Wastewater Treatment & Disposal I

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Version 1

Photo by the U.S. Air Force

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Chapter 1: Basic Overview/Introduction to Wastewater Treatment

Learning Outcomes:

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- Describe and construct the urban water cycle
- Analyze wastewater origins and how it is conveyed
- Differentiate between residential and industrial/commercial wastewater
- Evaluate the typical job function of a wastewater treatment operator
- Explain the certified wastewater treatment operator licensing requirements

Introduction

Proper wastewater treatment and disposal is essential for the vitality of a functioning society. Without it, a community's environment can be severely polluted and the health of the public is at great risk. To better understand the relationship between wastewater treatment and water treatment and distribution, examine the **urban water cycle** (link). Like the typical **hydrologic cycle**, which shows the natural movement of water in the environment, the urban water cycle shows how water is moved in an urban environment.

In some cases, as shown is FIG XX, (show detailed picture of typical community water/wastewater infrastructure) wastewater that has been treated by a wastewater treatment plant will be discharged back into a natural water body. Water from that water body will then be used by downstream communities as source water for their water treatment plants. If either of these two treatment facilities are not operating to current regulations and standards, public health is at risk. In addition, if the wastewater treatment facility is not operating properly there can also be additional environmental damage to the water body.

Currently, there is a paradigm shift in water treatment and the line between water, wastewater, and stormwater is becoming thinner and thinner. For example, the use of **reclaimed water** from wastewater treatment plants can be used for various beneficial uses instead of being discharged into a water body. The term **"One Water"** is being used more frequently to encompass the idea that all of these water sources are beneficial and more innovation is needed to use these sources more efficiently. However, the focus of this text book will be on the inner workings of a conventional wastewater treatment plant. The goal is to give you the vocabulary and knowledge needed to understand how wastewater treatment operators can take a contaminated water source and treat it to a level of quality that will not endanger the environment or public health.

The term wastewater has become the common term to describe sewage. In fact, when we talk about conventional wastewater treatment plants we are talking about facilities that take the used water from residences and businesses of a community and clean it up. Wastewater is anything and everything that goes down the drains of these households and businesses. All the water from sinks, garbage disposals, toilets, dishwashers, bathroom drains, and washing machines are considered residential wastewater. There is also commercial or industrial wastewater. Many manufacturing process that use water, typically for washing or cooling purposes, need to properly dispose of this water. In some cases, this wastewater may be treated onsite before it is discharged into the **wastewater collection system**. Some municipalities will require the manufacture to obtain an industrial waste permit that regulates what they are allowed to discharge.

Wastewater Treatment Plant Operators

A wastewater treatment plant operator's main responsibility is to ensure the wastewater treatment facility is being operated and maintained so the wastewater leaving the facility meets the limits of their National Pollutant Discharge Elimination System (NPDES) permit. We will learn the specifics of exactly what an NPDES is in later chapters. Throughout the rest of this book we will look at the main roles and functions that wastewater treatment plant operators do every day.

Licensing Requirements

The State Water Resources Control Board (SWRCB) is the regulatory authority in California for many aspects of water laws and regulations. They are also responsible for overseeing the Operator Certification Program. In California, it is mandatory to be certified by the SWRCB if you are employed in the operation of a water distribution system, water treatment facility, or wastewater treatment plant.

To become certified there are three things that must be accomplish by the individual seeking certification. First, is to obtain the required amount of education for the level of certification. Each vocation has five levels of certification, with grade five being the highest. As the level of certification increases the more education needed. The second requirement is experience. Just like education, the higher certifications require more experience. However, these two requirements work together. The more education one has the less amount of experience needed. Likewise, if one doesn't have a significant amount of education they can still obtain higher certifications by gaining more work experience. The education and experience requirements for the Wastewater Treatment Operator certifications can be found here (link). The final thing is to pass the certification exams which are offered twice a year, in the spring and fall.

Becoming certified as a Wastewater Treatment Operator Grade 1 requires that the applicant has gained one year of work experience. This one year of work experience is one of the hardest hurdles for many people to overcome. Many employers want to hire people that already have certifications, but you can't get certified if you don't have experience. Many wastewater treatment facilities understand this predicament and offer what is called an Operator-In-Training (OIT) position. To obtain a Grade 1 OIT certificate you must have a high school diploma or GED, have six educational points by taking a college level math or science course, and be employed by a wastewater treatment facility. These positions are becoming more competitive and often employers require additional related work experience or additional education. Successfully passing the certification examination can help set you apart from other applicants.

Type of Work

The type of work a wastewater treatment operator is involved in will be varied and depends on a lot of different factors. A common job description will include something along the lines of "to ensure the operation of the treatment facility and ancillary equipment in order to meet effluent requirements". The effluent of a wastewater treatment plant is the water the leaves the facility once it has been treated. To ensure the effluent requirements are met, an operators typical job will include monitoring and logging critical information such as pump pressures and flow rates, tank levels, and water quality parameters such as turbidity and chlorine residual. There is also preventative maintenance that is required. Some tasks could include taking portions of the treatment system offline for cleaning and/or repairs.

Throughout the treatment system water samples will need to be taken and tested for various constituents, either for regulatory compliance or process control. Depending on the facility, the sampling may be done by operators or by laboratory technicians. However, it will most always be the certified operators that will review the laboratory results and determine if any adjustments to the treatment process is needed.

It's important to note that wastewater treatment plants are industrial facilities and some of the work can be very dangerous. Operators can be working with heavy machinery such as forklifts, large pumps, and cranes. There is also high voltage electrical equipment that the operator will interact with on a daily basis. There can be situations where there are high pressure lines and even the possibility to be exposed to harmful chemicals. This book will have a whole section dedicated to covering these safety topics and more.

Jobs

There are many different types of work available in the wastewater treatment industry as a whole. While this text book will focus on the specifics of the job duties of a wastewater treatment operator (WTO), there are many other supporting jobs in both the public and private sector. Most of the WTO positions are available through the public sector. For example, a city will be the owner and operator of a municipal wastewater treatment facility. That city will then employ as many WTOs are necessary to operate the plant. However, there will be many other jobs required to keep the facility running besides the operators. Depending on the size of the plant, there can also be workers skilled in maintenance of pumps and machinery, electricians, and instrumentation technicians. These jobs can also have their own trade certifications that may be required by the employer. In addition, there may be laboratory staff, administration personnel, engineers, managers and financial experts. All of these positions will work together to keep the plant running. But it's important to remember that at the end of the day, it's the certified Wastewater Treatment Operators that can be legally responsible for the quality of water leaving the facility and compliance with the NPDES permit.

There are also many job opportunities in the private sector. There are many **"package plants"** that smaller private industries will operate to treat residual waste from a large scale manufacturing process. A brewery, for example, may need to treat their brewing process wastewater before the water can be disposed of in the municipal sewer system. As of 2013, these privately run wastewater treatment plants require workers that are involved in the operation of the plant to meet the same licensing requirements as publicly operated wastewater treatment plants.

Chapter 2: Wastewater Quality

Learning Outcomes:

- Understand the purpose of NPDES permits
- Explain how TMDLs are obtained and how they improve water quality
- Assess the difference between chemical and physical water quality contaminants
- Describe how different contaminants can effect water bodies

National Pollutant Discharge Elimination System (NPDES) permits

Wastewater treatment plants typically discharge their treated water into a water body that is nearby. Since 1972, with the passage of the Clean Water Act, it is illegal to discharge water from a **point source** into waters of the United States unless an NPDES permit is obtained. Since wastewater treatment facilities have all of their discharge leaving the plant from a single discharge pipe, it is considered a point source. This differs from **nonpoint sources** which have large areas of discharge like runoff from agricultural fields. An NPDES permit allows discharging the treated wastewater into a water body as long as it meets the requirements of the permit. These requirements can include limits on what can be discharged, how frequently samples must be taken, and other reporting requirements. There may also be other requirements specific to the discharger to assure that the water being discharged does not harm public health or the environment.

