the scale first. Here are the rules.

Rule 1 - to change °F to °C - subtract 32° then divide by 1.8

Rule 2 - to change °C to °F - multiply be 1.8 and add 32°

Conclusion

We now have two new formulas

$$°C = \frac{°F - 32°}{1.8}$$

$$°F = °C \times 1.8 + 32°$$

A Third Choice

Several text books show a third method of making this conversion. This is a three step method:

Step 1 - add 40° to the existing value

Step 2 - Multiply by 1.8 if going to °F and divide by 1.8 if going to °C

Step 3 - Subtract 40°

Example

Change 212°F to °C

Step 1 - 212°F + 40° = 252°F

Step 2 - 252°F ÷ 1.8 = 140 °

Step 3 - 140° - 40° = 100°C

Your Choice

It makes little difference which technique you use. Select the one that fits your style and proceed.

Temperature Conversion - Practice Problems

(Answers on page 502)

a. Change 212°F to °C

b. Change 70 °F to °C

c. Change 140 °F to °C

d. Change 20 °C to °F

e. Change 85 °C to °F

f. Change 4 °C to °F

Calculating Pressure & Head

Definition

Pressure[19] is the weight per unit area. Typical pressure units are pounds per square inch (lbs/in^2 - psi) and pounds per square foot (lbs/ft^2). The pressure on the bottom of a container is not related to the volume of the container, nor the size of the bottom. The pressure is dependent on the height of the fluid in the container. (There is more explanation on this topic in the section on hydraulics).

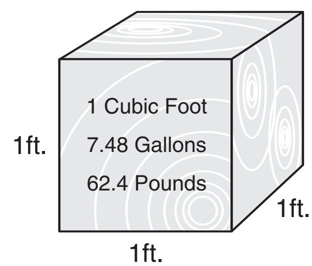
Pressure & Head

The height of the fluid in a container is referred to as **head**[20]**.** Head is a direct measurement in feet and is directly related to pressure.

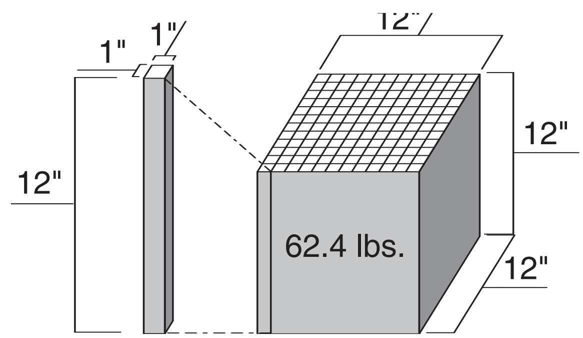
Relationship between feet & Head

Weight of wastewater

By definition wastewater weighs 62.4 pounds per cubic foot.



The surface of any one side of the cube contains 144 square inches (12" X 12" = 144 in^2). Therefore, the cube contains 144 columns of wastewater one foot tall and one inch square.



The weight of each of these pieces can be determined by dividing the weight of the wastewater in the cube by the number of square inches.

$$\text{Weight} = \frac{62.4\,\text{lbs}}{144\,\text{in}^2} = 0.433\,\text{lbs/in}^2$$

or 0.433 psi

[19] **Pressure** - The force exerted on a unit area. Pressure = Weight X height. In water, it is usually measured in psi (pounds per square inch). One foot of water exerts a pressure of 0.433 pounds per square inch.
[20] **Head -** The measure of the pressure of water expressed as height of water in feet 1 psi = 2.31 feet of head.

Since this is the weight of one column of wastewater one foot tall, the true expression would be 0.433 pounds per square inch per foot of head or 0.433 psi/ft.

Conversion

We now have a conversion between feet of head and psi.

1 foot of head = 0.433 psi

While it can be calculated from the relationship above, it is also desirable to know the relationship between pressure and feet of head. In other words 1 psi represents how many feet of head. This is determined by dividing 1 by 0.433 psi.

$$\text{feet of head} = \frac{1\text{ ft}}{0.433\text{ psi}} = 2.31\text{ ft/psi}$$

In other words if a pressure gauge were reading 10 psi, we know that the height of the wastewater necessary to represent this pressure would be 10 psi X 2.31 ft/psi = 23.1 feet.

Both Conversions

1 ft = 0.433 psi

1 psi = 2.31 feet

Which Conversion to Use

Many operators find having two conversions for the same thing confusing. They agree that it is best to memorize one and stay with it. The most accurate conversion is the 1 ft = 0.433 psi. This will be the conversion used in this text.

Examples

To convert 40 psi to feet of head. Use the standard conversion technique described earlier.

$$40\frac{\text{psi}}{1} \text{ X } \frac{\text{ft}}{0.433\text{psi}} = 92.4\text{ feet}$$

Convert 40 feet to psi.

$$40\frac{\text{ft}}{1} \text{ X } \frac{0.433\text{ psi}}{1\text{ ft}} = 17.3\text{ psi}$$

Another Way

As you can see, if you are attempting to convert psi to feet you divide by 0.433, and if you are attempting to convert feet to psi you multiply by 0.433. It can become confusing about when to divide and when to multiply. The above process can be most helpful in making that determination. However, there is another way. Notice that the relationship between psi and feet is almost two to one. It takes slightly more than two feet to make one psi. Therefore when looking at a problem where the data is in pressure and you want it in feet, we can see that the answer will be at least twice as large as the number we are starting with. For example - if the pressure were 20 psi, we know that the head is over 40 feet. Therefore, we must divide by 0.433 in order to obtain the correct answer.

Pressure/Head - Practice Problems

Make the following conversions: (Answers on page 503)

a. Convert a pressure of 45 psi to feet of head

b. Convert 12 psi to feet

c. Convert 85 psi to feet

d. It is 112 feet in elevation between the top of the water in a lift station and the water level in the manhole that is being pumped to. What will the static pressure be at the lift station?

e. A wet well is 20 feet deep. What will the pressure be at the bottom of the wet well when it is full of wastewater?

Determining Flow

Units

Flow is expressed in the English system of measurements using many terms. The most common flow terms are:

- gpm - gallons per minute
- cfs - cubic feet per second
- gpd - Gallons per day
- MGD - Million gallons per day

Conversions

Flow rates can be converted to different units using the conversion process described above. The most common flow conversions are: 1 cfs = 448 gpm & 1gpm = 1440 gpd

Gallons per Day (gpd) to MGD

To convert gallons per day to MGD, divide the gpd by 1,000,000. For example;

Convert 125,000 gallons to MGD.

$$\frac{125{,}000\ \text{gpd}}{1{,}000{,}000} = 0.125\ \text{MGD}$$

or convert 2,300,000 gpd to MGD

$$\frac{2{,}300{,}000\ \text{gpd}}{1{,}000{,}000} = 2.3\ \text{MGD}$$

Conversion of MGD to gpm

There are many instances where the design or plant information is given in MGD and we wish to have the flow in gpm. This conversion is accomplished in two steps. Step 1 is to convert gpd by multiplying by 1,000,000 and step two is to convert to gpm by dividing by the number of minutes in a day (1440 min/day). For Example:

Convert 0.125 MGD to gpm

First convert the flow in MGD to gpd

0.125 MGD X 1,000,000 = 125,000 gpd

Now convert to gpm by dividing by the number of minutes in a day (24 hrs per day X 60 min per hour) 1440 min/day.

$$\frac{125{,}000\ \text{gpd}}{1440\ \text{min/day}} = 86.6 \text{ or } 87\ \text{gpm}$$

Convert gpd to gpm

The process of converting gpd to gpm is shown in the example above. The process is to divide the flow in gpd by the number of minutes in a day (1440 min/day).

Conversion of gpm to cfs

The conversion from gpm to cfs is shown in the examples in the above section on conversions. The conversion is 1 cfs = 448 gpm.

Determining Flow

Flow in a pipe line, channel or stream is found using the equation:

$Q = VA$

Where

Q = flow in cubic feet per second (cfs - ft^3/sec)

V = velocity in feet per second (ft/sec)

A = area in square feet (ft^2)

Example

Find the flow in cfs in a 6 inch line, if the velocity is 2 feet per second.

- The first step is to determine the cross-sectional area of the line in square feet. Start by converting the diameter of the pipe to inches.
- The diameter is 6 inches, therefore the radius is 3 inches. 3 inches is 3/12 of a foot or 0.25 feet
- Now find the area in square feet

$A = \pi\ r^2$

$A = \pi\ (0.25\ ft)^2$

$A = \pi \times 0.0625\ ft^2$

$A = 0.196\ ft^2$

- Now find the flow

$Q = VA$

$Q = 2\ ft/sec \times 0.196\ ft^2$

$Q = 0.3927$ cfs or 0.4 cfs - ft^3/sec

Flow - Practice Problems

(Answers on page 504)

a. Find the flow in MGD when the flow is 34,000 gpd

b. Find the flow in gpm when the total flow for the day is 65,000 gpd

c. Find the flow in gpm when the flow is 1.3 cfs

d. Find the flow in gpm when the flow is 0.25 cfs

e. Find the flow in a 4 inch pipe when the velocity is 1.5 feet per second

Calculating Detention Time

Use

Detention time is the amount of time that a fluid stays in a container. Detention time is also important when evaluating the clarifiers, aeration basins and chlorine contact chambers.

Units

Detention time is expressed in units of time. The most common are seconds, minutes, hours and days.

Calculations

The simplest way to calculate the detention time is to divide the volume of the container by the flow rate into the container. The theoretical detention time of a container is the same as the amount of time it would take to fill the container if it were empty.

Volume Units

The most common volume units used are gallons. However, on occasion cubic feet may also be used.

Time Units

The time units, will be in whatever the units are used to express the flow. For instance, if the flow is in gpm then the detention time will be in minutes. If the flow is in gpd, then the detention time will be in days. If in the final result the detention time is in the wrong time units then simply convert to the appropriate units.

Example

The village septic tank has a capacity of 50,000 gallons. The wastewater flow from the village is 30,000 gallons per day. What is the detention time in the septic tank in hours?

$$DT = \frac{50{,}000 \text{ gal}}{30{,}000 \text{ gpd}} = 1.67 \text{ days or } 1.67 \text{ days X } 24 \text{ hrs/day} = 40 \text{ hours}$$

Detention Time - Practice Problems

(Answers on page 505)

a. How long will it take to fill a 50 gallon hypochlorite tank if the flow is 5 gpm?

b. Find the detention time in a 45,000 gallon reservoir if the flow rate is 85 gpm.

c. If the fuel consumption to the boiler is 35 gallons per day. How many days will the 500 gallon tank last before it runs out of fuel?

d. The secondary clarifier contains 5,775 gallons. What is the detention time if the flow is 175 gpm?

Ratio and Proportions

What is a Ratio?

A ratio is a relationship between two numbers. A ratio can be written using a colon (1:2, 5:9, 20:60) or a fraction, (1/2, 5/9, or 20/60).

What is a Proportion

A proportion exists when the relationship between one ratio is the same as the relationship between a second ratio.

How is this determined?

To determine if two ratios are proportional the two are cross multiplied. If the answers are equal then they are proportional.

Example 1

Determine if 3/9 is proportional to 6/18.

3

$$\frac{3}{9} \qquad \frac{6}{18}$$

9 X 6 = 54 and 3 X 18 = 54, therefore the two ratios are proportional.

Example 2

Determine if 5/9 and 6/20 are proportional.

3

$$\frac{5}{9} \qquad \frac{6}{20}$$

9 X 6 =54 and 5 X 20 = 100, therefore the two are not proportional.

So Now What?

While this process is nice to know it is basically academic and is the lead into the practical use of ratios and proportions to solve common wastewater problems. In order to utilize this process, we need to discuss one more major step and then provide some basic rules. The first step is what to do when one part of a ratio is unknown.

The Unknown

In order to solve for a unknown portion of a ratio follow these steps:

Step 1: Set up the ratios in a proportion format and place an "X" in ratio for the unknown value.

$$\frac{2}{15} : \frac{X}{50}.$$

Notice that we have set the two ratios up as a proportion with the colon (:) between them.

Step 2: Cross multiply.

(15) (X) = (2) (50)

Step 3, To get the X on the left side of the equation divide both sides by 15.

$$\frac{(15)(X)}{15} = \frac{(2)(50)}{15}$$

$$X = \frac{(2)(50)}{15}$$

Step 4, solve for X

X = 6.67

Practical Application

Proportion problems deal with larger and smaller values of the same units. For instance, a common proportion problem might be, if it takes 5 pounds of calcium hypochlorite to give the correct dosage in a 35 gallon tank, then how many pounds will it take to make 12 gallons.

