Wastewater Treatment & Disposal II

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Version 1

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CHAPTER 1: CONVENTIONAL TREATMENT REVIEW

Learning Outcomes:

- Describe the difference between wastewater, stormwater, and combined collection systems
- Understand the general treatment process of wastewater
- Compare and contrast the different stages of wastewater treatment

Wastewater Collection

The wastewater collection system is the network of pipes that convey the wastewater from households and business to a wastewater treatment facility. Each customer will have a lateral connected to the main sewer lines. In order to keep sediment from settling out in the collection system and causing a blockage the pipe is sloped to ensure a velocity of 2 ft/sec. A majority of the system will utilize the slope of the pipe and gravity so the water travels downhill. However, that is not always feasible and when needed a lift station will be installed. The lift station is comprised of a wet well where the wastewater is collected and pumps the water to a higher elevation where it can then resume to flow by gravity. The portion of the pressure pipe that is connected to the lift station is called a force main. The force main is always under pressure and the wastewater completely fills the pipe. Where a gravity sewer has minimal pressure and under normal conditions only about ⅓ of the pipe is filled with wastewater.

There are three different types of sewer systems; sanitary, stormwater, and combined. Sanitary sewer systems only convey wastewater that was derived from sanitary sources. This includes 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.

Preliminary Treatment

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.

Methods used in preliminary treatment include screening, communition, and grit removal. A wastewater treatment facility may use one or all of these methods to handle the large items that may enter the treatment facility. 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.

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.

Smaller inorganic solids, such as coffee grounds, eggshells, sand, silt, and gravel 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 in removing grit. One common method is an aerated grit chamber. Aerated grit chambers will have 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.

Primary Treatment

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. The sedimentation process works because these solids are heavier, relative to the wastewater, and will therefore settle to the bottom of the tank. 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.

In addition to settling solids, primary tanks will also remove floatables. Typically, these floatables are classified as fats, oils, and grease (FOG). 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.

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 in the sedimentation tanks 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.

Secondary Treatment

Secondary treatment methods typically involved some form of biological treatment to further reduce the amount of BOD_5. Trickling filters and activated sludge treatment plants will utilize a secondary clarifier to separate the treated wastewater from the microorganisms of the biological treatment step.

A key component of a trickling filter is the recirculation of the clarified effluent back to the 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.

A secondary clarifier is also 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 tank the goal is to concentrate the Mixed Liquor Suspended Solids(MLSS) so it can be returned to the aeration tanks.

CHAPTER 2: BIOLOGICAL TREATMENT OVERVIEW

Learning Outcomes:

- Understand which environments the different types of bacteria thrive
- Explain how activated sludge treatment process is more efficient than other methods
- Describe the nitrogen cycle and how it's used to remove nitrogen from wastewater

Aerobic, Facultative, and Anaerobic 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. 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.

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.

Activated sludge treatment systems consist of an aeration tank followed by a secondary clarifier. These two tanks each provide a unique function but also work together to reduce the

BOD_5 in the wastewater. In the aeration tanks, oxygen is diffused into the water so the bacteria can survive in aerobic conditions. The air diffusers also keep the bacteria in suspension so it can continually be in contact with the incoming wastewater. In the secondary clarifiers, the bacteria will separated from the treated wastewater. The treated wastewater will continue on to the tertiary treatment step. A majority of the settled bacteria will be sent back to the beginning of the aeration tanks. In the clarifier the bacteria were stressed due to lack of food and oxygen. They begin to undergo endogenous respiration and are so starved they begin to breakdown their own cells to survive. When the stressed bacteria are reintroduced into the aeration tanks they are now in an environment with plenty of oxygen and food. These bacteria will now quickly begin to breakdown the organic wastes in the wastewater much faster than before.

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

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.

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.

Mean Cell Residence Time

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; typically over a 24 hour period.

Review of Basic Principles of Operation

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".

Toxic Substances

Toxic substances can be detrimental to the efficacy of activated sludge systems. Activated sludge treatment relies on living bacteria to feed off the organic wastes and thus removing it from the wastewater. If toxic substances are introduced to the activated sludge system, the bacteria can die off. Without a significant population of bacteria, the organic wastes will not be consumed and the effluent of the treatment plant will have high amounts of BOD_5.