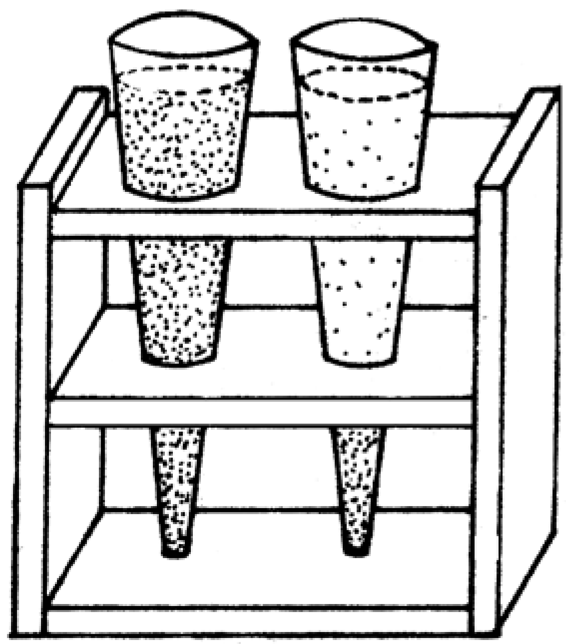
Total Maximum Daily Loads (TMDL)

The total maximum daily load (TMDL) is a calculated value of the maximum amount of a specific pollutant that a water body can receive without negatively impacting that water body. For example, 10,000lbs of pollutant X naturally occurs within a stream that has a TMDL of 50,000lbs for pollutant X and contains three point source discharges. Therefore, an additional 40,000lbs of pollutant X may be discharged into the stream without exceeding the TMDL. It's the job of permit writers to use the TMDLs of a water body and the total number of point source discharges to determine the **waste load allocation** (WLA) for each discharge and incorporate that into the NPDES permit as a limit. To continue with the example, a permit writer could determine that with three point source discharges each one would be allowed to discharge 10,000lbs of pollutant X. This would leave a margin of safety of 10,000lbs. So in theory, the discharge of pollutant X would not negatively impact the water body because the sum of all the discharges and naturally occurring contamination is below the TMDL of the water body.

Wastewater Solids

The solids found in wastewater are comprised of many different constituents including organic and inorganic material. A variety of laboratory tests can be performed to determine the total amount of solids. The **total suspended solids** (TSS) test will determine the total amount of solids that are suspended and that are easily settleable. This test is done by filtering a specific volume of the wastewater through a filter pad. The water and dissolved solids will pass through the filter; and the settleable solids and suspended solids will remain on top of the filter. The difference in weight of the filter before and after filtration is used to calculate the amount of TSS.

While all the solids remaining on the filter after the TSS test are suspended, not all of the solids are settleable. **Settleable solids** can be determined by using an **Imhoff cone**. Again, a specific volume, typically 1,000 mL, is poured into the Imhoff cone and allowed to settle. The settleable solids will collect on the bottom of the Imhoff cone. After an hour, the amount of solids that settled can be determined by the graduations on the Imhoff cone as seen in the figure below.



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The water that filtered through the filter pad during the TSS test still contains solids of contaminants that are dissolved into the water. Collectively this can be determined by completing a **Total Dissolved Solids** (TDS) test. This test takes the water left over from the TSS test and pours it into a pre-weighed dish. The water is then evaporated from the dish and weighed again. The difference in weight is then used to calculate the TDS.

Whether the solids are settleable, suspended, or dissolved, wastewater is generally made up of less than 1% solids. The other 99% is just water. The focus of the remainder of this text will be on treating the 1% of solids in wastewater. The difference in the type of solids will determine what type of treatment process is used. Settleable solids will easily settle during the primary sedimentation process. Suspended solids will require a secondary treatment process. TDS can only be removed by advanced treatment methods like membrane filtration or reverse osmosis. TDS will not be removed by conventional wastewater treatment methods.

Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of how much organic material is in the wastewater. When wastewater with high amounts of BOD is released to a water body, the organic material will consume the dissolved oxygen in the water body. If the BOD exceeds the TMDL of the water body, then the oxygen levels can be completely depleted. Without the dissolved oxygen, fish and other aquatic life will not be able to survive.

The BOD_5 test is completed in a laboratory by taking a sample of wastewater and measuring the dissolved oxygen concentration. The sample is kept in an airtight container in a refrigerator set to a temperature of 25°C. After 5 days, yes, that's why there is a subscript 5 in BOD_5, the dissolved oxygen concentration is measured again. The difference in oxygen concentrations is how much oxygen was consumed by the organic material in the wastewater. The more organic material there is, the higher the BOD_5 will be.

The BOD_5 test is the standard test that is used to measure the organic contamination in wastewater. It is one of the main regulatory components in an NPDES. However, it has one big drawback which is that it takes five days to get results. Another test that gives similar results is the **chemical oxygen demand** (COD). COD will measure the amount of oxygen needed to decompose organic material as well as inorganic chemicals. The difference between COD and BOD_5 is that COD will also measure other chemicals that can be oxidized besides ones that are biological. COD laboratory results can be determined in approximately 6 hours. If a wastewater treatment facility is only treating wastes from a community that is mainly residential and does not have many industrial discharges, then the COD and BOD_5 can be correlated after a significant number of samples are analyzed side by side. BOD_5 is routinely done to meet regulatory requirements while COD results are used for process control to make sure the treatment plant is operating efficiently.

Microbiological Contaminants and Pathogens

There are many different types of microorganisms that can be found in wastewater. Some of these microbes are **pathogenic**. A pathogen is a microorganism that is capable of causing disease. Some common pathogens that can be found in untreated wastewater are Cholera, Giardia, Streptococcus, E. Coli, Cryptosporidium and Salmonella. However, not all microorganisms are pathogenic and some non pathogenic bacteria will actually be utilized as a treatment aide to reduce the amount of BOD_5 in the wastewater.

One classification of microorganisms is a **protozoa**. A protozoa is a single-celled organism and is essential to the biological treatment processes. Amoebae, flagellates, and ciliates are some examples of protozoa commonly found in wastewater samples. **Metazoa** are mutli-celled organisms that can also be found in wastewater treatment facilities. Some examples of metazoa are rotifers, nematodes, tartigrade (waterbear). When we discuss the various biological treatment methods later in this text book, we will learn that a microscopic examination of wastewater samples can show the health of the treatment system by comparing the quantities of protozoa and metazoa organisms.

Viruses can also be detected in wastewater samples. Viruses must have a host organism in order to live and reproduce. Unfortunately, they can remain dormant in water until they find such a host. Hepatitis A and polio are examples of viruses that can be found in wastewater samples. Viruses can be difficult to identify in the laboratory and are not routinely tested for in wastewater samples.

Coliform bacteria is the most common laboratory test done to determine the potential of the presence of pathogenic organisms. Coliform bacteria are abundant in the natural environment and can be found in water and soils. Coliform bacteria is not pathogenic but its presence can determine if pathogenic organisms may also be present. For example, if a tested wastewater sample has large amounts of coliform bacteria, then we can say that there is a high chance that pathogenic organisms are also in that sample. If we find that there are very low amounts of coliform bacteria, then we can say that there is a very small chance that pathogenic bacteria are also present. Because of this, coliform bacteria is often called an indicator organism. The laboratory test results can be used to indicate whether the sample has the potential for containing pathogens. Since there are so many pathogenic organisms, it would be extremely cumbersome to test for each one individually. It is much more economical to complete the coliform test instead. Now if the coliform test does indicate that there are coliforms present, further testing can be done to determine if pathogenic bacteria are also there. Typically, the test to determine if *E. coli* is present.

Eutrophication Effects of Nitrogen and Phosphorus

Algae typically is not present in wastewater but wastewater can contain nutrients such as nitrogen and phosphorus which will promote algae growth in waterbodies. In pond treatment systems, algae will actually be used to aide the treatment process by supplying oxygen to beneficial bacteria that will reduce BOD_5.

When treated wastewater is discharged into a water way, the amount of nitrogen and phosphorus must be closely examined. If there is too much nitrogen and phosphorus in the waterbody, it can lead to an overabundance of algae. When there is too much algae growth, the algae will consume more oxygen from the waterbody. With large amounts of algae consuming the oxygen, there is not enough oxygen for other aquatic organisms to sustain life. This excess growth of algae resulting from the increased nutrient loading on a waterbody is called **eutrophication.**

Other Chemical Contaminants

In addition to nitrogen and phosphorus, there are other chemical contaminants that can be found in wastewater. Almost every element that can be found on the periodic table will molecularly combine with water under the right conditions. Collectively these will be determined when completing the TDS analysis. There are some elements that we are particularly concerned about and these concentrations are measured independently.