Rule 1

Set up the proportion with the same types of units on one side of the colon.

Using our example above, pounds would go on one side and gallons on the other.

Rule 2

The numerators must contain the same size of units (either larger or small units) and the denominator must contain the same size units (either larger or smaller). For instance:

$$\frac{\text{Smaller value}}{\text{Larger Value}} : \frac{\text{Smaller Value}}{\text{Larger Value}}$$

or

$$\frac{\text{Larger Value}}{\text{Smaller Value}} : \frac{\text{Larger Value}}{\text{Smaller Value}}$$

Rule 3

Place an “X” in the unknown value and solve for “X”.

Hint

Using our example above you can set up a verbal relationship. For instance, 5 pounds is to 35 gallons as X pounds is to 12 gallons. In order to place these in the equation, start in the upper left with the 5 pounds. The “is to” represents the colon. For instance:

$$\frac{5\text{ lbs}}{X} : \frac{35\text{ gal}}{12\text{ gal}}$$

$$(X)(35\text{ gal}) = (5\text{ lbs})(12\text{ gal})$$

$$X = \frac{(5\text{ lbs})(12\text{ gal})}{35\text{ gal}} = 1.7\text{ lbs}$$

Another Example

If one chlorine cylinder is used in 20 days how many will be used in 100 days?

Step 1. Set up the proportion - 1 cylinder is to 20 days as X cylinders is to 100 days.

$$\frac{1\ \text{cylinder}}{X} : \frac{20\ \text{days}}{100\ \text{days}}$$

Step 2 - Cross multiply

(X cylinders) (20 days) = (1 cylinder) (100 days)

Step 3 - Rearrange the equation to get "X" on the left by its self; divide both sides by 20 days.

$$X\ \text{cylinders} = \frac{(1\ \text{cylinder})(100\ \text{days})}{20\ \text{days}}$$

Step 4 - solve for X cylinders

X = 5 cylinders

Ratio and Proportion - Practice Problems

(Answers on page 506)

a. It takes 6 gallons of chlorine solution to obtain a proper residual when the flow is 45,000 gpd. How many gallons will it take when the flow is 62,000 gpd?

b. A motor is rated at 41 amps average draw per leg at 30 Hp. What is the actual Hp when the draw is 36 amps?

c. If it takes 2 operators 4.5 days to clean an aeration basin, how long will it take three operators to do the same job.

d. If it takes 20 minutes to pump a wet well down with one pump pumping at 125 gpm, then how long will it take if a 200 gpm pump is used?

e. It takes 3 hours to clean 400 feet of collection system using a sewer ball. How long will it take to clean 250 feet?

f. If it takes 14 cups of HTH to make a 12% solution. Each cup holds 300 grams, how many cups will it take to make a 5% solution?

Pounds Formula

Use

One of the most common formulas used by wastewater operators is the pounds formula. This formula is used to determine the loading on the plant and its various process units, the loading on the receiving water and the amount of chemicals needed for a specific function, such as disinfection. The formula can also be used to determine the amount of mixed liquor in the aeration basin and the amount of sludge to be disposed of in the landfill.

Basic Assumption

In using the formula it is assumed that all of the material found in water (TSS, BOD, MLSS, Chlorine, etc.) weighs the same as water. That is, 8.34 pounds per gallon.

The Formula

The basic pounds formula is:

$\text{Lbs} = \text{V},_{\text{MG}} \text{ X } 8.34_{\text{ lbs/gal}} \text{ X Conc},_{\text{ mg/L}}$

Where:

Lbs = pounds

V = flow or volume in millions of gallons

Conc = concentration or dosage in mg/L

Process

The process of using the pounds formula to determine pounds of a substance in water is relatively simple. Just plug the values into the appropriate slots and multiply. However, there are two items that can cause some confusion; flows of less than one million gallons and concentrations in ppm.

Flow

Flow and volume are often expressed in gallons per day, gallons per minute and millions of gallons per day. Regardless of how they are expressed they must be converted to MG in order for them to be placed in this formula. When the flow is in gallons or million gallons per day (MGD) the pounds must be expressed in lbs/day.

Flow or Volume in gpd

When a flow or volume is expressed in gallons it must be converted to MGD by dividing it by 1,000,000. For instance; a flow of 120,000 gpd is 0.12 MGD and a flow of 40,000 gpd is 0.04 MGD.

Flow or Volume in gpm

When a flow or volume is expressed in gpm it must be first converted to gpd by multiplying by the number of minutes per day (1440) and then divided by 1,000,000 to get MGD.

Example

The flow is 250 gpm. What is the flow in MGD.

250 gpm X 1440 min/day = 360,000 gpd

360,000 gpd ÷ 1,000,000 = 0.36 MGD

PPM

PPM or ppm is an abbreviation for parts per million. Parts per million is the same as mg/L, milligrams per liter. While they mean the same, mg/L is the preferred and more accepted unit.

Example

The final effluent of a plant contains 26 mg/L of BOD. The flow is 2.5 MGD. How many pounds of BOD are placed in the receiving stream each day?

lbs/day = Q, MGD X 8.34, lbs/gal X Conc, mg/L

lbs/day = 2.5 MGD X 8.34 lbs/gal X 26 mg/L

lbs/day = 542 pounds/day

Pounds Practice Problems

(Answers on page 508)

a. How many pounds of 100% gas chlorine are needed to disinfect a flow of 85,000 gpd at 12 mg/L?

b. The TSS of the influent of a 3.2 MGD plant is 360 mg/L. How many pounds of TSS are received each day?

c. The BOD in the influent of a plant is 320 mg/L. The BOD in the final effluent is 18 mg/L. When the flow is 45,000 gpd, how many pounds of BOD are removed?

d. A 40,000 gallon aeration basin has a MLSS of 2800 mg/L. How many pounds pf MLSS are under aeration?

e. How many pounds of calcium hypochlorite at 67% is needed to disinfect 125,000 gallon per day flow with a dosage of 8 mg/L?

Metric System (SI)

Description

The system of units and measures that is commonly called the metric system is more correctly titled the SI or System International. This is the system that is used throughout most of the world, except the United States. The metric system is a base 10 system. This base makes it very easy to convert between various units. While the system has not gained widespread acceptance in the U.S. it is widely accepted in most of the world and it is highly desirable that the operator be familiar with the basic components of the system.

Base Units

The following are the base units of this system.

Quantity	**Unit**	**Symbol**
Length	meter	m
Mass	gram	g
Time	second	s
Temperature	Kelvin	K
Volume	liter	L

Description of the Units

Length

The basic unit of measurement of length is the meter. A meter is approximately 3 feet in length (3.281 ft).

Mass

Mass in the metric system is used as a comparison with pounds in the English system. The base unit is the gram. There are approximately 454 grams in a pound.

Time

The time base of seconds in the metric system is the same as the time base in the English system.

Temperature

The basic unit of temperature in the metric system is the Kelvin unit. However, Celsius is the unit that is most commonly associated with this system. One degree Kelvin is the same size as one degree Celsius. The major difference is in the starting point (zero). In the Kelvin thermometer 0°K is equal to -273.15 °C.

Metric Prefixes

English

When a number becomes too large to handle easily, we convert it by dividing it by a value and call it something else. For instance, when we have too many feet, we divide by 3 and call the result yards, or we divide by 5,280 and call the result miles. Seldom are the divisions even numbers and they change with each set of units. Notice that yards are feet divided by 3 but miles are feet divided by 5280. This makes it very difficult to remember how to make the proper conversion.

Metric

In the metric system, there are standard prefixes to numbers that have been divided in order to reduce their size. In addition, the divisions are always in multiples of ten. The following is a listing of the basic metric prefixes:

Prefix	Symbol	Mathematical Value
giga	G	1,000,000,000
mega	M	1,000,000
kilo	k	1,000
hecto*	h	100
deka*	da	10
Base	none	1
deci*	d	0.1
centi*	c	0.01
milli	m	0.001
micro	μ	0.000,001
nano	n	0.000,000,0001

* Under normal circumstances these prefixes are seldom used and should, if possible be avoided.

Metric Abbreviations

Limitations

The following is a listing of common abbreviations that are used in math problems in the wastewater field. With a few exceptions this listing is limited to those abbreviations that are associated with the SI or metric system units of measurement. Abbreviations associated with the English system of measurements are found at the beginning of this lesson on metric units.

a	year	g	gram
h	hour	ha	hectare
j	joule	kg	kilogram
km	kilometer	L	liter
m	meter	m	meter
mg	milligram	min	minute
N	newton	Pa	pascal
s	second	w	watt
mL	Milliliter	KW	Killowatt

Metric to English Conversions

Area

From	To	Multiply	by	to get
square feet	square meters	ft^2	0.0929	m^2
square inches	square meters	in^2	6.4516×10^{-4}	m^2
acre	hectare	ac	0.4047	ha
square meter	square feet	m^2	10.76	ft^2
hectare	acre	ha	2.471	ac

Energy - work

kilowatt -hour	joules	kwh	3.6×10^6	j
horsepower-hour	joules	Hph	2.6845×10^6	j

Flow Rate

cubic feet per second	meters per second	cfs	0.028317	m^3/s
gallons per minute	liters per second	gpm	0.06309	L/s
liters/second	gallons per minute	L	15.85	gpm

Force

pounds	Newtons	lbs	4.4482	N

Length

inch	meters	in	0.0254	m
inch	centimeters	in	2.54	cm
foot	meters	ft	0.3048	m
mile	meters	mi	1609.3	m
mile	kilometers	mi	1.609	km
meter	foot	m	3.281	ft
kilometer	mile	km	0.6214	mi

Mass

ounce	kilogram	oz	0.02835	kg
pound	kilogram	lb	0.45359	kg
pound	gram	lb	453.6	g

liter of water	kilogram	L	1	kg
kilogram	pounds	kg	2.205	lb

Power

From	To	Multiply	by	to get
horsepower	watts	Hp	746	w
Joules/second	watts	J/s	1	w

Pressure

pounds /square inch	pascal	psi	6895	Pa
pounds /square inch	kilopascal	psi	6.9	kPa
pounds / square inch	newtons /square meter	psi	6895	N/m^2
kilopascal	pounds/square inch	kPa	0.145	psi

Velocity

foot/second	meter/second	ft/s	0.3048	m/s
miles/hour	meter/second	mph	0.44704	m/s
kilometers/hour	meter/second	km/hr	0.27778	m/s

Volume

acre-foot	cubic meters	ac-ft	1233.5	m^3
cubic foot	cubic meters	ft^3	0.028317	m^3
gallon (U.S.)	cubic meters	gal	3.7854 x 10-3	m^3
gallon (U.S.)	liters	gal	3.78	L
gallon (Imperial)	cubic meters	gal(I)	4.5459 x10-3	m^3
liter	cubic meters	L	1000	m^3
yard	cubic meters	yd	0.76455	m^3
cubic meters	gallons	m^3	264.2	gal
cubic meters	cubic feet	m^3	35.31	ft^3
cubic meters	yards	m^3	1.308	yd

Metric Conversions

Two Types

Like the English system, there are two types of conversions; reducing or enlarging a value within the same base and converting between bases.

Conversions in Same Base

Prefix is the Key

The key to making conversions within the same base lies in an understanding of the prefixes and their associated values. For instance the prefix kilo indicates 1000, therefore a kilogram is 1000 grams and a kilometer is 1000 meters.

Linear Conversions

The base unit of linear measurement is the meter. The common divisions of the meter are:

kilometer = 1000 meters

centimeter= 1/100 of a meter or there are 100 centimeters in a meter.

millimeter = 1/1000 of a meter or there are 1000 millimeters in a meter.

Conversion Example #1

Convert 4500 meters to kilometers.

Step 1 - divide the number of meters by 1000 (kilo)

$$\frac{4{,}500\,\text{meters}}{1{,}000\,\text{meters/kilometer}} = 4.5\,\text{kilometers}$$

Conversion Example #2

Convert 4.6 meters to centimeters.

Step 1 - Multiply meters times 100 (centi)

4.6 meters X 100 c/m = 4600 c

Volume Conversions

The most common volume conversion is between liters and milliliters. Since milli is the prefix for 0.001, liters can be converted to milliliters by multiplying times 1000. Like wise milliliters can be converted to liters by dividing by 1000.

1L = 1000 mL

Conversion Example #3

Convert 2,400 mL to liters.