Toxic substances can include heavy metals, pesticides, high concentrations of salts, cyanide, PCBs, and other chemicals. These toxic substances, if introduced in the wastewater collection system, will be sent to the wastewater treatment facility and can destroy the population of bacteria that treats organic wastes. To prevent toxic substances from entering the collection system, municipalities will have pre-treatment programs. These programs will have a public outreach component to inform the community of it's wastewater infrastructure and the harm it can cause if chemicals and other toxic materials are dumped down the drain. In addition to household waste, pre-treatment programs will also work closely with manufacturing and processing facilities to ensure they are not discharging toxic materials in to the wastewater collection system.

Pure Oxygen Treatment

Many treatment plants utilize air blowers or surface aerators to provide oxygen to the bacteria in the aeration tanks. These systems provide oxygen that's in the atmosphere and diffuses it into the wastewater in the tank. One drawback of these methods is that our atmosphere is only around 21% oxygen. A majority of the atmosphere is nitrogen. Having a pure oxygen system is more efficient because the oxygen concentrations can be has high as 99% pure oxygen. However, there are many drawbacks to pure oxygen plants. First off extra equipment will be needed to create pure oxygen. This equipment will have electrical, maintenance, and operational costs associated with it. Secondly, pure oxygen can be extremely hazardous to deal with. At higher purities oxygen can be explosive. Extra caution must be taken to ensure no sparks, oil, or other contaminants are near the pure oxygen generators.

Enhanced Biological Treatment

If the treated wastewater leaving a treatment facility is being discharged into an impaired waterbody, the NPDES permit will most likely have limits on ammonia, nitrogen, and phosphorus. These nutrients at high concentrations can cause eutrophication in a waterbody. Eutrophication occurs when there is an excess of nutrients in a waterbody that spurs algae growth. The algae population will become out of control and consume dissolved oxygen in the waterbody to the point where fish and other aquatic life can not survive. Nitrogen and phosphorus can be removed from the treatment plant by utilizing biological nutrient removal (BNR) processes.

Nitrogen Removal

Nitrogen can be removed from the wastewater by making slight modifications to the activated sludge treatment process. Nitrogen enters the treatment plant has ammonia (NH_3). In the aeration tank aerobic bacteria will nitrify this ammonia to create nitrite (NO_2) and nitrate (NO_3). In a well operated plant a majority of the nitrogen formed is nitrate. The wastewater is then conveyed to an anoxic tank. Anoxic means that the environment where the bacteria are living contains no free dissolved oxygen but there is combined oxygen. The combined oxygen is due to the NO_3 sent to the tank from the aeration tanks. In this anoxic conditions facultative bacteria break apart the NO_3 bond and use the oxygen for respiration. The nitrogen molecules combine to form nitrogen gas (N_2) which is vented back to the atmosphere. Recall, that 78% of the Earth's atmosphere is N_2 gas.

The anoxic tanks in a BNR system can be placed in a number of different configurations. Since the nitrification process is required first to create the NO_3 one would expect to have the anoxic tanks following the aeration tanks. While there are treatment plants that operate in this manner, it may require additional chemicals as the denitrification process requires a certain amount of carbon for the bacteria to feed off of. The amount of carbon available in the wastewater can be measured by the $CBOD_5$ or carbonaceous biochemical oxygen demand. At the end of the aeration tank the aerobic bacteria have significantly reduced the amount of $CBOD_5$ in the wastewater. A process alternative is having the anoxic tank prior to the aeration tank. The wastewater at end of the aeration tank that has been nitrified is then recycled back to the anoxic tank. Here fresh wastewater with high amounts of $CBOD_5$ are mixed with the NO_3 and the conditions will be just right for denitrification to occur. This will also lessen the aeration demands since some of the $CBOD_5$ will be reduced in the anoxic tanks before it enters the aeration tank. One drawback is that not all of the nitrate will be captured and sent back to the anoxic tank. Therefore, another process set up is to have alternating zones of anoxic, aerobic, anoxic, aerobic.