Chlorides can be introduced into wastewater from road salts, food waste, water softeners, and naturally occurring surface water contamination. Chlorides can be found in water as sodium chloride, potassium chloride, calcium chloride, and magnesium chloride. When there are excess levels of chlorides in a waterbody, it can have adverse effects on aquatic organisms. Excessive chlorides can interfere with the biological processes going on inside the bodies of freshwater aquatic organisms.

Heavy metals found in wastewater typically come from industrial discharges. Metal finishing, electroplating processing, mineral extraction operations, and textile industries can contribute to heavy metals in wastewater. Lead, copper, zinc, mercury, arsenic, nickel, and silver are some common heavy metals that can be found in wastewater samples. Although, any metal on the periodic table can find their way into the sewer system. Heavy metals are a concern due to their toxicity in aquatic systems and adverse effects on plants and animals.

The **pH** of wastewater is very important and can influence the treatability of wastewater. If the pH is not between 6.5 and 8.5, chemicals may need to be added to bring the pH into that range. **Alkalinity** is another important characteristic of wastewater. Alkalinity is the ability of the wastewater to buffer against changes in pH. Alkalinity is measured by determining the amount of acid neutralizing basics. It is commonly measured in mg of $CaCO_3$ equivalents per liter. Alkalinity is critical to the physical, chemical, and biological treatment processes we will discuss throughout this book. These processes do not operate well under acidic conditions. Sufficient alkalinity is needed to ensure the pH stays within the 6.5 to 8.5 range.

Other Physical Contaminants

Odor, color, turbidity, and temperature are all physical characteristics of wastewater. Unlike the biological and chemical characteristics discussed previously, physical contaminants can be observed by the human senses. We can see what the color is, we can smell if the odor is foul, and we can feel if the sample is warm or cold. Although laboratory equipment can be used to obtain more quantitative data.

As you can imagine, untreated wastewater can give off a foul odor. However, odor can give an operator great insight. If the wastewater smells like rotten eggs, this is a sign that there can be high amounts of hydrogen sulfide in the wastewater**.** In densely populated areas where the wastewater treatment plant is in close proximity to residents, odors may be captured and sent to an air treatment unit to reduce the objectionable odors from the facility.

Color can also provide insight to what's happening in the wastewater or where it's coming from. An unusual color in the wastewater can indicate an industrial discharge such as dye's from a manufacturing process. If the wastewater is dark or black, then it has most likely undergone septic or anaerobic conditions. Fresh wastewater typically has a murky yellowish/brown color.

Turbidity can be physically seen in wastewater samples and is often described as the cloudiness in the water. In the laboratory, a nephelometer is used to obtain a quantitative result measured in Nephelometric Turbidity Units (NTU). A nephelometer works by shining a light through the sample of wastewater. If the water has high amounts of turbidity the light will scatter and not make it to the detector on the other side of the sample. High amounts of turbidity can impact the effectiveness of disinfection. The small particles that cause turbidity can shield microorganisms from coming in contact with the disinfectant.

Chapter 3: Wastewater Collection

Learning Outcomes:

- Examine how wastewater is conveyed from the source to a wastewater treatment facility
- Assess the impacts and causes of odor in a collection system and explain how to mitigate the negative impacts for a community
- Analyze how gravity sewer design is used to maintain sufficient velocity
- Evaluate system conditions to determine when a sewer pump station is needed
- Differentiate between the various methods to maintain and clean sewer systems

Gravity Sewers

The main purpose of a wastewater collection system is to convey the wastewater from the source to a treatment facility. Recall from Chapter 1 that the source of wastewater contains anything and everything that goes down the drain. There are residential sources such as homes, apartments, and office buildings. And, there are industrial sources like restaurants and manufacturing processes. These sources will have **laterals** that are connected to a **main sewer** line. Laterals are usually privately owned and the maintenance on them is the responsibility of the property owner. The lateral is a direct connection from the source to the main sewer line. The main sewer line is typically owned, operated, and maintained by a public utility. The main line is several sizes larger than the laterals as it will be required to have enough capacity to accommodate all of the laterals that are being discharged into it. In larger cities there may also be interceptors or trunk lines. These larger trunk lines collect all of the main lines through the city and send the wastewater to the wastewater treatment facility.

Whenever possible the collection system will utilize gravity to send the wastewater from a higher point to a lower point. To achieve gravity flow, the main sewer lines are designed and constructed on a slope. The amount the line is sloped is dependent on the size of the pipe and the expected quantity of wastewater. The collection system must have a minimum wastewater flow velocity of 2 ft/second (fps). At this velocity solids will be kept in suspension. Slower velocities will allow settling in the piping collection system. If solids settle in the collection system, these depositions will accumulate over time and can cause a **blockage**. If the blockage becomes too severe, then wastewater will not be able to flow freely. If the blockage is large enough, it can cause the wastewater to back up and overflow onto the streets.

Pressure or Force Mains

Gravity sewer lines cannot be used in every situation. Areas that are very flat or communities that are located in a valley will require a lift or pump station. A lift station uses pumps to lift the wastewater from a lower elevation to a higher elevation. The section of pipe from the discharge to the gravity sewer connection is known as a **force main**. Unlike a gravity sewer, a force main is completely full and under pressure. The pressure comes from the energy of the pump which is needed to lift the wastewater to a higher elevation.

Different Types of Sewers

There are three different types of sewer systems; sanitary, stormwater, and combined. Sanitary sewer systems only convey wastewater that was derived from sanitary sources. As discussed in Chapter 1, this is wastewater from household toilets, showers, and dishwashers, as well as industrial sources of wastewater from manufacturing processes. Sanitary sewers differ from stormwater sewers in that they contain fecal matter from human waste. It's paramount that these wastes are conveyed to a wastewater treatment facility so they can be removed and stabilized to protect public health and the environment.

Stormwater sewers are a network of pipes that collect only stormwater runoff and directs the flow to a nearby waterbody or the ocean. While stormwater does have a direct connection to human or animal waste, it is considered less harmful and can be discharged without treatment. However, it's important to understand that stormwater is by no means "fresh water". Stormwater can have large amounts of trash, plant material, silt gravel, oil & grease. There are even fairly high amounts of harmful bacteria from animal wastes. The theory is that during storm events there is a significant amount of water flowing through these systems that these contaminants become diluted and are not as concentrated. This theory is constantly being challenged and stormwater is now being seen as another water source that can be treated and even beneficially reused.

A combined sewer is a network of pipes that conveys both sanitary wastes as well as stormwater. This can be beneficial during **dry weather** flows were there is minimal stormwater. The storm water that does exist is sent to a wastewater treatment facility where harmful contaminants are removed prior to discharging to a waterbody. However, combined sewer systems can be overwhelmed during storm events. Systems that have older infrastructure which has not been upgraded to deal with larger populations and storm events are especially vulnerable. When this happens instead of only diluted stormwater being sent to a waterbody, sewage containing high amounts of fecal matter from the sanitary sewer are also discharged. This can cause increased pollution to the waterbody.

Infiltration and Inflow

Collectively referred to as I & I, infiltration and inflow is wastewater that has entered into the collection system unregulated. An **inflow** is when water other than sanitary wastewater enters the collection system through an illicit connection such as rain gutters, basement drains, or foundation drains. **Infiltration** is water such as groundwater and stormwater that finds its way into the sewer piping from manhole covers and cracks in the piping.

Odor Control

Sewage can have an extremely foul odor. As the organic material starts to breakdown in the sewer system, it will generate foul odors. Often, this breakdown of organic material and the biological reduction of sulfates in the wastewater will create hydrogen sulfide (H_2S). H_2S has a very distinctive rotten egg smell and can cause several problems in a wastewater collection system. H_2S is extremely toxic and workers working near or inside a wastewater collection system must continuously monitor the atmospheric conditions and properly ventilate the work space to ensure that the environment is free of H_2S and other hazardous atmospheric conditions. H_2S will also breakdown in the collection system forming sulfuric acid which can corrode pipes, manholes, and other parts of the system. Although H_2S is heavier than air, it is still able to escape the collection system and cause nuisance odor conditions to the surrounding community.