Step 1 - Divide the number of milliliters by 1000

$$\frac{2{,}400\,\text{mL}}{1{,}000\,\text{mL/L}} = 2.4\,\text{L}$$

Conversion Example #4

Convert 0.35 L to milliliters

Step 1 - Multiply the number of liters times 1000.

0.35 L X 1000 mL/L = 350 mL

Mass Conversion

The two most common mass conversions are between kilograms and grams and between milligrams and grams. Since kilo is 1000 grams, it can be converted to kilograms by dividing by 1000. Since milli is 1000, grams can be converted to milligrams by multiplying by 1000.

Conversion Example #5

Convert 2,600 mg to grams

Step 1 - divide the 2,600 mg by 1,000

$$\frac{2{,}600\,\text{mg}}{1{,}000\,\text{mg/g}} = 2.6\,\text{g}$$

Conversion Example #6

Convert 1,345,000 g to kilograms

Step 1 - divide 1,345,000 g by 1,000

$$\frac{1{,}345{,}000\,\text{g}}{1{,}000\,\text{g/kg}} = 1{,}345\,\text{kg}$$

Conversion to Another Base

Key

The common conversion made between basic units is between mass and volume. Volume in the metric system is expressed as liters, cubic meters or cubic centimeters.

The relationship between mass and volume is:

1g=1ml=1cc, (one gram is equal to 1 milliliter is equal to 1 cubic centimeter).

Other Relationships

1 cubic meter (m^3) = 1000 liters

1kg = 1 L

Cubic Measurements

It is common practice to convert liters to cubic meters when the volume exceeds 1000 liters.

Conversion Example #7

Convert 500 kilograms of wastewater to liters.

Since kilograms and liters are the same base the conversion is a simple matter of changing the units.

500 kg = 500 L

Conversion Example #8

Convert 3,600 L to cubic meters

Step 1 - Divide the liters by 1000

$$\frac{3{,}600\,\text{L}}{1{,}000\,\text{L/m}^3} = 3.6\,\text{m}^3$$

Metric Conversion - Practice Problems

(Answers on page 509)

a. Convert 4.2 Kg to g

b. Convert 0.5 Kg to g

c. Convert 4600 g to Kg

d. Convert 3.4 Km to m

e. Convert 0.5 Km to m

f. Convert 10,000 m to Km

Answers to Practice Problems

Practice Problems - Rounding

Round the following to the nearest hundredths.

2.4568 =	2.46
27.2534 =	27.25
128.2111 =	128.21
364.8762 =	364.88
354.777777 =	354.78
34.666666 =	34.67
67.33333 =	67.33

Round the following to the nearest tenths.

2.4568 =	2.5
27.2534 =	27.3
128.2111 =	128.2
364.8762 =	364.9
354.777777 =	354.8
34.666666 =	34.7
67.33333 =	67.3

Practice Problems - Significant Digits

Round the following answers off to the most significant digit.

26.34 X 124.34567 = 3,275.26495 =	3,275.26
25.1 + 26.43 = 51.53 =	51.5
128.456 - 121.4 = 7.056 =	7.1
23.5 ft X 34.25 ft = 804.875 ft^2 =	804.9 ft^2
12,457.92 X 3 = 37,373.76 =	37,374

Equations - Practice Problems

a. Find the diameter of a clarifier that has a circumference of 126 feet.

$C = \pi D$

$126' = \pi D$

$$D = \frac{126\,\text{ft}}{\pi} = 40\,\text{ft}$$

b. Find the diameter of a pipe that has a circumference of 12 9/16".

12 9/16" = 12.56"

$C = \pi D$

$12.56'' = \pi D$

$$D = \frac{12.56\ \text{in}}{\pi} = 4\,\text{in}$$

c. Find the diameter of a clarifier that has a surface area of 113 ft^2.

$A = \pi r^2$

$113\ ft^2 = \pi r^2$

$$r = \sqrt{\frac{113\,\text{ft}^2}{\pi}} = 5.997\ \text{or}\ 6\,\text{ft}$$

6 ft X 2 = 12 ft diameter

d. Find the diameter of a clarifier that has a surface area of 314 ft^2.

$A = \pi r^2$

$314\ ft^2 = \pi r^2$

$$r = \sqrt{\frac{314\,\text{ft}^2}{\pi}} = 9.997\ \text{or}\ 10\,\text{ft}$$

D = 10 ft X 2 = 20 ft

e. The detention time in a chlorine contact chamber is 42 minutes. If the chamber holds 3200 gallons, what is the flow rate in gpm?

$$DT = \frac{\text{Volume}}{\text{flow}}$$

$$42\text{ min} = \frac{3{,}200\text{ gal}}{\text{flow, gpm}} = \text{flow, gpm} = \frac{3{,}200\text{ gal}}{42\text{ min}}$$

flow = 76 gpm

f. A primary clarifier has a detention time of 2 hours. What is the flow rate in gpm if the clarifier holds 8000 gallons?

$$DT = \frac{\text{Volume}}{\text{flow}}$$

2 l
$$120\text{ min} = \frac{8{,}000\text{ gal}}{\text{flow, gpm}} = \text{flow, gpm} = \frac{8{,}000\text{ gal}}{120\text{ min}}$$

flow, gpm = 67 gpm

g. A rectangular clarifier has a weir length of 10 feet. What is the weir overflow rate when the flow is 80,000 gpd?

$$WO = \frac{\text{Flow rate in gpd}}{\text{Weir length in feet}}$$

$$WO = \frac{80{,}000\text{ gpd}}{10\text{ ft}} = 8{,}000\text{ gpd/ft}$$

h. A circular clarifier is 18 feet in diameter. What is the weir overflow rate when the flow is 450 gpm?

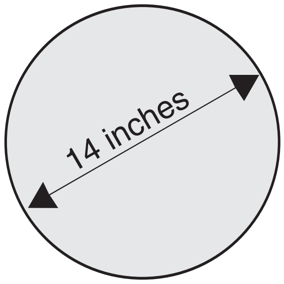
$$WO = \frac{\text{flow rate in gpm}}{\pi D}$$

$$WO = \frac{\text{flow rate in gpm}}{\text{weir length in feet}}$$

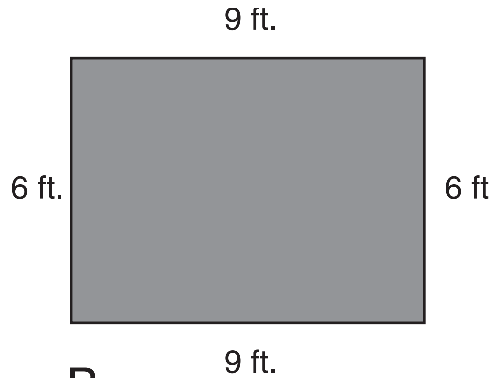
$$WO = \frac{450\text{ gpm}}{\pi\ 18\text{ ft}} = 7.96\text{ gpm/ft}$$

Perimeter & Circumference - Practice Problems

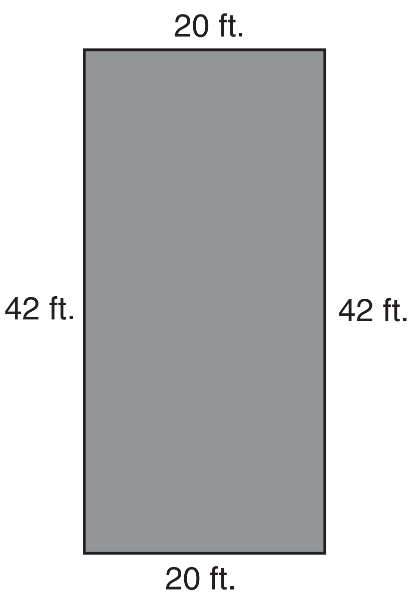
Find the perimeter or circumference of the following items.



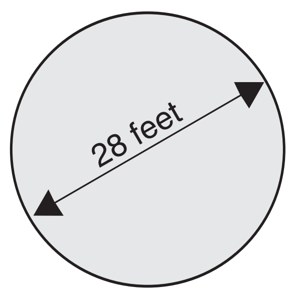
A



B



C



D

A = π X 14 inches = 44 inches

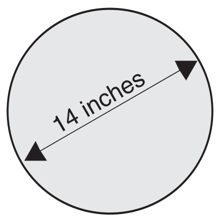
B = 6' + 9' + 6' + 9' = 30'

C = 42' + 20' + 42' + 20' = 124'

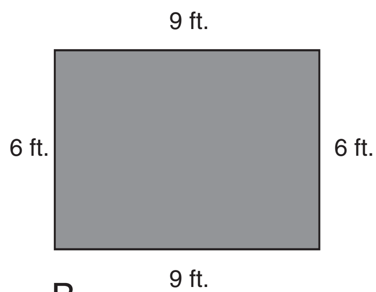
D = π X 28 feet = 88 feet

Area - Practice Problems

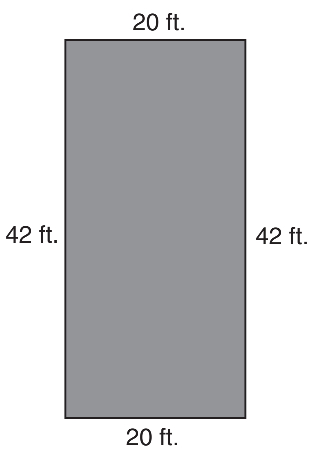
Find the area of the following items.



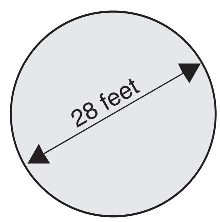
A



B



C



D

A - Diameter is 14 inches therefore, the radius being 1/2 of the diameter is 7 inches.

$A = \pi \text{ X } (7\text{in})^2$

$A = \pi \text{ X } 49 \text{ in}^2$

$A = 154 \text{ in}^2$

B - A = L X W

$A = 9' \text{ X } 6' = 54 \text{ ft}^2$

C - A = L X W

A = 42' X 20'

$A = 840 \text{ ft}^2$

D - The diameter is 28 feet. The radius is one half of the diameter, therefore the radius is 14 feet.

$A = \pi r^2$

$A = \pi \text{ (14 feet)}^2$

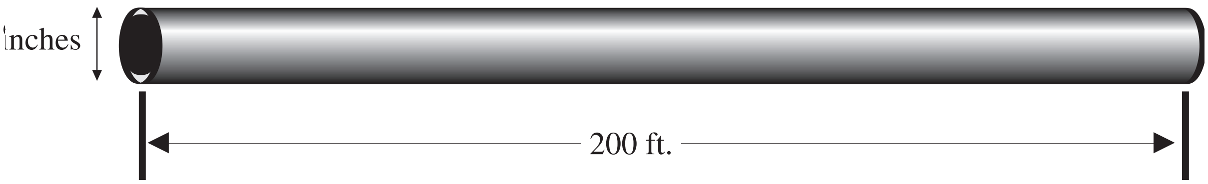
$A = \pi \text{ X } 196 \text{ ft}^2$

$A = 616 \text{ ft}^2$

Volume - Practice Problems

Find the volume of the following:

a. A 3 inch pipe 200 feet long. (Hint, change the diameter of the pipe from inches to feet)



- Change diameter to feet 3 ÷ 12 = 0.25 ft
- Find the radius by dividing the diameter by 2

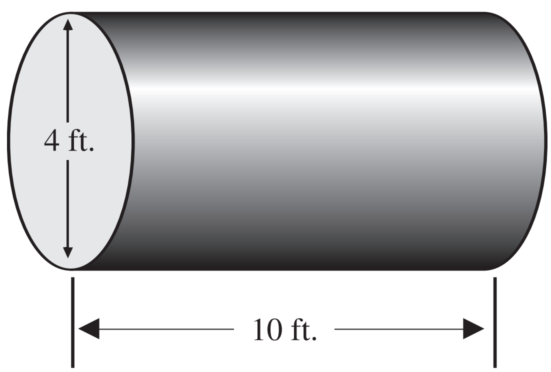
  0.25 ft ÷ 2 = 0.125 ft
- Find the volume
- $V = L \text{ X } \pi \, r^2$

  $V = 200 \text{ ft X } \pi \, (0.125\text{ft})^2$

  $V = 200 \text{ ft X } \pi \text{ X } 0.01563 \text{ ft}^2$

  $V = 9.8 \text{ ft}^3$

b. Find the volume of a fuel tank 4 feet in diameter and 10 feet long.