Phosphorus

Phosphorus can also be reduced in a well operated wastewater treatment facility. The amount of phosphorus coming into the facility will determine the level of treatment required. Much of the phosphorus can be removed during the primary and secondary sedimentation processes. If more phosphorus removal is required then treatment plants can utilize enhanced biological phosphorus removal (EBPR). EBPR uses polyphosphate accumulating bacteria (PAO) that, under anaerobic conditions, will accumulate phosphorus in their cells and remove it from the wastewater. A typical configuration of an EBPR process is the RAS and influent wastewater will be mixed in an anaerobic tank where phosphorus reduction occurs. Then the wastewater enters the anoxic tank where the RAS, influent wastewater, and nitrified effluent from the aeration tanks create the ideal environment for denitrification. Then everything is conveyed to the aeration tanks where free dissolved air is added. The incoming ammonia is nitrified to NO_3 and the remaining BOD_5 is reduced.

CHAPTER 3: TERTIARY TREATMENT

Learning outcomes:

- Explain which water quality characteristics tertiary treatment is targeted to remove
- Describe the breakpoint chlorination curve
- Understand how the mixture of ammonia and chlorine creates chloramines
- Compare different methods of wastewater disinfection

Filtration

After the wastewater leaves the secondary clarifiers, filtration is commonly used to remove fine particles that were carried over in the clarifier. Conventional filtration methods use sand and anthracite coal to filter the treated wastewater. The sand and anthracite coal are referred to as media. The filtration process works by gravity. If needed the water will be pumped to a higher elevation, then the gravity will force the water through the media. The media creates small voids between the grains of sand and coal. These voids are small enough that water molecules will pass through but the solids will be trapped. Underneath the media there is an underdrain system that will collect the treated water and convey it to the next treatment process. Eventually the media will be clogged with solids and needed to be backwashed. During a backwash cycle, the filter is isolated so water is entering the filter. Air is then piped into the filter that agitates the media and separates the solids from the media. The air is then turned off and water is pumped from the bottom of the tank and is directed towards a backwash drain. The media is typically heavier than the solids being removed so the media will settle back to the bottom of the filter while the solids are carried with the water into the backwash drain. When the backwash cycle is complete the filter is put back online.

More advanced filtration methods include membrane filtration such as microfiltration and reverse osmosis. These filtration methods work in a similar manner as sand filters but are able to filter smaller sizes. The membranes are manufactured and can have very small pores. Membrane filtration is able to remove contaminants such as arsenic, asbestos, atrazine, fluoride, lead, mercury, nitrate, radium, benzene, and other unwanted chemicals. With the very small micro-holes in the membrane, gravity does not provide enough pressure to force the water through the membrane. Therefore, the water is pumped through the membrane filtration system which increases the pressure.

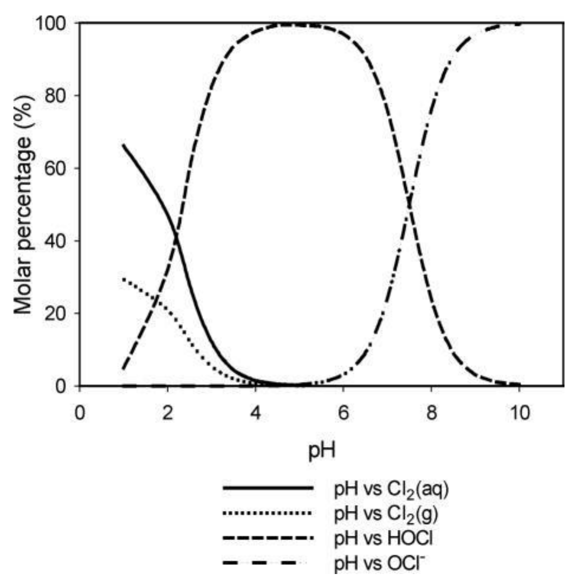
Disinfection

Disinfection is a critical treatment step to ensure that the wastewater treatment facility is protecting public health and the environment. Pathogenic organisms such as *E. coli, Vibrio cholerae, and Salmonella* can spread disease to aquatic life and humans. There are other bacteria, microorganisms, and viruses that can be present in wastewater. The disinfection process will limit the presence of pathogens. It's important to note that the disinfection process is not the same as sterilization. Sterilization will remove all of the bacteria but comes at an extremely high cost that is uneconomical considering the volume of wastewater that must be treated. However, disinfection is still highly effective at limiting pathogens to a level that is acceptable to protecting public health and the environment.