These sewer gases can be mitigated in several different ways. One way is to add chemicals to the collection system that will prohibit the formation of H_2S. For example, iron salts such as ferric chloride will react with the sulfides in the wastewater and do not allow the molecules to form H_2S. Another way to remove H_2S is to let it form in the sewer system and then have a fan that will pull the foul sewer gases from the sewer and convey the odors to a treatment site. Typically, the air treatment is achieved by carbon adsorption or bio-filtration. Carbon in this filter form is extremely porous when examined under a microscope. When the foul sewer gases are forced through a media of carbon particles, the gasses will adhere to these microscopic pores and be removed from the air flow. In a bio-filtration set up, the sewer gases are conveyed to a large tank where bacteria will metabolize the H_2S and thus remove it from the air flow.

Collection System Maintenance

Collection systems, while underground and out of sight from the general public, still require a significant amount of maintenance to ensure that the wastewater flowing through the system stays underground. If the wastewater cannot flow through the network of pipes, it will begin to back up and overflow out of the manhole covers in the streets. When this happens, it is called either a Sanitary Sewer Overflow (SSO) or a Combined Sewer Overflow (CSO) depending on which type of wastewater collection system is used within the community. To prevent this from happening, wastewater professionals have several tools available to them.

Bucketing, rodding, flushing, jetting, and closed circuit television are the primary means used to maintain a wastewater collection system. Flushing is a hydraulic process that is great for light cleaning of wastewater lines. Flushing moves a high volume of water with low pressure through the wastewater line that needs to be cleaned. Adding this extra water increases the velocity in the line. At high velocities, the flushing water scours the sediments and debris in the line and pushes everything down stream.

Rodding and bucketing are both mechanical mechanisms that use machinery to physically remove any obstructions and debris from the wastewater pipeline. This is typically used when flushing is insufficient to remove the debris. Rodding occurs when a cable with a special attachment at the end of it is sent down the wastewater pipe that needs to be cleaned. The rod is then rotated and the tool can break through the obstruction in the line.

Jetting combines both hydraulic and mechanical tools. Jetting is similar to rodding except a heavy-duty hose that can handle high pressures is used instead of a rod. At the end of the hose there is nozzle specifically designed to send concentrated streams of water at high pressures against the interior wall of the pipe to remove any debris or obstructions.

Chapter 4: Preliminary Treatment

Learning Outcomes:

- Understand why preliminary treatment is necessary
- Compare and contrast the different types of preliminary treatment methods
- Evaluate the benefits of different treatment methods

Nuisance Substances

Preliminary treatment is the first step in treating raw wastewater. When the wastewater first enters the wastewater treatment facility there are a lot of nuisance materials that have found their way into the collection system. Items such as large rags, bottles, tree branches, and numerous other nuisance items can be found in the influent to the treatment facility. These large items can cause damage to downstream pumps, take up valuable space in settling tanks, and can be hazardous to other mechanical equipment needed in the treatment process. So the first, or preliminary step is to remove these large items.

Screening

One method to remove large debris items is by using a bar screen. Bar screens are capable of removing items that are larger than the spacing between the bars. For example, a ¾" bar screen will hold back any debris that is larger than ¾" and anything smaller will pass through it. Common items that are removed in this preliminary treatment step are rags, roots, large rocks and aggregate, bottles, cans, and numerous other large objects that can make their way into the wastewater collection system.

Over time, the debris collected behind the bar screen will need to be removed. This is done either manually or automatically. Manual bar screens typically have large spacing, 2" to 4" is common, between the bars. To manually clean a bar screen an operator will use a rake and pull out all of the debris stuck behind the bar screen. This can be extremely laborious and dangerous as the operator is lifting heavy objects over an open trench. Ideally, a wastewater treatment plant will have two or more channels with bar screens. This way one channel can be isolated and the debris can be removed without having wastewater flowing through it. Although this is safer, it is still laborious.

Newer bar screens are raked automatically. On more sophisticated systems, the channel where the bar screen is installed will have an upstream and downstream level sensor. When the debris is blocked by the bar screen it will also inhibit the flow of wastewater through the screen. This will cause the upstream water level to rise. When the difference between the upstream and downstream levels reaches a predetermined setpoint, the motorized rake will swing down and automatically pull the debris out of the channel and into a hopper. Other systems will automatically initiate the raking sequence based on a timer or will just run continuously.

Most automatic bar screens will have a washer/compactor that receives the removed debris. The washer/compactor will wash the debris removing any of the organic matter and then compact it. Washing is important because in this preliminary step we are only trying to remove the large inorganic items. We want to keep the organic material in the wastewater stream as it will be utilized in subsequent treatment processes. Compacting the debris is critical as it removes most of the water makes it easier to transport for disposal.

Since automatic bar screens can run autonomously, the bar spacing can be smaller. Most models are around ⅝" to ¾" but newer models can be ½" or less. While automatic bar screens are capable of removing more debris with less manual labor, there is still a skill set required to properly operate this machinery. Operators will check the equipment multiple times during a day. Checks can include monitoring the rake arm and motor for proper function, removing compacted debris to a larger disposal truck, checking motor amps are within range, and calibrating level sensors.

Comminution and Barminution

An alternative to screen these large debris items is to shred or grind them. A comminutor is a device that sits inside the channel where wastewater is flowing into the treatment facility. The comminutor will grind the large debris items, turning them into smaller items. Communitors are designed to produce a solid size of a certain diameter. By breaking up the debris into smaller diameters, the downstream pumps and equipment will not be as impacted. It's important to note that comminutors do not remove the debris from the flow of wastewater. The debris is just broken down to more manageable sizes. The debris will still need to be removed in the subsequent treatment process.

Barminutors combine a bar screen with a comminutor. There is a bar screen set inside of a channel where the wastewater flows. The debris is trapped behind the bars and then a device travels up and down the bars which breaks up the large solids into smaller pieces. The ground up solids stay within the flow of wastewater and move onto the treatment process.

Grit Removal

Once the large items are managed, the next step in the treatment process is to remove the smaller inorganic solids, such as coffee grounds, eggshells, sand, silt, and gravel. These small diameter solids are collectively called grit. Grit must be removed because it will cause excessive wear on plant equipment such as the impeller of a pump. Also, this inorganic material can settle in the subsequent treatment process and take up valuable space in tanks which decreases plant efficiency and can inhibit further treatment. While most gritty materials are inorganic, large organic solids such as corn kernels and other food waste may also be removed.

There are several methods that can be used to remove grit but all of the methods rely on the fact the gritty material is relatively heavy. Compared to the organic solids, grit is much heavier and will settle faster. Grit can be removed by controlling the velocity of wastewater through a tank, adding air to the tank to aide in settling, or by using centrifugal force.

The basic concept of removing grit is to reduce the velocity of the wastewater flowing through a tank to less than 2 fps. Recall that in the collection system we want to achieve a velocity of 2 fps. The higher velocity in the collection system will keep all of the solids in suspension so they make their way to the treatment plant. But now that we are trying to remove these solids, we want to get the velocity between 0.7 and 1.4 fps. At this lower velocity the heavy inorganic solids will settle to the bottom of the tank.

Detention time is a critical factor in designing the tank dimension for grit removal. The detention time needs to be long enough to allow the gritty material to settle to the bottom. Typical detention time of grit chambers is around 2 to 5 minutes. However, if the detention time is too great, then smaller organic solids will also settle out. These items are better dealt with in the next step of primary treatment.

Aerated grit chambers are set up in a similar manner except there will be air piped to diffusers at the bottom of the tank. The addition of air in the tank creates a rolling action of solids which helps keep the lighter organic solids in suspension while the heavier grit material is directed to the bottom of the tank. In aerated grit chambers the amount of air sent to the chamber is a critical operating parameter. If too much air is supplied, then the grit material will stay in suspension and not be removed. If not enough air is supplied, then the lighter organic material can settle out.

Cyclone separators are another method of removing grit. These separators use centrifugal force to push the gritty solids to the edge of a circular chamber where they are then directed to the bottom of the tank. To create the centrifugal force, cyclone separators will require a higher velocity of wastewater moving through the unit. Typically a velocity of 2 fps to 3 fps will be sufficient.