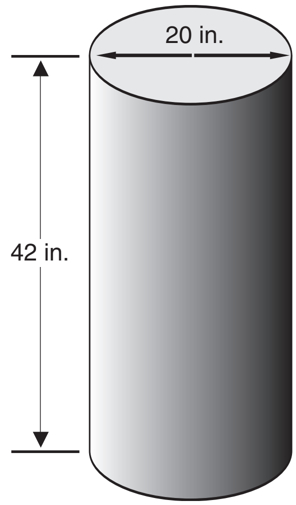
- Find the radius of the tank. The radius is one-half of the diameter. 4 ft ÷ 2 = 2 ft
- Find the volume
- $V = L \text{ X } \pi \, r^2$

  $V = 10 \text{ ft X } \pi \, (2 \text{ ft})^2$

  $V = 10 \text{ ft X } \pi \text{ X } 4 \text{ ft}^2$

  $V = 125.7 \text{ ft}^3$

c. Find the volume of a chlorine barrel that is 20 inches in diameter and 42 inches tall.



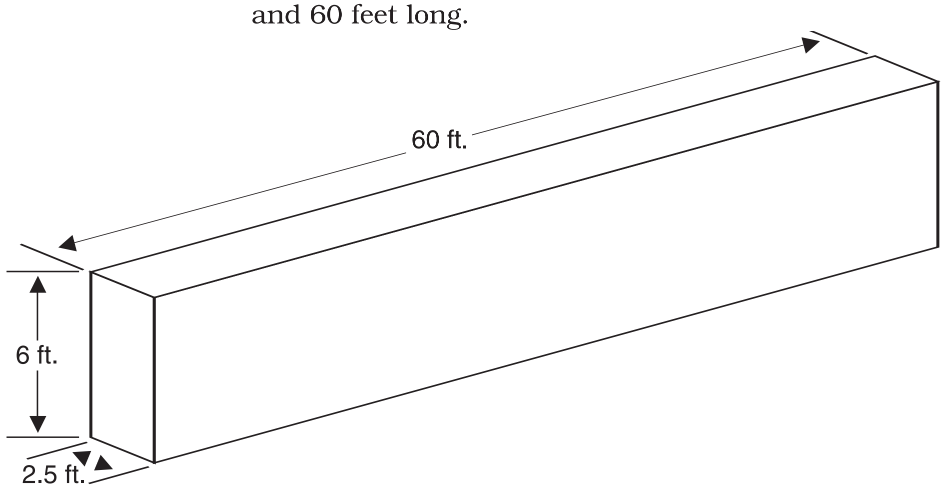
- Find the radius of the tank. The radius is one-half of the diameter. 20 inches ÷ 2 = 10 inches
- Find the volume
- $V = H \times \pi r^2$

$V = 42 \text{ in} \times \pi (10 \text{ in})^2$

$V = 42 \text{ in} \times \pi \times 100 \text{ in}^2$

$V = 13{,}195 \text{ in}^3$

d. Find the volume of a trench 2.5 feet wide, 6 feet deep and 60 feet long.



- $V = L \times W \times D$

$V = 60 \text{ ft} \times 2.5 \text{ ft} \times 6 \text{ ft}$

$V = 900 \text{ ft}^3$

Percentage - Practice Problems

a. 25% of the chlorine in a 30 gallon vat has been used. How many gallons are remaining in the vat?

- Find the percentage of chlorine remaining.

100 % - 25% = 75%

- Change the percent to a decimal

75% ÷ 100 = 0.75

- Multiply the percent as a decimal times the tank volume

0.75 X 30 gal = 22.5 gal

b. The annual public works budget is $147,450.00. If 75% of the budget should be spent by the end of September, how many dollars are to be spent? How much is remaining?

- Change the percentage to a decimal
- 75% ÷ 100 = 0.75
- Multiply the budget amount by the percent to be used

$147,450.00 X 0.75 = $110,587.50 to be spent

- Find what will be remaining

$147,450.00 - 110,587.50 = $36,862.50

c. There are 50 pounds of pure chlorine in a barrel. If the chlorine is 67% calcium hypochlorite, how much does the barrel weigh?

- Change the percent to a decimal

67% ÷ 100 = 0.67

- Divide the weight by the percentage

$$\frac{50\,\text{lbs}}{0.67} = 74.61\text{bs}$$

d. 3/4 is the same as what percentage?

- Change the fraction into a decimal

$$\frac{3}{4} = 0.75$$

- Convert to a percentage

0.75 X 100 = 75%

e. A 2% chlorine solution is what concentration in mg/L?

- Change the percentage to a decimal

  2% ÷ 100 = 0.02

- Multiply times one million

  0.02 X 1,000,000 = 20,000 mg/L

f. A wastewater plant treats 84,000 gallons per day. 7,560 gallons are removed as sludge. What percentage of plant flow is removed as sludge?

- Divide the part by the whole

$$\frac{7{,}560\text{ gal}}{84{,}000\text{ gal}} = 0.09$$

- Change the value to a percentage

  0.09 X 100 = 9%

g. The average day winter flow of a community is 14,500 gallons. If the summer flow is estimated to be 72% greater than the winter, what is the estimated summer flow?

- Change the percent to a decimal

  72% ÷ 100 = 0.72

- Add this value to 1

  1 + 0.72 = 1.72

- Multiply the demand times this value

  14,500 gal X 1.72 = 24,940 gal

h. The city manager has informed the plant operator that 36% of the $5,700.00 budget has been spent. How many dollars are left for the remaining 7 months of the budget year?

$$\text{Percent} = \frac{\text{Part}}{\text{Whole}} \text{ X } 100$$

$$36\% = \frac{\text{Part}}{\$5{,}700.00} \text{ X } 100$$

$$\frac{\$5{,}700.00 \text{ X } 36\%}{100} = \$2052.00$$

$5,700.00 - $2052.00 = $3648.00

Efficiency - Practice Problems

a. The BOD of the raw influent is 260 mg/L, the final BOD of the plant is 26 mg/L. What is the percentage of BOD removal?

$$\frac{(260\text{ mg/L} - 26\text{ mg/L})}{260\text{ mg/L}} \text{ X } 100 = 90\%$$

b. The TSS of the raw sewage is 460 mg/L. The effluent of the primary clarifier is 320 mg/L. The final effluent is 24 mg/L. What is the percent removal of TSS in the primary portion of the plant?

$$\frac{(460\text{ mg/L} - 320\text{ mg/L})}{460\text{ mg/L}} \text{ X } 100 = 30.4\%$$

c. The raw influent BOD in St. Mary's is 380 mg/L. The final effluent is 31 mg/L. What is the percent removal?

$$\frac{(380\text{ mg/L} - 31\text{ mg/L})}{380\text{ mg/L}} \text{ X } 100 = 91.8\%$$

d. The efficiency of a pump is determined to be 75%. The efficiency of the motor is estimated at 94%. What is the efficiency of the lift station?

0.75 X 0.94 = 0.705 X 100 = 70.5%

e. The water horsepower of a lift station with a submersible pump has been calculated at 8.2 WHp. The Output of the electric motor is measured as 10.3 BHp. What is the efficiency of the pump?

$$\frac{8.2\text{ WHp}}{10.3\text{ BHp}} \text{ X } 100 = 79.6\%$$

Conversion - Practice Problems

Convert the following

a. 750 ft^3 of wastewater to gallons

$$750\,\frac{ft^3}{1} \times \text{-----------------}\frac{?}{ft^3} =$$

$$750\,\frac{ft^3}{1} \times \text{-----------------}\frac{gal}{ft^3} =$$

$$750\,\frac{ft^3}{1} \times \frac{7.48\,gal}{ft^3} = 5{,}610\,gal$$

b. 50 gallons to pounds

$$50\,\frac{gal}{1} \times \text{-----------}\frac{?}{gal} =$$

$$50\,\frac{gal}{1} \times \text{-----------}\frac{lbs}{gal} =$$

$$50\,\frac{gal}{1} \times \frac{8.34\,lbs}{gal} = 417\,lbs$$

c. 560 gpm to cfs

$$560\,\frac{gpm}{1} \times \text{------------}\frac{?}{gpm} =$$

$$560\,\frac{gpm}{1} \times \text{------------}\frac{cfs}{gpm} =$$

$$560\,\frac{gpm}{1} \times \frac{1\,cfs}{448\,gpm} = 1.25\,cfs$$

d. 4 lbs to ounces

$$4\,\frac{lbs}{1} \times \text{-------------}\frac{?}{lbs} =$$

$$4\,\frac{lbs}{1} \times \text{------------}\frac{oz}{lbs} =$$

$$4\,\frac{lbs}{1} \times \frac{16\,oz}{lbs} = 64\,oz$$

e. 128 ft^3 of wastewater to weight in pounds

$$128 \frac{ft^3}{1} \text{ X } \frac{?}{ft^3} =$$

$$128 \frac{ft^3}{1} \text{ X } \frac{lbs}{ft^3} =$$

$$128 \frac{ft^3}{1} \text{ X } \frac{62.4 \text{ lbs}}{ft^3} = 7{,}987 \text{ lbs}$$

f. 340 in^2 to ft^2

$$340 \frac{in^2}{1} \text{ X } \frac{?}{in^2} =$$

$$340 \frac{in^2}{1} \text{ X } \frac{ft^2}{in^2} =$$

$$340 \frac{in^2}{1} \text{ X } \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 2.4 \text{ ft}^2$$

g. 3.4 cfs to gpm

$$3.4 \frac{cfs}{1} \text{ X } \frac{448 \text{ gpm}}{1 \text{ cfs}} = 1{,}523 \text{ gpm}$$

h. 65 ft^3 to yd^3

$$65 \frac{ft^3}{1} \text{ X } \frac{1 \text{ yd}^3}{27 \text{ ft}^3} = 2.4 \text{ yd}^3$$

i. 3,000 gallons to ft^3

$$3{,}000 \frac{gal}{1} \text{ X } \frac{1 \text{ ft}^3}{7.48 \text{ gal}} = 401 \text{ ft}^3$$

j. 250,000 gallons to MG

$$250{,}000 \frac{gal}{1} \text{ X } \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 0.25 \text{ MG}$$

k. 75 gpm to MGD

75 gpm X 1440 min/day = 108,000 dpd

$$108{,}000\,\frac{\text{gpd}}{1}\ \text{X}\ \frac{1\,\text{MGD}}{1{,}000{,}000\,\text{gpd}} = 0.108\,\text{MGD}$$

l. 8 inches to feet

$$8\,\frac{\text{in}}{1}\ \text{X}\ \frac{1\,\text{ft}}{12\,\text{in}} = 0.667\,\text{ft}$$

m. 2.4 MGD to cfs

$$2.4\,\frac{\text{MGD}}{1}\ \text{X}\ \frac{1{,}000{,}000\,\text{gpd}}{1\,\text{MGD}} = 2{,}400{,}000\,\text{gpd}$$

$$2{,}400{,}000\,\frac{\text{gal}}{\text{day}}\ \text{X}\ \frac{1\,\text{day}}{1440\,\text{min}} = 1{,}667\,\text{gpm}$$

$$1{,}667\,\frac{\text{gpm}}{1}\ \text{X}\ \frac{1\,\text{cfs}}{448\,\text{gpm}} = 3.7\,\text{cfs}$$

n. 2.4 MGD to gpm

$$2.4\,\frac{\text{MGD}}{1}\ \text{X}\ \frac{694.5\,\text{gpm}}{1\,\text{MGD}} = 1666.8\,\text{gpm}$$

o. 65 pints to gallons

$$65\,\frac{\text{pnt}}{1}\ \text{X}\ \frac{1\,\text{gal}}{8\,\text{pnt}} = 8.125\,\text{gal}$$

p. 2.5 ft^2 to square inches

$$2.5\,\frac{\text{ft}^2}{1}\ \text{X}\ \frac{144\,\text{in}^2}{1\,\text{ft}^2} = 360\,\text{in}^2$$

q. 7 yards to feet

$$7\,\frac{\text{yd}}{1}\ \text{X}\ \frac{3\,\text{ft}}{1\,\text{yd}} = 21\,\text{ft}$$

r. 36,000 gpd to gpm

$$36{,}000\,\frac{\text{gpd}}{1}\ \text{X}\ \frac{\text{gpm}}{1440\,\text{gpd}} = 25\,\text{gpm}$$

s. 125 gpm to gph

125 gpm X 60 min/hr = 7,500 gph

Temperature Conversion - Practice Problems

a. Change 212°F to °C

$$°F = \frac{°C - 32}{1.8} = \frac{212°F - 32°F}{1.8} = 100°C$$

b. Change 70 °F to °C

$$°C = \frac{70°F - 32°F}{1.8} = 21\ °C$$

c. Change 140 °F to °C

$$°C = \frac{140°F - 32°F}{1.8} = 60°C$$

d. Change 20 °C to °F

°F = °C X 1.8 + 32°

°F = 20°C X 1.8 + 32°F

°F = 68°F

e. Change 85 °C to °F

°F = °C X 1.8 + 32°

°F = 85°C X 1.8 + 32°F

°F = 185°F

f. Change 4 °C to °F

°F = °C X 1.8 + 32°

°F = 4°C X 1.8 + 32°F

°F = 39°F

Pressure/Head - Practice Problems

Make the following conversions:

a. Convert a pressure of 45 psi to feet of head

$$45\frac{\text{psi}}{1} \text{ X } \frac{1\text{ ft}}{0.433\text{ psi}} = 103.9\text{ ft}$$

b. Convert 12 psi to feet

$$12\frac{\text{psi}}{1} \text{ X } \frac{1\text{ ft}}{0.433\text{ psi}} = 27.7\text{ ft}$$

c. Convert 85 psi to feet

$$85\frac{\text{psi}}{1} \text{ X } \frac{1\text{ ft}}{0.433\text{ psi}} = 196.3\text{ feet}$$

d. It is 112 feet in elevation between the top of the reservoir and the watering point. What will the static pressure be at the watering point.