Chlorination and Chloramination

Chlorine is the most common form of disinfectant in the United States and has been in use for over one hundred years in the water and wastewater industry. Chlorine is commercially available as gaseous chlorine or in the liquid form as sodium hypochlorite. Gaseous chlorine is more pure so less gas is needed for disinfection. However, because of the high purity gaseous chlorine can be very dangerous to work around. Treatment facilities that use gaseous chlorine have to comply with rigorous safety training and purchasing regulations. Sodium hypochlorite is commonly sold with a chlorine concentration of 12.5%. Safety precautions must still be used when handling sodium hypochlorite but is a lot safer and easier to work with than gaseous chlorine. Chlorination works due to the fact that chlorine is highly reactive. When chlorine is added to the wastewater it begins to react with all of the chemicals and organic matter in the wastewater. This is known as the demand. Once the chlorine demand is met the extra chlorine added will begin to react with the water creating hypochlorous and hydrochloric acid. Both of these chemicals will be created and the amount of each will depend on the pH of the water.

Hypochlorous acid is more efficient at disinfection and is more prominent at lower pH values. Typical wastewater has a pH of around 6.5 - 7.5 and hypochlorous is the predominant acid. If the pH is above 7.5 treatment facilities may look into adding chemicals to reduce the pH to increase the efficacy of disinfection. When operating chlorination in this manner it's called free chlorine. Enough chlorine has been added to satisfy the demand and the residual is measured as free chlorine. Free chlorine is highly reactive and is a strong disinfectant. Because it's highly reactive the residual does not persist for a long time.



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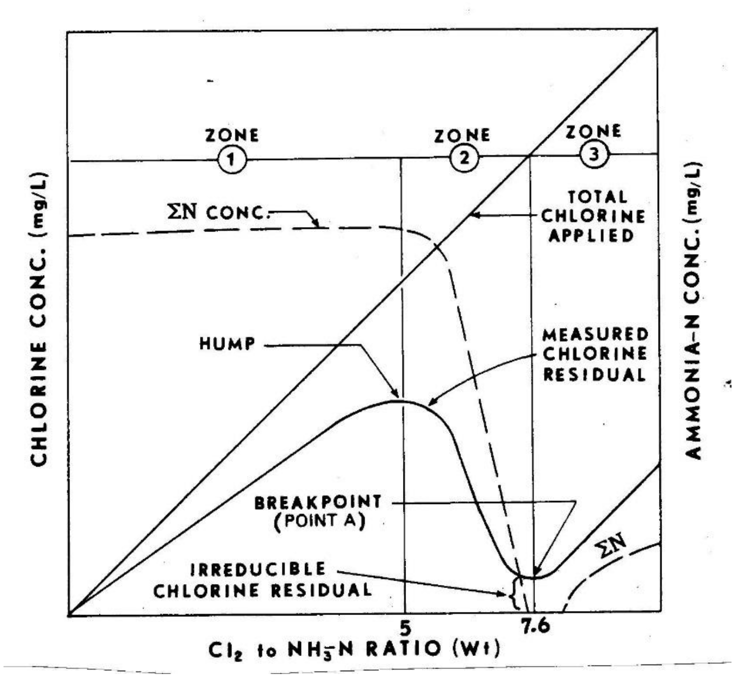
An alternative to chlorination is chloramination. Chloramination is a combined chlorine compound and is created by mixing chlorine and ammonia. Depending on the ratio of chlorine to ammonia, the chloramines created are monochloramine, dichloramine, and trichloramine. Monochloramine is the desired form as it provides a better disinfectant. A ratio of five parts chlorine to one part ammonia will typically yield monochloramine. Chloramination provides some benefits to chlorination. Less chlorine is used since all of the demand doesn't have to be met. Free chlorine has the potential of creating disinfection-by-products. Since chloramination is not as reactive there is a less chance of creating disinfection-by-products. One disadvantage of chloramination is that since it's not as reactive as free chlorine it takes a longer time to achieve the same level of disinfection as free chlorine.