Any of the grit removal methods described will result in an accumulation of material at the bottom of the unit. If these solids are not removed periodically, they will accumulate to the point where the unit will be ineffective. The tanks are designed to direct the gritty material toward the bottom of the tank which is sloped towards one end. This allows the settled grit to be removed from the tank for further treatment. The mixture of grit and wastewater is pumped and sent to a grit washer. Grit washers will wash out the organic material and send it back into the flow of wastewater as it moves onto the next treatment process. This allows only the inorganic abrasive solids to be collected for ultimate disposal. Once the gritty material is washed and collected it is sent to a landfill.

Chapter 5: Primary Treatment

Learning Outcomes:

- Describe different methods to measure wastewater flow
- Examine the purpose of primary treatment
- Compare and contrast conventional primary treatment with chemically enhanced primary treatment
- Assess how specific gravity and density relates to the removal of solids able to settle

Flow measurement

After preliminary treatment, and all of the large debris and inorganic solids are removed, it's vital to measure the amount of wastewater flowing into the treatment facility. This flow rate will be an important number for process control. Many wastewater treatment plants have a typical diurnal flow pattern as flow into the wastewater treatment plant is not constant. Over a 24 hour period, the flow can fluctuate significantly. There are usually two peaks during the day, typically in the late morning and evening. In the morning, the population that the treatment facility serves, is waking up, taking showers, making coffee, cooking breakfast, and using the restroom. The flow tends to lessen in the late afternoon and then increases again in the evening. In the evening, a majority of the population is cooking dinner, washing dishes, doing laundry, and taking showers. In the middle of the night most people are sleeping and not sending water down the drain.

There are several ways that flow can be measured. A simple way to measure flow is by using a weir. Weirs can either be square or V-notched, but the principal behind them is the same. As the flow of wastewater travels through a channel, the weir is placed in its path. The wastewater is then forced to move over the crest of the weir. Based on the dimension of the square or v-notched section in the weir, the flow can be determined by the height of the wastewater over the weir crest. If there is a significant amount of flow, then the height of wastewater will also be large. When the flow decreases, the height of wastewater over the weir will be lessened.

A Parshall Flume is another way to determine the flow rate entering or leaving the treatment facility. It works similar to a weir in that the water is forced through a restriction in the channel and the height of water before and after the restriction is used to calculate a flow rate. All Parshall Flumes have similar shape. There is a converging section, a throat section, and a diverging section. The converging section is where the flow is channeled and forced through a narrow section. The throat section is where the wastewater flow is restricted by traveling through a slimmer channel. This restriction will increase the velocity of the wastewater as it passes through the throat section and cause the level to rise in the converging section. Just like in a weir, higher flow rates will cause the wastewater level to increase and lower flow rates will show a decrease in the wastewater level. Many treatment plants have markings in the converging section to indicate the wastewater level. Modern treatment plants will have ultrasonic level transmitters that will record the level precisely. This data can be automatically transferred to a computer system where the flow rate is instantly calculated and recorded. A benefit of using the Parshall Flume instead of a weir is that the restriction in the channel will not cause any solids to settle out. In a weir, as water builds up behind it, the velocity is reduced and solids can settle out. Those solids will have to be removed periodically or odors can become problematic.

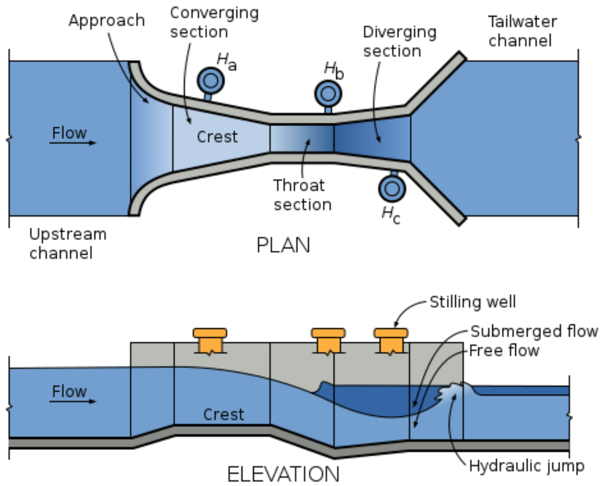

Diagram of a Parshall Flume by Inductiveload is in the public domain

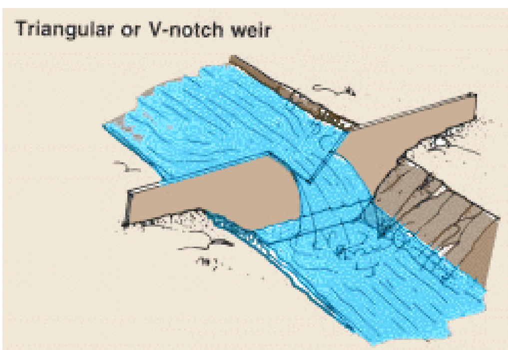

Image of a v-notch weir by the FAO is licensed under CC BY-NC-SA 3.0 IGO

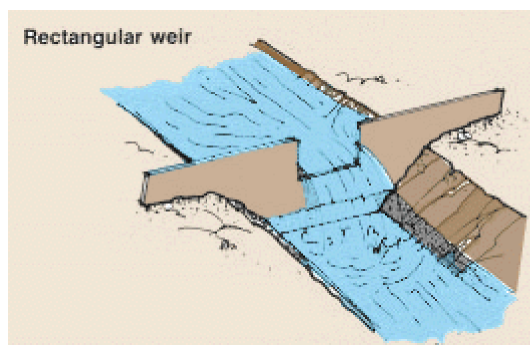

Image of a rectangular weir by the FAO is licensed under CC BY-NC-SA 3.0 IGO

The most modern method of monitoring flow throughout a treatment facility is a magnetic flow meter, or “mag meter” for short. Mag meters work by having the wastewater flow through a pipe. The mag meter is connected to the pipe either by strapping the device to the outside of the pipe or more permanently, by bolting it between two sections of pipe. The device creates a magnetic field inside the pipe and as the water moves through, it creates a disturbance that is measured by the meter. Higher flow rates cause more of a disturbance. The meter can very accurately measure the flow of wastewater moving through the pipe. The benefit to mag meters is that there are no moving parts inside the pipe. So influent wastewater with lots of solids and organics will not interfere with the flow measurement. Mag meters are also very reliable and require little maintenance.

Magnetic Flow Meter by Mtaylor848 is licensed under CC BY-SA 3.0

Some treatment facilities may have flow equalization. Recall that the incoming wastewater has an inconsistent flow rate that fluctuates drastically throughout a 24-hour period. This change in flow will also result in changing detention times which many of the treatment process are dependent on. A treatment plant that utilizes flow equalization will attempt to even out the flow so it is consistent throughout the treatment plant all the time. By looking at historical data the plant operators will have a good idea of what the average flow rate for the plant is. This average flow rate is the target of the flow equalization. When the incoming wastewater is greater than the average flow, the excess amount will be directed towards a holding basin. When the flow is less than the average, typically in the middle of the night, the wastewater is pumped from the holding tank into the treatment facility. This can also reduce energy cost as day time pumping will be reduced. Energy costs are usually higher during peak periods. Some treatment facilities have flow equalization at the end of the treatment process. They may have restrictions in their discharge permit which may limit the flow rate leaving the facility. Other treatment plants don't have any flow equalization.

Sedimentation

After the incoming flow rate is measured the next step in the treatment process is primary sedimentation. The primary goal of sedimentation is to remove the settleable solids. A well operated primary sedimentation tank can remove around 90% - 95% of settleable solids. There will also be a reduction in total suspended solids and a slight reduction in BOD_5. Recall that settleable solids are the large solids in the wastewater and are measured by an Imhoff cone in the laboratory. The sedimentation process works because these solids are heavier, relative to the wastewater, and will therefore settle to the bottom of the tank. These tanks are referred to as Primary Clarifiers or Primary Sedimentation Basins. A clarifier is a tanks or basin where the sedimentation process will occur. The rate at which the solids will settle is determined by Stokes Law which takes into account the size of the solid particle, the specific gravity of the particle, and the specific gravity of the liquid. Specific gravity is a unitless number and is a measure of density relative to a reference liquid. For this book when talking about specific gravity, we will assume water is the reference liquid and it has a specific gravity of 1. When determining how quickly solids will settle in the sedimentation tank, the specific gravity of the solids will be a significant factor. If the solids have a specific gravity less than 1, they will not settle at all, in fact they will float on the water. If the specific gravity is only slightly greater than one, the solids will settle but at a much slower rate than another particle with a larger specific gravity. This is fairly intuitive. Clearly the heavier the solids the quicker they will settle.