$$112\frac{\text{ft}}{1} \text{ X } \frac{0.433\text{ psi}}{1\text{ ft}} = 48.5\text{ psi}$$

e. A reservoir is 20 feet deep. What will the pressure be at the bottom of the reservoir.

$$20\frac{\text{ft}}{1} \text{X} \frac{0.433\text{ psi}}{1\text{ ft}} = 8.7\text{ psi}$$

Flow - Practice Problems

a. Find the flow in MGD when the flow is 34,000 gpd

$$\frac{34{,}000 \text{ gpd}}{1{,}000{,}000} = 0.034 \text{ MGD}$$

b. Find the flow in gpm when the total flow for the day is 65,000 gpd

$$\frac{65{,}000 \text{ gpd}}{1{,}440 \text{ min/day}} = 45 \text{ gpm}$$

c. Find the flow in gpm when the flow is 1.3 cfs

$$1.3 \; \frac{\text{cfs}}{1} \; \text{X} \; \frac{448 \text{ gpm}}{1 \text{ cfs}} = 582 \text{ gpm}$$

d. Find the flow in gpm when the flow is 0.25 cfs

$$0.25 \frac{\text{cfs}}{1} \; \text{X} \frac{448 \text{ gpm}}{1 \text{ cfs}} = 112 \text{ gpm}$$

e. Find the flow in a 4 inch pipe when the velocity is 1.5 feet per second.

• The diameter of the pipe is 4 inches. Therefore the radius is 2 inches. Convert the 2 inches to feet.

$$\frac{2}{12} = 0.1667 \text{ ft}$$

$A = \pi r^2$

$A = \pi (0.167 \text{ ft})^2$

$A = \pi \text{ X } 0.028 \text{ ft}^2$

$A = 0.09 \text{ ft}^2$

$Q = VA$

$Q = 1.5 \text{ ft/sec X } 0.09 \text{ ft}^2$

$Q = 0.14 \text{ cfs}$

Detention Time - Practice Problems

a. How long will it take to fill a 50 gallon hypochlorite tank if the flow is 5 gpm

$$\frac{50\,\text{gal}}{5\,\text{gal/min}} = 10\,\text{min}$$

b. Find the detention time in a 45,000 gallon reservoir if the flow rate is 85 gpm.

$$\text{D.T.} = \frac{45{,}000\,\text{gal}}{85\,\text{gal/min}} = 529\,\text{min} \text{ or } \frac{529\,\text{min}}{60\,\text{min/hr}} = 8.8\,\text{hrs}$$

c. If the fuel consumption to the boiler is 35 gallons per day. How many days will the 500 gallon tank last before it runs out of fuel?

$$\text{Days} = \frac{500\,\text{gal}}{35\,\text{gal/day}} = 14.3\,\text{days}$$

d. The secondary clarifier contains 5,775 gallons. What is the detention time if the flow is 175 gpm.

$$\text{D.T.} = \frac{5{,}775\,\text{gal}}{175\,\text{gal/min}} = 33\,\text{min}$$

Ratio & Proportion - Practice Problems

a. It takes 6 gallons of chlorine solution to obtain a proper residual when the flow is 45,000 gpd. How many gallons will it take when the flow is 62,000 gpd?

$$\frac{6\,\text{gallons}}{X\,\text{gallons}} : \frac{45{,}000\,\text{gpd}}{62{,}000\,\text{gpd}}$$

(X gallons) (45,000 gpd) = (6 gallons) (62,000 gpd)

$$X\,\text{gal} = \frac{(6\,\text{gal})\,(62{,}000\,\text{gpd})}{45{,}000\,\text{gpd}} = 8.3\,\text{gal}$$

b. A motor is rated at 41 amps average draw per leg at 30 Hp. What is the actual Hp when the draw is 36 amps?

$$\frac{41\,\text{amps}}{36\,\text{amps}} : \frac{30\,\text{Hp}}{X\,\text{Hp}}$$

(41 amps) (X Hp) = (36 amps) (30 Hp)

$$X\,\text{Hp} = \frac{(36\,\text{amps})\,(30\,\text{Hp})}{41\,\text{amps}} = 26.3\,\text{Hp}$$

c. If it takes 2 operators 4.5 days to clean an aeration basin, how long will it take three operators to do the same job.

$$\frac{2\,\text{operators}}{3\,\text{operators}} : \frac{X\,\text{days}}{4.5\,\text{days}}$$

(2 operators) (X days) = (3 operators) (4.5 days)

$$X\,\text{days} = \frac{(2\,\text{operators})\,(4.5\,\text{days})}{3\,\text{operators}} = 3\,\text{days}$$

d. If it takes 20 minutes to pump a wet well down with one pump pumping at 125 gpm, then how long will it take if a 200 gpm pump is used?

$$\frac{20\,\text{min}}{X\,\text{min}} : \frac{200\,\text{gpm}}{125\,\text{gpm}}$$

(X min) (200 gpm) = (20 min) (125 gpm)

$$X\,\text{min} = \frac{(20\,\text{min})\,(125\,\text{gpm})}{200\,\text{gpm}} = 12.5\,\text{min}$$

e. It takes 3 hours to clean 400 feet of collection system using a sewer ball. How long will it take to clean 250 feet?

$$\frac{3\,\text{hrs}}{X\,\text{hrs}} : \frac{400\,\text{ft}}{250\,\text{ft}}$$

(X Hrs) (400 ft) = (3 hrs) (250 ft)

$$X\,\text{hrs} = \frac{(3\,\text{hrs})\,(250\,\text{ft})}{400\,\text{ft}} = 1.9\,\text{hrs}$$

f. If it takes 14 cups of HTH to make a 12% solution. Each cup holds 300 grams, how many cups will it take to make a 5% solution?

$$\frac{14\,\text{cups}}{X\,\text{cups}} : \frac{12\%}{5\%}$$

(X cups) (12%) = (14 cups) (5%)

$$X\,\text{cups} = \frac{(14\,\text{cups})\,(5\%)}{12\%} = 5.8\,\text{cups}$$

Pounds - Practice Problems

a. How many pounds of 100% gas chlorine are needed to disinfect a flow of 85,000 gpd at 12 mg/L?

lbs = 0.085 MGD X 8.34 lbs/gal X 12 mg/L

lbs = 8.5 pounds

b. The TSS of the influent of a 3.2 MGD plant is 360 mg/L. How many pounds of TSS are received each day?

lbs = 3.2 MGD X 8.34 lbs/gal X 360 mg/L

lbs = 9,607 pounds

c. The BOD in the influent of a plant is 320 mg/L. The BOD in the final effluent is 18 mg/L. When the flow is 45,000 gpd, how many pounds of BOD are removed?

lbs = 0.045 MGD X 8.34 lbs/gal X (320 mg/L - 18 mg/L)

lbs = 0.045MGD X 8.34 lbs/gal X 302 mg/L

lbs = 113.3 pounds

d. A 40,000 gallon aeration basin has a MLSS of 2800 mg/L. How many pounds of MLSS are under aeration?

lbs = 0.04 MG X 8.34 lbs/gal X 2800 mg/L

lbs = 934 pounds

e. How many pounds of calcium hypochlorite at 67% is needed to disinfect 125,000 gallon per day flow with a dosage of 8 mg/L?

For 100 % chlorine

lbs = 0.125 MGD X 8.34 lbs/gal X 8 mg/L

lbs = 8.34 pounds of 100%

This is the part of the whole.

$$\text{Percent} = \frac{\text{Part}}{\text{Whole}} \text{ X } 100$$

$$67\% = \frac{8.34\text{ lbs}}{\text{Whole}} \text{ X } 100$$

$$\text{Whole} = \frac{8.34\text{ lbs}}{67\%} \text{ X } 100 = 12.45 \text{ pounds}$$

Metric Conversion - Practice Problems

a. Convert 4.2 kg to g

4.2 kg X 1000 g/Kg = 4,200 g

b. Convert 0.5 kg to g

0.5 Kg X 1000 g/Kg = 500 g

c. Convert 4600 g to Kg

$$\frac{4600\,\text{g}}{1000\,\text{g/Kg}} = 4.6\,\text{Kg}$$

d. Convert 3.4 Km to m

3.4 Km X 1000 m/Km = 3,400 m

e. Convert 0.5 Km to m

0.5 Km X 1000 m/Km = 500 m

f. Convert 10,000 m to Km

$$\frac{10{,}000\,\text{m}}{1000\,\text{m/Km}} = 10\,\text{Km}$$

Common abbreviations, Units and Formulas

Abbreviations

cm = centimeters
L = liters
g = grams
ft^2 = square feet
acre foot = one square acre, 1 foot deep
gpm = gallons per minute
MGD = Million Gallons per Day

cc = cubic centimeters
mL = milliliter
mg = milligrams
ft^3 = cubic feet
cfs = cubic feet per second
slope = feet of rise per 100 feet of run

Basic Wastewater Units

1 ft^3 of wastewater weighs 62.4 pounds and contains 7.48 gallons
1 gallon of wastewater weighs 8.34 pounds

Some Common Conversions

Area
1 acre = 43,560 ft^2
1 ft^2 = 144 in^2

Linear Measurements
1" = 2.54 cm
1' = 30.5 cm
1 meter = 100 cm = 3.281 feet = 39.4"
1 yard = 3 feet

Volume
1 gal = 3.78 liters
1 ft^3 = 7.48 gal
1 ft^3 = 62.4 lbs
1 gal = 8.34 lbs
1 L = 1000 mL
1 acre foot = 43,560 cubic feet
1 gal = 8 pint
1 gal = 16 cups
1 pint = 2 cups
1 pound = 16 oz dry wt
1 yd^3= 27 ft^3
1gpm = 1440 gpd

Weight
1 ft^3 of water= 62.4 lbs
1 gal = 8.34 lbs
1 lb = 453.6 grams
1 kg = 1000 g = 2.2 lbs
1 % = 10,000 mg/L

Pressure
1 ft of head = 0.433 psi
1 psi = 2.31 ft of head

Flow
1 cfs = 448 gpm
1 cfs = 0.6463 MGD
1 MGD = 694.5 gpm

Formulas

Perimeter = $L_1 + L_2 + L_3 + L_4$
Area = L X W
Volume = L X W X D
Q = VA

Circumference of Circle = πD
Area of a Circle = πr^2
Volume of a cylinder = H X πr^2
°C = 5/9 (°F - 32°)
°F = (9/5 X°C) + 32

Glossary

Absorption (Ab-SORP-shun) - Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

AC Asbestos Cement - A piping material made from Portland cement, long fiber asbestos and silica sand. The pipe is formed on a spinning anvil and cured in an autoclave. Also referred to as AC pipe and Transite™.

AC Alternating Current - An electric current of constantly changing value which reverses direction of flow at regular intervals.

Acceptable Entry Conditions The conditions that must exist in a permit space to allow entry and to ensure that employees involved with a permit-required confined space entry can safely enter into and work within the space. Acceptable conditions within a permit space must be maintained throughout the period that workers are inside the permit space.