Another phenomenon that occurs in the sedimentation process is that as the solids collect at the bottom of the tank, the weight of the solids begin to compact and compress. This causes the solids to be thickened and have slightly less water content. Detention time, or how long the wastewater takes to travel through the tank, is a critical design parameter of primary sedimentation tanks. There needs to be enough time to allow the solids to settle but not so much time that the solids start to decompose. Decomposition will cause gas bubbles to form which can hinder solids settling and create foul odors.

Primary sedimentation tanks can either be circular or rectangular. Regardless of the configuration, the tanks will have similar components. At the inlet structure where the wastewater enters the tank, the velocity is typically high in order to prevent solids settling in the piping network as the wastewater comes from the preliminary unit process to the primary tank. Once in the primary tank, the velocity must be slowed. To accomplish this there will be some type of diffuser at the inlet end that will redirect flow and prevent short-circuiting. The dimensions of the primary sedimentation tank must be able to accommodate the flow of wastewater but must also reduce the velocity.

Flotation

As discussed earlier, the specific gravity of the material in the wastewater will determine how it interacts with the wastewater in the sedimentation tank. In addition to settling solids, primary tanks will also remove floatables. Typically, these floatables are classified as fats, oils, and grease (FOG). The specific gravity of these materials is less than 1 so they will rise to the top of the sedimentation tank and be removed. A rectangular primary tank will have flights that span the width of the tank. They are connected by a chain that is motor driven to slowly move with the flow of wastewater. The flights provide several functions. They prevent short circuiting of material on the surface, they convey the FOG on the surface to a collection trough at the end of the tank, and they convey the settled solids to a hopper at the beginning of the tank. Circular tanks have a similar mechanism called a swing arm that provides the same functions.

Sludge Removal

Once the solids have settled to the bottom of the tank, they are conveyed to a hopper in the tank. Circular tanks are typically coned at the bottom so the solids build up in the center. Rectangular tanks have a hopper at the front of the tank and the flights convey the solids there. The solids must be removed from the tank periodically so they do not cause adverse conditions. There is organic matter in the solids and if it starts to decompose, it will create foul odors and gas bubbles that will hinder other solids from settling. Typically incoming wastewater is around 1% solids. Due to the sedimentation process the percent solids concentration increases to around 4% to 8%. Due to the high amounts of solids, a standard pump cannot be used. Instead, special pumps including a progressive cavity type pump or a stator/rotor pump are commonly used.

The stator/rotor pump has a stationary part, the stator, and a rotating element, the rotor. Both have a corkscrew type shape and the rotor moves with in the stator. As it rotates, it is passing the mixture of solids and water progressively through the pump. These pumps are designed to be able to handle the abrasive nature of the solids and not clog up. The solids are sent to an anaerobic digester where they are further treated and stabilized. Eventually, they will be dewatered and sent to a landfill for disposal.

Chemical Addition

To further enhance the sedimentation process, chemicals can be added. These chemicals will adhere to the solids and increase their specific gravity. With a higher specific gravity, the solids will settle more quickly. This can either be done to increase the amounts of solids and BOD_5 or can be used to achieve average results in a smaller footprint. This process is referred to as chemically enhanced primary treatment (CEPT). Typically, ferrous or ferric chloride is used as the chemical aide. Other chemicals such as polymers may also be used. Polymers make the solids clump together which subsequently results in quicker settling in the sedimentation tank.

This process is not used as often anymore due to increasing regulatory requirements. Early in the wastewater industry a treatment plant could have removed enough solids and BOD_5 using the CEPT process. But as regulations became more stringent, many utilities upgraded to secondary treatment systems. This secondary biological treatment process is dependent on the BOD_5. If too much is removed in the primary process, it will adversely affect treatment.

Chapter 6: Biological Treatment Overview

Learning Outcomes:

- Describe different methods to biologically treat wastewater
- Examine what target contaminants are being removed by the different biological processes
- Compare and contrast different biological processes and the type of bacteria and environmental conditions needed

Aerobic, Anaerobic, and Facultative Organisms

Aerobic bacteria require an environment that has free dissolved oxygen. The bacteria use that oxygen for respiration to live. They feed on the organic matter and other nutrients in the wastewater. As the bacteria consume these materials, they are removed from the wastewater, making it less contaminated. The byproduct of the aerobic decomposition of organic matter is carbon dioxide (CO_2).

Anaerobic bacteria require an environment that has no free or combined oxygen. Free oxygen is when there is excess oxygen dissolved in the water and is available as O_2. Combined oxygen is when the oxygen molecule is bound to another element. Common examples of combined oxygen in wastewater is nitrate (NO_3). In anaerobic conditions there is absolutely no oxygen available to the bacteria for respiration. Anaerobic bacteria have more sophisticated means of respiration by using other chemical reactions instead of using oxygen directly. However, similar to aerobic bacteria, when anaerobic bacteria breakdown the chemicals in wastewater for respiration and feed off other organics, they subsequently remove the contaminants from the wastewater. The byproduct of anaerobic decomposition is methane gas.

Facultative bacteria have the ability to thrive in either aerobic or anaerobic conditions. While they prefer aerobic conditions, they have the ability to adapt when no oxygen is available and survive in anaerobic conditions.

Stabilization Ponds

Stabilization ponds are a simple way to reduce the amount of organic material in wastewater and require low maintenance. However, they require a lot of land and are mainly used for smaller rural communities. The concept of ponds is pretty simple. You have a large pond filled with wastewater. The size of the pond allows for a very long detention time. The pond creates an ecosystem for bacteria to thrive and those bacteria breakdown the organic matter. Since the detention time is very long, typically 45 days or longer, solids will also settle to the bottom and be removed from the effluent. Eventually the solids will have to be removed but a well operated pond can go a few decades before that is needed to be done.

As discussed earlier there are several different types of ponds depending on what type of bacteria are expected to be prevalent. Aerobic ponds utilize aerobic bacteria and require oxygen. These ponds are typically more shallow, around 2ft to 5ft, since the oxygen is provided by the atmosphere and algae that is produced on the surface of the pond. Ponds have a complex relationship between how much dissolved oxygen is available to the bacteria. This is driven by sunlight over a 24-hour period and photosynthesis. Photosynthesis is where plants such as algae use sunlight and carbon dioxide (CO_2) to thrive. During the day when there is plenty of sunlight, the algae will utilize the CO_2 in the water and produce oxygen. This will cause the pH in the pond to decrease and the dissolved oxygen concentration to increase. This is a good thing because in an aerobic pond, the bacteria need oxygen to live and breakdown the organic waste. During the night when the sun goes down, the reverse happens. Without sunlight photosynthesis is reduced and the algae will utilize the oxygen and produce CO_2. This causes the pH to increase and the dissolved oxygen will decrease. Because sunlight is an important factor in pond performance, there will also be seasonal variations in addition to daily fluctuations. During the winter when the sun isn't as prevalent, the amount of oxygen produced via algae and photosynthesis will be reduced. If more oxygen is required than what can be produced naturally, it can be provided by mechanical means. Surface aerators and a mixing system can be installed. However, the mechanical systems in these aerated ponds will require more maintenance. They will also require more electricity to run the aeration equipment.

Anaerobic ponds utilize anaerobic bacteria which require no oxygen. To create this environment in a pond system, the depth is increased. Typically depths can range from 6 ft to 16 ft. At these increased depths, oxygen from the atmosphere is unable to penetrate the water and a no oxygen environment, ideal for the anaerobic bacteria to thrive, is created. In these types of ponds, the bacteria are breaking down the more complex solids and organics that are found in the wastewater. It can provide sufficient removal of nitrogen, phosphorus, and BOD_5. The solids are further stabilized, broken down and collected as sludge at the bottom of the pond. Like the aerobic ponds, these solids will eventually need to be removed.

Facultative ponds are a mix of aerobic and anaerobic ponds. There depth is on the order of 3ft to 8ft. Recall, that facultative bacteria can switch from living in anaerobic conditions to aerobic conditions. This can be useful during seasonal variations where little oxygen is available. The facultative bacteria can then focus on breaking down organics by anaerobic decomposition. When sufficient oxygen is available they will switch mechanisms and break down the organic matter by aerobic decomposition.

Pond Performance

To improve pond performance, it is very common to have multiple types of ponds in series. Anaerobic ponds can handle higher influent BOD_5 loading, so they would be the first pond. Then a facultative pond would follow, where further BOD_5 reduction is achieved. Lastly would be an aerobic pond that would reduce organic wastes and remove pathogenic organisms.

Pond performance is going to be dependent on the loading of organic wastes and detention time. Typically a max of 30lbs of BOD_5/day/acre is the desired loading rate. However, ponds are able to handle fluctuations if loading rates are exceeded for short periods of time. The wastewater must remain in the pond long enough so the bacteria can come in contact with the organic matter and consume it. Anaerobic ponds will maintain a detention time of 1 to 7 days. Facultative ponds have a detention time of 5 to 30 days and aerobic ponds are usually 30 days or greater.

Chapter 7: Biological Treatment Methods

Learning Outcomes:

- Describe different methods to biologically treat wastewater
- Compare and contrast fixed film treatment methods with other biological treatment methods
- Understand the operation of a trickling filter and how to control it

Fixed Film Processes

A fixed film treatment process is still a biological treatment method and utilizes the same type of bacteria as discussed in Chapter 6. The difference is that instead of the bacteria floating near the bottom of a pond, they are fixed to some type of medium. The media can either be natural stone, synthetic plastics, or large rotating disks.

Rotating Biological Contactors

Rotating biological contactors (RBCs) utilize aerobic bacteria to decompose the incoming BOD_5. They are composed of a series of closely spaced circular disks. The disks are connected to a shaft that is coupled to a motor. The set of disks lay horizontally in a tank and rotate at a slow speed. The incoming wastewater enters the tank and submerges approximately 40% of the disks. The water moves through the tank and comes in contact with the aerobic bacteria that are growing on the disks. When the disks are submerged in the wastewater, the bacteria have access to the BOD_5 and will consumed it. As the disks rotate out of the liquid in the tank, they are exposed to the atmosphere where the bacteria can utilize oxygen for aerobic decomposition of the BOD_5.

The disks are typically 12 feet in diameter and multiple disks are combined together to make a long cylinder. Common lengths are 25 feet. The motor spins the disks at approximately 1.5 rpm. It's not uncommon to see multiple RBCs being used in both parallel and series configuration. As the bacteria thrive in this environment, eventually they will build up on the disks and start to slough off. The effluent of the RBC is sent to a finishing pond or clarifier to further treat these solids.

Each of the RBCs are covered for several reasons. Disks are commonly made out of plastic so covers will protect the disks from becoming brittle due to sun damage. Foul odors from the wastewater and H_2S gasses will be present in the RBCs. Covering them will reduce these odors and prevent nuisance complaints from the community. Lastly, covers will protect the bacteria from being washed off the disks during rain events. Fiberglass covers are commonly used and are more cost effective than building the RBCs in a building. The humidity and wastewater gases can be corrosive to cement, metals, and other building materials.

Trickling Filters

Trickling filters are another form of fixed film biological treatment. They are comprised of circular tanks filled with stone, lava rock, ceramic, or synthetic material all which are referred to as media. Standard media is approximately 1 inch to 4 inches in diameter. The bacteria will become fixed to this media and aerobic decomposition will occur as the incoming wastewater comes in contact with the bacteria. While trickling filters can be relatively deep, around 3 to 8 feet, there is ample air flow in the voids of the media to allow for aerobic bacteria to thrive. Trickling filters often have ventilation ports near the bottom to ensure there is sufficient air flow to the bacteria. The wastewater enters the trickling filter at the top of the filter. Then gravity takes over and the wastewater trickles down through the media to the bottom of the tank where it is captured in an underdrain system.

The wastewater is conveyed from the primary sedimentation tanks to the trickling filters. This is either done by gravity or by using a pump. Either way a trickling filter uses this pressure in the water to evenly distribute the wastewater to the trickling filter. There is a distributor arm that expands the diameter of the circular tank. The wastewater is forced out through small outlets on the distributor arm that will cause the arm to rotate.

The wastewater trickles through the media and comes in contact with the bacteria fixed to media. The bacteria are now in a sufficient environment where aerobic decomposition will occur and reduce the BOD_5 of the wastewater. Over time the bacteria will build up on the media and eventually will fall or slough off. These solids will be captured in the underdrain system and sent to the secondary clarifier. In the clarifier, sedimentation will occur and the solids will settle to the bottom of the clarifier and be removed.

Recirculation

Recirculation of the clarified effluent is a key operational component of a trickling filter. Water from the secondary clarifiers has already gone through the biological treatment process of the trickling filter and has a lower amount of BOD_5. By recirculating this treated water with the incoming wastewater, it will dilute the incoming BOD_5. Recirculation will also be able to control the dissolved oxygen level in the trickling filters. Increasing the recirculation rate will cause the dissolved oxygen to increase and lowering the recirculation rate will cause it to decrease. An optimal concentration of dissolved oxygen in the trickling filter is 1.5 mg/L to 2.0 mg/L.

Organic Loading

Trickling filters can be further classified by how much BOD_5 is being sent to the treatment unit. Low rate trickling filters receive up to 25 lbs of BOD_5/1000 cubic feet/day. At this lower organic load, an operator can expect to achieve 80% - 90% BOD_5 removal. Intermediate filters can handle up to 40 lbs of BOD_5/1000 cubic feet/day but will see lower removal efficiencies of BOD_5. High rate and roughing filters will have BOD_5 loading in excess of 50 lbs of BOD_5/1000 cubic feet/day. At these higher loadings, BOD_5 removal significantly drops and will not meet current regulatory requirements. High rate and roughing filters are often used as a preliminary step and are combined with other forms of treatment to ensure regulatory compliance is achieved.

Chapter 8: Activated Sludge

Learning Outcomes:

- Compare and contrast the difference between fixed film and suspended growth biological treatment systems
- Describe how the activated sludge process can more efficiently reduce organic wastes
- Understand how different process control strategies work in an activated sludge system
- Examine how a secondary clarifier is utilized in an activated sludge system

Suspended Growth Processes

Unlike the fixed film biological systems discussed in Chapter 7, activated sludge uses a suspended growth process. This means that there is no media for the bacteria to become fixed to. The microorganisms are suspended in the tanks either by a mixer or air diffusers and are then mixed in with the incoming wastewater. This mixture of wastewater and microorganisms is referred to as the Mixed Liquor Suspended Solids (MLSS). A sample can be taken from the activated sludge system and analyzed in a laboratory to determine how many mg/L there are of MLSS in the system. This laboratory result will be a critical design and operational parameter that will need to be continually monitored to ensure effective treatment.

Activated Sludge Treatment

The activated sludge process was developed by two scientists, Edward Arden and William Lockett, in England in 1914. Their experiments showed that by taking the microorganisms that were already established from aerobic decomposition and introducing them to fresh wastewater, it would speed up the decomposition of the new organic wastes. Instead of relying on the 30 to 45 days it would normally take to breakdown these organic wastes, the activated sludge process can achieve the same level of treatment in less than one day. This means that an activated sludge wastewater treatment system will be able to handle higher flow rates and higher organic loading than pond treatment or fixed film systems.

To achieve this on a large scale, conventional activated sludge systems are comprised of an aeration tank followed by a secondary clarifier. In the secondary clarifier the microorganisms will separate from the now treated wastewater. A majority of those microorganisms will be returned back to the reactor and are now activated to treat more of the incoming wastewater. In the aeration tanks the bacteria are in an environment with dissolved oxygen readily available and organic matter to consume. Like the other biological processes, this is how the reduction of BOD_5 occurs, through aerobic decomposition. What makes activated sludge unique is that in the secondary clarifier, the bacteria become stressed because their food source has been drastically decreased and there is no more dissolved oxygen. They begin to go through endogenous respiration. The bacteria basically become so starved that they begin to breakdown their own cellular structure. Before the bacteria completely cannibalize themselves, they are sent back to the aeration tank where they are re-introduced to readily available dissolved oxygen and organic matter. The starved bacteria are then able to rapidly re-start aerobic decomposition and quickly reduce the BOD_5 in the wastewater.