Activated Sludge Process A biological wastewater treatment process which speeds up the decomposition of wastes in the wastewater being treated. Activated sludge is added to wastewater and the mixture (mixed liquor) is aerated and agitated. After some time in the aeration tank, the activated sludge is allowed to settle out by sedimentation and is disposed of (wasted) or reused (returned to the aeration tank) as needed. The remaining wastewater then undergoes more treatment.

Adsorption (add-SORP-shun) - The gathering of a gas, liquid, or dissolved substance on the surface or interface zone of another substance.

Aeration The process of adding air. In wastewater treatment, air is added to freshen wastewater and to keep solids in suspension. With mixtures of wastewater and activated sludge, adding air provides mixing and oxygen for the microorganisms treating the wastewater.

Aeration Basin A basin where raw or settled wastewater is mixed with return sludge and aerated. The same as aeration bay, aerator, or reactor.

Aerobic A condition in which "free" or dissolved oxygen is present in the aquatic environment.

Aerobic Digestion (air-OH-bic) - The process in which wastewater solids, primarily waste activated sludge, are placed in an open tank, and aerobic bacteria and other aerobic microorganisms decompose the solids into water, gases and solids.

Agglomeration — The growing or coming together of small scattered particles into larger flocs or particles which settle rapidly.

Alkalinity — The buffering capacity of wastewater to retard the change in pH by an acid. Alkalinity is composed of bicarbonates, carbonates and hydroxides.

Amperage — (AM-per-age) - The measurement of electron flow.

Anaerobic — A condition in which "free" or dissolved oxygen is not present in the aquatic environment.

Anaerobic Digestion — (AN-air-OH-bik) - Wastewater solids and water (about 5% solids) are placed in a large tank where bacteria decompose the solids in the absence of oxygen. At least two general groups of bacteria act in balance; Saprophytic (acid-forming) bacteria break down complex solids to volatile acids and methane-fermenters breakdown the acids to methane, carbon dioxide and water.

Aquatic — Pertaining to water.

Aquifer — (AK-wuh-fur) - A porous, water-bearing geologic formation.

Arctic Pipe — PVC or HDPE pipe, called the carrier, coated with several inches of high density polyurethane or polystyrene insulation. The outside of the insulation is covered with polyvinyl chloride butyl rubber or 16 gauge corrugated steel or aluminum.

Area — The extent of a surface, measured by the number of squares of equal size it contains.

Atom — The smallest part of an element which still retains the properties of that element.

Average — An arithmetic mean. The value is arrived at by adding the quantities in a series and dividing the total by the number in the series.

Bacteria — Living organisms, microscopic in size, which consist of a single cell. Most bacteria utilize organic matter for their food and produce waste products as the result of their life processes.

Baffle — A flat board or plate, deflector, guide or similar device constructed or placed in flowing water, wastewater, or slurry systems to cause more uniform flow velocities, to absorb energy, and to divert, guide, or agitate liquids.

Barminutor — (bar-mi-NEW-ter) A bar screen of standard design fitted with an electrically-operated shredding device that sweeps vertically up and down the screen cutting up material retained on the screen.

Biodegradable	(BUY-o-dee-GRAD-able) - Organic matter that can be broken down (decomposed) by bacteria to more stable forms which will not create a nuisance or give off foul odors.
Biosolids	A formal name for stabilized sludge from a wastewater treatment plant.
Blockage	When a collection system becomes plugged and the flow backs up, it is said to have a blockage.
Bloodborne Pathogens	Pathogens carried in the blood of a human.
BLT	Blanket Thickness - The depth of the sludge blanket.
BOD	Biochemical (BY-oh-KEM-ih-kul) Oxygen Demand - The quantity of oxygen required by microorganisms when stabilizing decomposable organic matter under aerobic conditions at 20° C.
Brake Horsepower	The output horsepower of an electric motor. The representation of the amount of work that the motor can perform. Providing work of 33,000 foot pounds per minute is equivalent to one horsepower.
Branch Sewer	A sewer that receives wastewater from a relatively small area and discharges into a main sewer serving more than one branch sewer area.
Building Sewer	A gravity, pressure or vacuum flow pipeline connecting a building wastewater collection system to a lateral or branch sewer. The building sewer may begin at the outside of the building's foundation wall or some distance (such as 2 to 10 feet) from the wall, depending on local sewer ordinances.
Calcium Hypochlorite	A dry powder consisting of lime and chlorine combined in such a way that when dissolved in water, it releases active chlorine.
Capital Construction	Projects which consist of the purchase, construction or major rehabilitation/renewal of capital assets.
Cash	Money in the form of currency or checks.
Cave-in	The separation of a mass of soil or rock material from the side of an excavation, or the loss of soil from under a trench shield or support system, and its sudden movement into the excavation, either by falling or sliding, in sufficient quantity so that it could entrap, bury, or otherwise injure and immobilize a person.
CCTV	Closed Circuit Television - used to inspect the interior of pipelines.
Centrifugal Force	The force that when a ball is whirled on a string, pulls the ball outward. On a centrifugal pump, it is the force which throws water from the spinning impeller.

Centrifugal Pump A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, having an inlet and discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.

Cesspool A lined or partially lined excavation or pit for dumping raw household wastewater for natural decomposition and percolation into the soil.

cfs Cubic Feet per Second - A measurement of flow. 1 cfs is equal to 448 gpm.

Chart of Accounts A listing of account numbers and titles used in an accounting system.

Check Valve A special valve with a disc, flap or ball designed in a way so that it opens in the direction of normal flow and is forced shut when flows attempt to go in the reverse or opposite direction of normal flows.

Circumference The perimeter of a circle .

Circumventional A break in a line that travels around the circumference of the pipe. The break does not have to travel the complete circumference.

Cleanout A point of access to a wastewater collection system for insertion of tools, rods or snakes to effect pipeline cleaning.

Close-coupled Pumps End suction centrifugal pumps in which the pump shaft and motor shaft are the same shaft. The pump bearings and motor bearings are also the same. The impeller is attached directly onto the end of the motor shaft.

Coliform Bacteria The coliform group of bacteria is a bacterial indicator of contamination. This group has as one of its primary habitats the intestinal tract of human beings. Coliforms also may be found in the intestinal tract of warm-blooded animals, and in plants, soil, air and the aquatic environment.

Colloidal Any substance in a certain state of fine division in which the particles are less than one micron in diameter.

Combined Chlorine Residual The amount of chlorine available as a combination of chlorine and nitrogen.

Combined Sewer A sewer intended to receive both wastewater and storm or surface water.

Comminutor A device to reduce the size of the solid chunks in wastewater by shredding (comminuting). The shredding action is like many scissors cutting or chopping to shreds all the large influent solids material.

Competent Person	One who is capable of identifying existing and predictable hazards in the surroundings, or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them.
Concentric Manhole Cone	A cone that tapers uniformly from the barrel to the manhole cover ring.
Concentric Reducer	A device used to connect a large pipe to a smaller pipe so that the center lines of both pipes are aligned.
Conductor	A substance, body, device or wire that readily conducts or carries electrical current.
Confined Space	A space that: Is large enough and so configured that an employee can bodily enter and perform assigned work; and has limited or restricted means for entry and exit; and is NOT designed for continuous employee occupancy.
Constituent	The parts of a whole. All of the components of wastewater other than H_2O.
Consumable Inventory	Supplies and materials which will be used up or converted within a year to provide a service. Consumables include chemicals, office supplies, and repair parts.
Contaminant	(Kun-TAM-uh-NAY-ant) - Toxic material, bacteria, or other deleterious agents that make the water unfit for its intended use.
Contamination	(Kun-TAM-uh-NAY-shun) The introduction into water of toxic materials, bacteria, or other deleterious agents that make the water unfit for its intended use.
Cross Sectional Area	The area at right angles to the length of a pipe or basin.
Cross-connection	Any physical arrangement whereby a public water supply is connected, directly or indirectly, with a non-potable or unapproved water supply or system.
Cubic Feet	A measurement of volume in the number of cubes that are 1 foot on a side.
Cylinder	A solid or hollow figure, traced out when a rectangle rotates using one of its sides as the axis of the rotation.
DC	Direct Current - A flow of electrons in a single direction at a constant rate so that the value remains stable.
DCIP	Ductile Cast Iron Pipe - Ductile pipe is made by injecting magnesium into the cast iron during the molding process. The magnesium alters the shape of the carbon structure of the cast iron. This gives the pipe superior beam strength. It will resist high impacts and is more corrosion resistant than gray cast iron.

Debris	(de-BREE) – Any material in wastewater found floating, suspended or moving along the bottom of a sewer.
Decant	The removal by pouring or drawing off the liquid from a vessel in such a way as to not disturb the sediment on the bottom of the container.
Decibel	A unit for measuring relative loudness of sounds, equal to the smallest difference of loudness detectable by the human ear. (The range of sensitivity of the human ear based on this unit is 130 decibels, the average pain threshold, where 1 decibel is the faintest audible sound.)
Degradation	(degg-rah-DAY-shun) - Water Quality - The reduction of the quality of the water. (Chemistry - The conversion of a substance to a simpler compound. For example, the degradation of organic matter to carbon dioxide and water.)
Denitrification	A condition that occurs when nitrite or nitrate ions are reduced to nitrogen gas and bubbles are formed as a result of this process. The bubbles attach to the biological flocs and float the flocs to the surface of the secondary clarifiers. This condition is often the cause of rising sludge observed in secondary clarifiers or gravity thickeners.
Detention Time	The time required to fill a tank at a given flow or the theoretical time required for a given flow of wastewater to pass through a tank.
Diameter	The distance across a circle - A straight line passing through the center of a circle.
Diffuser	A device (porous plate, tube, bag) used to break the air stream from the blower system into fine bubbles in an aeration tank or reactor.
Digester	(dy-JES-tur) - A tank in which sludge is placed to allow sludge digestion to occur. Digestion may occur under anaerobic or aerobic conditions.
Digestion	The biological decomposition of organic matter in sludge, resulting in partial gasification, liquefaction, and mineralization.
Dilution	(Dih-LEW-shun) - The process of making weaker by adding water.
Disbursements	The actual outlay of cash to make payment on an operating expenditure or capital expenditure or to retire debt. Note that the expenditure is the creation of the obligation to pay and the disbursement is the actual payment.
Disinfection	The process used to control pathogenic organisms.

Displacement Pumps	Pumps in which the energy is added to the water periodically and the water is contained in a set volume.
Dissolved Oxygen	Molecular oxygen dissolved in water or wastewater, usually abbreviated DO.
Dissolved Solids	The material in wastewater that will pass through a glass fiber filter and remain in an evaporating dish after evaporation of the water.
Distributor	A rotating mechanism that distributes the wastewater evenly over the surface of a trickling filter or other process unit.
DMR	Discharge Monitoring Report - The form that is used to report effluent quality and quantity to a state agency or EPA.
DOB	Depth of Blanket - The distance from the water surface to the top of the blanket.
Dry Well Lift Station	A lift station composed of two tanks. One tank contains the wastewater and the second tank contains the pumps. Dry well lift stations are used so that the pumps may be dry and in a suction-head condition.
Dynamic	A condition in which there is motion, or the application of force as a result of motion.
Dynamic Pumps	Pumps in which the energy is added to the water continuously and the water is not contained in a set volume.
Eccentric Manhole Cone	A cone that tapers non-uniformly from the barrel to the manhole ring. One side is usually vertical.
Eccentric Reducer	A device used to connect a large pipe to a smaller pipe so that one edge of both pipes is aligned.
Effluent	(EF-lew-unt) - Sewage, water , or other liquid , partially or completely treated, or in its natural state, as the case may be, flowing out of reservoir, basin, or treatment plant, or part thereof.
Electromagnetism	(1) The magnetic force produced by an electric current (2) The science which studies the interrelation of electricity and magnetism.
Electron	A negative charged particle that travels around the nucleus of an atom.
Element	Any of the more than 132 fundamental substances that consist of atoms of only one kind and that singly or in combinations constitute all matter.
EMF	Electromotive Force - The electrical pressure (voltage) which forces an electric current through a conductor.
End Suction Centrifugal Pumps	The most common style of centrifugal pump. The center of the suction line is centered on the impeller eye. End suction centrifugal pumps are further classified as either frame-mounted or close-coupled.

Energy	The ability to do work. Energy can exist in one of several forms, such as heat, light, mechanical, electrical or chemical. Energy can neither be created nor destroyed, but can be transferred from one form to another. Energy also can exist in one of two states - either potential or kinetic.
Environment	(in-VI-row-ment)-The surroundings, material and spiritual influences which affect the growth, development and existence of a living being.
Evaporate	(ee-VAP-o-rate) - The process of conversion of liquid water to water vapor.
Exfiltration	(EX-fill-TRAY-shun) - Liquid waste and liquid carried waste which unintentionally leak out of a sewer pipe system and into the environment.
Extended Aeration	A modification of the activated sludge process that provides for aerobic sludge digestion within the aeration system. The process includes the stabilization of organic matter under aerobic conditions and disposal of the gaseous end products into the air.
F/M Ratio	Food to microorganism ratio. A measure of food provided to bacteria in an aeration tank.
Facultative	In reference to microorganisms - those that can switch from an aerobic to anaerobic or from an anaerobic to an aerobic environment.
Fecal Coliform Bacteria	The Fecal coliform group of bacteria is a bacterial indicator of contamination. This group has as one of its primary habitats the intestinal tract of human beings. Coliforms also may be found in the intestinal tract of other warm-blooded animals. Also called E. Coli or Escherichia Coli
Feces	(Fee-seez) - Dung, excrement of man or animal.
Flights	Scraper boards, made from redwood or other rot-resistant woods or plastic, used to collect and move settled sludge or floating scum.
Flow	To be in constant movement, typically in a single direction. In wastewater this term typically relates to a volume per unit of time-gallons per minute, cubic feet per second, etc.
Flume	An open conduit of wood, masonry, metal, or plastic with a defined constriction that allows the measurement of head. The height of the head can be directly converted to flow based on the shape and size of the flume.
Force	Influence (as a push or pull) that causes motion. Physics - The mass of an object times its acceleration $F = ma$.

Force Account	The use of municipal staff and equipment for the construction, alteration or rehabilitation of buildings and system improvements rather than an outside contractor.
Force Main	A pipe that conveys wastewater under pressure from the discharge side of a pump to a point of gravity flow downstream (usually a manhole).
Frame-mounted Pumps	End suction centrifugal pumps designed so that the pump bearings and pump shaft are independent of the motor. This type of pump requires a coupling between the pump and the motor in order to transfer energy from the motor to the pump.
Free Chlorine Residual	The amount of chlorine available as dissolved gas, hypochlorous acid or hypochlorite ion that is not combined with ammonia or other organic compounds. It is 25 times more powerful than the combined chlorine residual.
Freeboard	The vertical distance from the normal water surface to the top of the confining wall.
Fuse	A safety device used to prevent overloading a circuit. It consists of a short length of conducting metal which melts at a certain temperature and breaks the circuit.
Gases	Of neither definite volume nor shape, they completely fill any container in which they are placed.
Graywater	Wastewater from kitchen sinks, showers and laundry, excluding human toilet wastes.
Grit	The heavy mineral material present in wastewater, such as sand, eggshells, gravel, and cinders.
Grit Removal	Accomplished by providing an enlarged channel or chamber which causes the flow velocity to be reduced and allows the heavier grit to settle to the bottom of the channel where it can be removed.
HDPE	High Density Polyethylene pipe - HDPE is manufactured using a heat extrusion process and polyethylene resins.
Head	The measure of the pressure of water expressed as height of water in feet - 1 psi = 2.31 feet of head.
Headloss	The loss of energy, commonly expressed in feet, as a result of friction. The loss is actually a transfer to heat.
Heater	A device designed for overload protection of electric motors. The device is heat sensitive and is placed in the power circuit with an electrical connection to the control circuit.
Hertz	The frequency at which a cycle repeats within one second. For instance, a repeat of a cycle at a rate of 60 times per second is called 60 Hertz.

Horsepower A measurement of work, 33,000 foot pounds per minute of work is 1 horsepower.

HVC High Velocity Cleaner - A machine designed to remove grease and debris from the interior of sewer lines with jets of high velocity water.

Hydraulic Loading Refers to the flows (MGD or cu m/day) to a treatment plant or treatment process. Detention times, surface loading and weir overflow rates are directly influenced by flows.

Hydrologic Cycle (HY-druh-LOJ-ik SY-kul) - Nature's method of continuously recycling between the earth and atmosphere the earth's limited water supply, making it possible to use this water over and over again.

Hydrosphere (HY-druh-sfer) - All of the water on the earth.

Hypochlorite (HY-po-KLOR-yt) - Compounds containing chlorine that are used for disinfection. They are available as liquids or solids, in barrels, drums and cans.

Hypochlorite Ion An ion that results from the reaction of chlorine gas and water. Hypochlorite ion (OCl-) along with hypochlorous acid are called free chlorine residual. However, the hypochlorite ion is not as powerful a disinfectant as hypochlorous acid.

Hypochlorous Acid An unstable, strongly oxidizing but weak acid (HOCl) obtained in solution along with hydrochloric acid by reaction of chlorine with water.

Impeller A rotating set of vanes designed to impart rotation to a mass of fluid.

Inert A material that will not react with any other material.

Inertia The tendency of matter to remain at rest or in motion.

Infiltration (In-fil-TRAY-shun) - The initial movement of water from the earths surface into the soil.

Infiltration (In-fil-TRAY-shun) - The water entering a sewer system, including service connections, from the ground, through such means as, but not limited to, defective pipes, pipe joints, connections or manhole walls.

Inflow The water discharged into a sewer system and service connections from such sources as, but not limited to, roof drains, cellar drains, yard and area drains, foundation drains, cooling water discharges, drains from springs, and swamps, and around manhole covers or through holes in the covers, cross-connections from storm and combined sewer systems, catch basins, storm waters, surface runoff, street wash waters or drainage.

Influent	(IN-flew-unt) - Sewage, water, or other liquid, raw or partly treated, flowing into a treatment plant or part thereof.
Inorganic	Chemical substances of mineral origin.
Insulator	A substance, body, or device that prevents the flow of electrical current.
Land Application	The disposal of stabilized sludge onto or under the surface of the land. Commonly, this process requires placing the sludge a few inches below the surface with specially designed trucks.
Lateral Sewer	A sewer that discharges into a branch or other sewer and has no other common sewer tributary to it. Sometimes called a side sewer.
Lift Station	A wastewater pumping station that lifts the wastewater to a higher elevation. Also called a pump station.
Lithosphere	(LITH-o-sfer) - The solid crust of the earth. It consists of the thin, loose layer known as soil and the mass of hard rock, several miles in thickness, upon which soil lies.
Lockout/Tagout	A process of physically locking and tagging hazardous energy sources to prevent energizing during maintenance.
Longitudinal	Cracks or breaks that run the direction of the length of the pipe.
Magnetic Breaker	An electrically operated mechanical device used for overcurrent protection.
Magnetic Starter	An electrically operated mechanical switch used to connect power to an electric motor.
Main Sewer	A sewer line that receives wastewater from many tributary branches and sewer lines and serves as an outlet for a large territory.
Maintenance Management	A systematic process of planning, organizing, scheduling and controlling preventive and repair maintenance in order to provide a defined level of service at a specific cost.
Manhole	An opening in a sewer provided for the purpose of permitting workers or equipment to enter or leave a sewer.
Master Plan	A long-range plan for a municipal service, facility or utility which 1) Identifies the municipality's growth management, development and financing policies and outlines the communities needs and desired service levels; 2) Identifies the constraints and advantages presented by the physical environment and existing patterns of development; 3) Details all federal, state and local design standards for the service, facility or

	utility; 4) Assesses the condition of any relevant physical plant, the quality of operations and maintenance and the current financial position ; and 5) Develops a strategy tying together needs, constraints, local government policies and design standards, state and federal standards, operational improvements, long-term capital improvements and long-term financing.
Mechanical Seal	A mechanical device used to control leakage from the stuffing box of a pump. Usually made of two flat surfaces, one of which rotates on the shaft. The two flat surfaces are of such close tolerances as to prevent the passage of water between them.
mg/L	Milligrams per liter. A unit of the concentration of a constituent in wastewater. It is 0.001g of the constituent in 1,000 mL of wastewater. mg/L has replaced the PPM (parts per million) in reporting results in wastewater.
MGD	Million Gallons per Day. A unit of flow and a unit of volume.
Microorganisms	Minute organisms, either plant or animal, invisible or barely visible to the naked eye.
Microscreen	A device with a fabric straining media with openings usually between 20 and 60 microns. The fabric is wrapped around the outside of a rotating drum. Wastewater enters the open end of the drum and flows out through the rotating screen cloth. At the highest point of the drum the collected solids are backwashed by high pressure water jets into a trough located within the drum.
Mixed Liquor	When the activated sludge in the aeration tank is mixed with primary effluent or the raw wastewater and return sludge, this mixture is then referred to as mixed liquor as long as it is in the aeration tank. Mixed liquor also may refer to the contents of mixed aerobic or anaerobic digesters.
MLSS	Mixed Liquor Suspended Solids - The suspended solids content of the mixed liquor of an activated sludge facility.
MLVSS	Mixed liquor volatile suspended solids - The organic or volatile suspended solids in the mixed liquor of an aeration tank.
MSDS	Material Safety Data Sheet - Written material produced by the chemical manufacturer describing properties and safe handling procedures.
NIST	National Institute of Standards and Technology, formally the National Bureau of Standards

Neutron	A neutral charged particle in the nucleus of an atom. This particle has the same weight as a proton, an atomic weight of 1.
NFR	National Fire Rating System - This system provides the users of chemicals with a four diamond placard that indicates the health concern, flammability, and reactivity levels of the chemical.
Nitrification	A process in which bacteria change the ammonia and organic nitrogen in wastewater into oxidized nitrogen (usually nitrate). The second-stage BOD is sometimes referred to as the “nitrification stage”.
Non-code Ordinance	An ordinance which is not part of the permanent code of ordinances. Examples of non-code ordinances include budget ordinances and emergency ordinances.
NPDES	National Pollutant Discharge Elimination System permit is the regulatory agency document designed to control all discharges of pollutants from point sources into U.S. waterways. NPDES permits regulate discharges into navigable waters from all point sources of pollution, including industries, municipal treatment plants, large agricultural feed lots and return irrigation flows.
Organic	Chemical substances of animal or vegetable origin, made basically of carbon structure.
OSHA	Occupational Safety and Health Act - The 1970 federal act requiring the federal government to establish minimum health and safety standards. Also called the Williams-Steiger Act.
Overflow Rate	One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Overflow rate in gpd/ft2 equals flow in gallons/day divided by surface area in square feet.
Oxidation	The addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In wastewater treatment, organic matter is oxidized to more stable substances.
Package Lift Station	A lift station built by a supplier and delivered as a single item to the site. Installation requires digging a hole and connecting the piping and wiring.
Packing	Material made of woven animal, plant, mineral or metal fiber and some type of lubricant, placed in rings around the shaft of a pump and used to control the leakage from the stuffing box.
Pathogenic Organisms	Bacteria, virus and protozoa which can cause disease.
Peak Flow	The maximum design flow of a wastewater treatment plant.

Percolation	(PUR-cuh-LAY-shun) - Movement of water into and through the ground.
Permafrost	(PER-ma-fra-st) - Soil, bedrock or other material that has remained below 0°C for two or more years.
Permit-Required Confined Space	A confined space that has one or more of the following characteristics. Contains or has the potential to contain a hazardous atmosphere. Contains material(s) which have the potential to engulf an entrant. Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor which slopes downward and tapers to a smaller cross-section. Contains any other recognized serious safety or health hazards.
pH	An expression of the intensity of the basic or acidic strength of a water. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion concentration. pH may range from 0 to 14, where 0 is the most acid, 14 most alkaline, and 7 neutral.
Photosynthesis	(foto-SIN-the-sis) - A process in which organisms with the aid of chlorophyll (green plant enzyme) convert carbon dioxide and inorganic substances to oxygen and additional plant material, utilizing sunlight for energy.
pi	Greek letter (≠) used as a symbol denoting the ratio of the circumference of a circle to its diameter
Pin Floc	Very small compact floc, usually less than 1/32" in diameter, may be observed suspended throughout moderately turbid final clarifier supernatant.
Pit Toilet	A toilet constructed by digging a pit in the ground and placing a small building over the pit. Also called an out house.
Plug Valve	A valve consisting of a body and tapered movable closure which is held in place by force from the bonnet. The closure contains an oblong opening that when open provides full flow with little or no restriction. Opening or closing the valve requires 1/4 turn.
Pollution	(puh-LEW-shun) - A condition created by the presence of harmful or objectionable material in water.
Precipitation	The process by which atmospheric moisture is discharged onto the earths crust. Precipitation takes the form of rain, snow, hail and sleet.
Preliminary Treatment	The process of grinding material that can clog equipment, removing rags with screens and the removal of grit. Preliminary treatment is commonly a part of primary treatment.