Food to Microorganism Ratio

A key parameter to determine the effectiveness of activated sludge systems is the food to microorganism ratio, or F/M. The food is determined by the amount of BOD_5 in the incoming wastewater and the amount of microorganisms available to consume that food is determined by the amount of MLSS in the aeration tanks. Since it's a ratio, the units of these two laboratory results must be the same. The mg/L concentration of the laboratory results is converted into a mass with the units of lbs. While each treatment plant will determine which level of F/M has historically given effective treatment, a common range is around 0.2 to 0.5.

Return Activated Sludge

The return activated sludge, or RAS, are the bacteria that have settled in the secondary clarifier and are being sent back to the aeration tank. The rate of speed at which the microorganisms are returned is something that the operator can control.

Waste Activated Sludge (WAS)

Like the other biological process discussed, the bacteria, overtime will grow and their population will increase. To control the amount of bacteria in the system, a portion of the RAS will not be returned to the aeration tank but instead is directed to a separate solids handling treatment unit. Typically, these solids are combined with the settled solids from the primary sedimentation tanks and sent to an anaerobic digester. After anaerobic digestions the solids will be dewatered and ultimately sent to a landfill for disposal.

How much bacteria remains in the system and how much is wasted can be determined by the mean cell residence time or MCRT. The MCRT is a theoretical calculation of the average time a single bacteria will stay within the activated sludge system before being wasted. To calculate the MCRT an operator would determine how many pounds of MLSS there is in the system and divide that by how many pounds were removed from the system.

Process Control

The F/M ratio, MCRT, RAS, WAS, and dissolved oxygen concentrations can all be manipulated by the operators of a wastewater treatment facility to optimize the effectiveness of treatment. In fact, those parameters are the only things that can be easily controlled. The amount of incoming wastewater is going to be what it is and it will fluctuate throughout a 24 hour period as well as vary by season. The incoming BOD_5 loading is what it's going to be and the operators can't control it.

If the F/M is too low, it means that there are more bacteria than what is needed to consume the available food. This is inefficient because supplying the oxygen to the bacteria requires a significant amount of energy. If there are too much bacteria in the system and not enough food, the bacteria will still be consuming oxygen but the BOD_5 won't be further reduced. To increase the F/M ratio operators can only control the "M" portion of the equation. By increasing the wasting rate, the MLSS will be reduced causing the F/M ratio to increase.

If the F/M ratio is high, then there is not enough bacteria to consume the large amounts of incoming BOD_5. This will lead to poor treatment and the effluent will have a high BOD_5

concentration. Operators cannot decrease the amount of BOD_5 coming into the plant so they will have to increase the amount of MLSS in the system. They can do this by decreasing or stopping the wasting rate. Decreasing the wasting rate will cause the MLSS to increase and the F/M ratio will be reduced.

The MCRT is another process control tool that is used to determine the wasting rate by manipulating the equation to calculate the MCRT. Often the desired MCRT rate is determined by the design of the treatment facility or from historical data. By taking the pounds of MLSS in the system and dividing it by the desired MCRT, you will determine what the wasting rate needs to be to achieve that MCRT. However, the MCRT and F/M methods for determining the wasting rate can often conflict with each other. Operators need to look at the changes in MCRT and F/M over time and make minor adjustments to the process so the bacteria aren't "shocked".

Alternative Process Configurations

There are many different types of process configurations of activated sludge systems that differ by how the wastewater enters the aeration tanks. A plug flow reactor has all of the wastewater and RAS entering at the beginning of the tank. This will have a large organic loading at the beginning of the tank and as the wastewater moves through the tank, the load will lessen. Often, tapered aeration will be used in plug flow reactors. Tapered aeration will have lots of air diffusers in the beginning of the tank so more oxygen is available to the bacteria to handle the increased organic loading. As the wastewater flows through and the BOD_5 is reduced, the air diffusers are also reduced.

An alternative is a step feed reactor where the incoming wastewater is split and sent to different portions of the tank. For example, 25% of the flow is sent to the first ¼ of the tank another 25% sent to the second ¼ of the tank and so on. This allows for a more even distribution of the organic loading as well as more uniform demand for the air diffusers. Typically, a steep feed system will use less air overall than a plug flow reactor.

Secondary Clarification

A secondary clarifier is a key component of the activated sludge system. Not only does it separate out the microorganisms from the now treated wastewater, but it will also concentrate them through the sedimentation process. A secondary clarifier works exactly as discussed previously in primary sedimentation. The only difference is that in a primary sedimentation tank the main goal is to remove unwanted solids. In a secondary sedimentation (or clarifier) tank the goal is to concentrate the MLSS so it can be returned to the aeration tanks.

How the biomass is settling in the clarifier can be difficult to see in real time as the tanks are typically below grade and made of concrete. A "sludge judge" is used to determine how many feet of MLSS are settled on the bottom and how much clear water there is on top. The tool is simply a clear PVC pipe with a ball check valve at the bottom. As the pipe is inserted into the water, the ball check valve opens, letting liquid in. When the stick hits the bottom, the operator will pull the PVC pipe out of the water forcing the ball check to close producing a cross sectional sample of MLSS on the bottom and clear water on top. There are markings on the PVC pipe for every foot. So as the operator pulls it out of the clarifier, they can see where the clear water stops and where the MLSS is settling. Typically a sludge blanket of 1 to 3 feet on the bottom of the clarifier is optimal.

The settleability of the MLSS can also be seen in the laboratory by taking a sample of the MLSS and putting it into a 1000 mL beaker. After 30-minutes have gone by, the graduations of where the MLSS has settled will be recorded. Dividing the settled sludge volume in mL/L, dividing by the MLSS in mg/L, and multiplying by 1,000 mg/g will yield the Sludge Volume Index (SVI) in mL/g. The SVI is utilized to gauge how well the MLSS will settle in the clarifier and will also shed light on how the activated sludge plant is operating.

Typical SVI is around 100 to 200 mL/g. Less than 100 mL/g will often show rapid settling of the sludge in the clarifier. When the MLSS settles too quickly, smaller “pin floc” particles will remain suspended in the middle of the clarifier. This will also be seen in the sludge judge test where there is clear water on top of the sludge judge, murky water in the middle, and darker solids on the bottom. This is usually caused by having a higher MCRT. An SVI greater than 200 mL/g will have sludge settling very slowly in the clarifier. This can be caused by having a low MCRT.

The water leaving the secondary clarifier has now gone through all of the previous treatment steps from preliminary screening, to primary sedimentation, and activated sludge treatment. In some areas with less stringent regulations this water is clean enough to be discharge to the ocean or a nearby waterbody. However, some additional treatment like filtration and disinfection may be needed to meet regulatory compliance. Also, the solids that were removed from the primary and secondary process will still need to be treated and disposed of.

Glossary

pH – A measure of the acidity or basicity of a solution from a scale of 0 to 14. Zero being the most acidic and 14 being the most basic.

Alkalinity – The ability of a solution to buffer against changes in pH.

Eutrophication – an increase in nutrients in a waterbody that promotes excessive algae growth to the point where oxygen levels in the waterbody are depleted and unable to support other aquatic life.

Coliform – the general group of bacteria that can be used as an indicator to determine if pathogenic microorganisms are also present.

Protozoa – A single-celled microorganism

Metazoa – A multi-celled microorganism

Pathogen – A microorganism found in water that can cause disease to a person.

Point source – A single identifiable source where treated wastewater is discharged into a water body.

Nonpoint source – Sources of pollution that cover a wide area of land. A source that is difficult to identify as a single source of pollution into a water body.

Waste Load Allocation – The total amount of a certain pollutant that can be discharged by a point source and still meet the TMDL of a water body.

Settleable solids – Solids that will settle to the bottom on an Imhoff cone.

Imhoff cone - Inverted cone shaped laboratory equipment used to determine the amount of settleable solids.

Total suspended solids (TSS) – Solids in wastewater than can be trapped by a filter and measured in mg/L.

Total dissolved solids (TDS) – Solids in wastewater that will pass through a filter and are molecularly combined with the water molecules.