Pressure	The force exerted on a unit area. Pressure = Weight X Height. In water, it is usually measured in psi (pounds per square inch). One foot of water exerts a pressure of 0.433 pounds per square inch.
Primary Treatment	The first major (sometimes the only) treatment in a sewage treatment works. This process takes place in a rectangular or circular tank and allows those substances in wastewater that readily settle or float to be separated from the water being treated.
Privies	Another name for a pit toilet.
Proton	A positive charged particle in the nucleus of an atom. They have an atomic weight of 1 and an atomic charge of plus 1.
Protozoa	A small one-celled animal including, but not limited to, amoebae, ciliates, and flagellates.
PVC	Polyvinyl Chloride - A piping material used to make plastic pipe. The manufacturing process uses an extruding mold to form a continuous pipe that is cut into the desired lengths.
QA/QC	Quality Assurance - Quality Control - The formal process of assuring the laboratory is performing testing in the most accurate and precise manner possible in order to comply with specified regulations.
R & R	Renewal and Replacement. A systematic process or budgeting for the repair and replacement of equipment that either requires a significant annual repair cost or has a life expectancy of less than ten years.
Radius	A line from the center of a circle or sphere to the circumference of the circle or surface of the sphere.
Receiving Stream	A stream, river, lake or ocean into which treated or untreated wastewater is discharged.
Receiving Water	A stream, river, lake or ocean into which treated or untreated wastewater is discharged.
Rectangle	A 4-sided figure with 4 right angles.
Resistance	The opposition offered to the flow of electrical current. Usually measured as Ohm's.
Resolutions	An official opinion or statement of the policy-making body on a particular subject. A resolution is a formal, written expression adopted by the policy-making body at a public meeting. Common uses of a resolution are to voice support for a project or issue, call attention to a problem affecting the community, or direct the administration to do something.
Resources	The people, time, money, information and physical facilities necessary to accomplish the goal of providing safe potable water to the community

Return Activated Sludge The settled mixed liquor that is collected in the clarifier underflow and returned to the aeration basin.

Runoff Water that is the result of precipitation which is flowing over the earth's surface to rivers, streams, lakes and oceans.

Sanitary Sewer A sewer that carries water and water carried waste from residences, commercial buildings, industrial plants, and institutions, together with minor quantities of ground, storm, and surface water that are not admitted intentionally.

Screenings Relatively coarse floating and suspended solids removed from wastewater by straining through racks or screens.

Scum A mass of sewage matter which floats on the surface of sewage.

Seal Water The water supplied to the stuffing box to lubricate and flush the packing or the mechanical seal.

Secondary Treatment A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated. Usually a biological treatment process.

Septic This condition is produced by anaerobic bacteria. If severe, the wastewater turns black, gives off foul odors, contains little or no dissolved oxygen and creates a heavy oxygen demand.

Sewage Largely the water supply of a community after it has been contaminated by various uses.

Shield A structure that is able to withstand the forces imposed on it by a cave-in and thereby protect employees within the structures.

Shock Load The arrival at a plant of a waste which is toxic to organisms in sufficient quantity or strength to cause operating problems. Possible problems include odors and sloughing off of the growth or slime on the trickling-filter media. Organic or hydraulic overloads also can cause a shock load.

Shoring A structure such as metal hydraulic, mechanical or timber shoring system that supports the sides of an excavation and which is designed to prevent cave-ins.

Short Circuiting A condition that occurs in tanks or ponds when some of the wastewater travels faster than the rest of the flowing wastewater.

Shroud The front and /or back of an impeller.

Sidestream	Wastewater flows that develop from other storage or treatment facilities. This wastewater may or may not need additional treatment. For instance the water from a belt press that is piped back to the front of the plant is called a sidestream.
Single Phase Power	A circuit or generator in which only one alternating current is produced.
Sloping	A method of protecting employees from cave-ins by excavating to form sides of an excavation that are inclined away from the excavation so as to prevent cave-ins.
Sloughings	Trickling-filter slimes that have been washed off the filter media. They are generally quite high in BOD and will lower effluent quality unless removed.
Sludge	(SLUJ) - The accumulated settled solids deposited from sewage or industrial wastes, raw or treated, in tanks or basins, and containing more or less water to form a semi-liquid mass.
Sludge Age	A measure of the length of time a particle of suspended solids has been undergoing aeration in the activated sludge process.
Sludge Blanket	That portion of the clarifier containing sludge.
Sodium Hypochlorite	A water solution of sodium hydroxide and chlorine, in which sodium hypochlorite is the essential ingredient.
Solids	As it pertains to wastewater - Suspended and dissolved material in wastewater.
Soluble	Capable of being dissolved.
Specific Gravity	The weight of a substance in relation to the weight of an equal volume of water at a set temperature. Water at 4°C has a specific gravity of 1.0. Particles found in wastewater have a specific gravity between 0.8 and 2.6.
Split Case Pumps	A centrifugal pump designed so that the volute case is split horizontally. The case divides on a plane that cuts though the eye of the impeller.
Stabilization	The process of converting a material to a form that resists change. Organic material is stabilized by bacteria which converts the material to gases and other relatively inert substances. Stabilized organic material generally will not give off obnoxious odors.
Staff Gauge	A vertical graduated scale placed on a wood or metal plate, used to determine the height of fluid above a specified point.
Static	A non-moving condition.
Stoppage	Another name for a blockage. When a sewer system or sewer becomes plugged and the flow backs up, it is said to have a stoppage.

Storm Sewer	A sewer that carries storm water and surface water, street wash and other wash waters, or drainage, but excludes domestic wastewater and industrial wastes.
Straggler Floc	At times, small, almost transparent, very light fluffy, buoyant sludge particles (1/8 to 1/4 inch in diameter) may rise to the clarifier surface near the outlet weirs.
Stuffing Box	That portion of the pump which houses the packing or mechanical seal. Usually referred to as the dry portion of the pump, the stuffing box is located in back of the impeller and around the shaft.
Suction Head	A pumping condition where the eye of the impeller of the pump is below the surface of the water from which the pump is pumping.
Suction Lift	A pumping condition where the eye of the impeller of the pump is above the surface of the water from which the pump is pumping.
Supernatant	(SEW-pur-NAYT-unt) - The liquid in a digestor that lies between the sludge at the bottom and the top of the scum on the top of the tank.
Surcharge	Sewers are surcharged when the surface of the wastewater in manholes is above the top of the sewer pipe. The sewer is then placed under pressure rather than being at atmospheric pressure. This condition contributes to exfiltration and the backup of sewage into individual homes.
Suspended Solids	The quantity of material deposited when a quantity of water, sewage or other liquid is filtered through a glass fiber filter.
SVI	Sludge Volume Index - The volume in milliliters occupied by one gram of activated sludge after settling for thirty minutes.
Symbiosis	The living together or close association of two dissimilar organisms with mutual benefit.
Tertiary Treatment	(TER-she-AIR-ee) - Any process of water renovation that upgrades treated wastewater to meet specific reuse requirements. May include general cleanup of water or removal of specific parts of wastes insufficiently removed by conventional treatment processes. Typical processes include chemical treatment and pressure filtration.
Three Phase Power	A circuit or generator in which three power sources 120° out of phase with each other are produced.
Total Chlorine Residual	The sum of the combined and free chlorine residuals.

Total Dynamic Head	The total energy needed to move water from the center line of a pump (eye of the first impeller of a lineshaft turbine) to some given elevation or to develop some given pressure. This includes the static head, velocity head and the headloss due to friction.
Topography	A description of the surface features of the land.
Total Solids	The solids in water, sewage, or other liquids. They include the suspended solids (largely removable by a filter) and filterable solids (those which pass through the filter).
Transpiration	(TRAN-spur-RAY-shun) - The process by which water vapor is lost to the atmosphere from living plants.
Trench	A narrow excavation made below the surface of the ground. In general, the depth is greater than the width, but the width of a trench is not greater than 15 feet.
Trickling Filter	A treatment process in which the wastewater trickles over media that provide the opportunity for the formation of slimes or biomass which contain organisms that feed upon and remove wastes from the water treated.
TSS	Total Suspended Solids - The quantity of material deposited when a quantity of water, sewage, or other liquid is filtered through a glass fiber filter.
Turbidity	A condition in wastewater caused by the presence of suspended matter, resulting in the scattering and absorption of light rays.
Vector	An agent who transmits pathogenic organisms from one organism to another. In a sewer this includes birds, mice, rats, flies and other insects.
Velocity	The speed at which wastewater moves, expressed in feet per second.
Velocity Head	The amount of energy required to bring a fluid from a standstill to its velocity. For a given quantity of flow, the velocity head will vary indirectly with the pipe diameter.
Vertical Turbine Pumps	A classification of centrifugal pumps that are primarily mounted with a vertical shaft; the motor is commonly mounted above the pump. Vertical turbine pumps are either mixed or axial flow devices.
Virus	A submicroscopic organism which passes through filters which will strain out bacteria.
Visioning	A formal process of identifying community and economic development concerns using a community forum technique.

Vitrified Clay Pipe A piping material made from clay and shale. The mixture is extruded through a die to form a pipe section. Each section is allowed to dry and then fired in a kiln.

Voltage The measurement of EMF between two points.

Volume The amount of space occupied by or contained in an object. Measured by the number of cubes, each with an edge 1 unit long that can be contained in the object

Volute The spiral shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

Waste Activated Sludge The excess growth of microorganisms which must be removed to keep the biological system in balance.

Wastewater The used water and solids from a community that flow to a treatment plant or receiving stream.

Waterborne Disease A disease caused by organisms or toxic substances which are carried by wastewater. The most common waterborne diseases are typhoid fever, Asiatic Cholera, Dysentery, and other intestinal disturbances.

Waterborne Pathogens Bacteria, virus and protozoa which cause disease and are carried by wastewater.

Weir A vertical obstruction, such as a wall, or plate, placed in an open channel and calibrated in order that. 1) a depth of flow over the weir (head) can easily be measured and converted into flow in cfs, gpm or MGD, 2) velocity through the channel can be controlled.

Wet Well Lift Station A lift station in which there is a single tank. Pumps can be installed in a wet well lift station in either a suction lift or suction head condition.

Zoogleal Film A complex population of organisms that form a “slime growth” on the trickling filter media and break down the organic matter in wastewater. These slimes consist of living organisms feeding on the wastes in wastewater, dead organisms, silt, and other debris.

Common Abbreviations, Units and Formulas

Abbreviations

cm = centimeters
L = liters
g = grams
ft^2 = square feet
acre foot = one square acre, 1 foot deep
gpm = gallons per minute
MGD = Million Gallons per Day

cc = cubic centimeters
mL = milliliter
mg = milligrams
ft^3 = cubic feet
cfs = cubic feet per second
slope = feet of rise per 100 feet of run

Basic Wastewater Units

1 ft^3 of wastewater weighs 62.4 pounds and contains 7.48 gallons
1 gallon of wastewater weighs 8.34 pounds

Some Common Conversions

Area
1 acre = 43,560 ft^2
1 ft^2 = 144 in^2

Linear Measurements
1" = 2.54 cm
1' = 30.5 cm
1 meter = 100 cm = 3.281 feet = 39.4"
1 yard = 3 feet

Volume
1 gal = 3.78 liters
1 ft^3 = 7.48 gal
1 ft^3 = 62.4 lbs
1 gal = 8.34 lbs
1 L = 1000 mL
1 acre foot = 43,560 cubic feet
1 gal = 8 pint
1 gal = 16 cups
1 pint = 2 cups
1 pound = 16 oz dry wt
1 yd^3= 27 ft^3
1gpm = 1440 gpd

Weight
1 ft^3 of water= 62.4 lbs
1 gal = 8.34 lbs
1 lb = 453.6 grams
1 kg = 1000 g = 2.2 lbs
1 % = 10,000 mg/L

Pressure
1 ft of head = 0.433 psi
1 psi = 2.31 ft of head

Flow
1 cfs = 448 gpm
1 cfs = 0.6463 MGD
1 MGD = 694.5 gpm

Formulas

Perimeter = $L_1 + L_2 + L_3 + L_4$
Area = L X W
Volume = L X W X D
Q = VA

Circumference of Circle = ≠D
Area of a Circle = ≠ r^2
Volume of a cylinder = H X ≠r^2
°C = 5/9 (°F - 32°)
°F = (9/5 X°C) + 32