The relationship between the different chloramines and free chlorine is best understood by examining the breakpoint chlorination curve.



In the first part of the breakpoint curve chlorine is applied but no residual is seen. This is because there is an excess demand of organic matter and other chemicals. Once that initial demand has been met more chlorine is applied and a combined residual is formed. In this second zone, ammonia begins to react with the chlorine to create chloramines. In this early stage, monochloramine is the predominant form. If the treatment plant is utilizing chloramination, then ammonia will be added to purposefully stay in this zone. As more chlorine is applied the ratio of chlorine to ammonia increases. In the third zone, the chlorine residual will decrease as the extra chlorine further reacts with the ammonia creating dichloramine and trichloramine. Once the chlorine has reacted with all of the ammonia it reaches breakpoint. After the breakpoint only free chlorine is available.

Dechlorination

Once the wastewater has been properly disinfected the chlorine residual must be neutralized. Chlorine can be harmful to aquatic life and the environment. Since most wastewater is discharged into a waterbody it must be dechlorinated. There are two common chemicals used for dechlorination, sulfur dioxide and sodium bisulfite. Sulfur dioxide is available in its gaseous form and has a lot of the same equipment and safety regulations requirements as gaseous chlorine. Therefore, if a treatment plant is uses gaseous chlorine for disinfection they will most likely be using sulfur dioxide for dechlorination. Sodium bisulfite is available in its liquid form is commonly used at treatment facilities that use sodium hypochlorite for disinfection.

UV disinfection

Chlorine is not the only method that can be used for disinfecting pathogens in wastewater. Ultraviolet (UV) light is becoming a popular alternative. UV disinfection is a physical process rather than a chemical process, like chlorination and chloramination. Because no chemicals are used, there is no residual effect that could be harmful to public health and the environment. UV disinfection works by the intensity of the UV light that disrupts the cell walls of the pathogens. Because the light needs to come in contact with the bacteria, it is critical that the turbidity of the water being disinfected is low. If there is too much turbidity in the wastewater the pathogens will be shield by the material causing the high turbidity.

Ozonation

Ozonation is more widely used in Europe and Asia. Ozone is three oxygen molecules bonded together, O_3. Ozone his highly reactive and must be generated onsite and directly mixed in with the wastewater being disinfected. Ozone is made my taking atmospheric oxygen, O_2, and using electricity to break apart the bond between the two oxygen molecules. The individual oxygen molecules then combined with existing O_2 molecules to create O_3. When the O_3 reacts with the wastewater it will create hydrogen peroxide (H_2O_2) and hydroxyl (OH). These compounds are highly reactive and will disinfect the pathogenic organisms in the wastewater.

CHAPTER 4: WATER RECYCLING

Learning Outcomes:

- Understand the requirements of Title 22 for recycled water
- Know what level of treatment is needed for different recycled water uses

Discharge

By now the wastewater has been completed treated. By undergoing preliminary, primary, biological, secondary, tertiary, and disinfection treatment the water should now meet the rigorous requirements of a National Pollutant Discharge Elimination System (NPDES) permit and be able to discharge in a nearby waterbody. Often the addition of this treated water provides a riparian habitat to many aquatic species. However, a lot of time, money, and energy was put into treating this water. If advanced treatment methods like BNR and membrane filtration were utilized, then the water can be used for other beneficial reuses.

Non-Potable Reuse & Reclamation

To reuse treated wastewater for non-potable reuse, meaning it can not be consumed, it must comply with Title 22 of the California Code of Regulations. Title 22 outlines what level of treatment is required for different types of reuse applications. There are four different types of classifications of water under Title 22, undisinfected secondary recycled water, disinfected secondary-23 recycled water, disinfected secondary-2.2 recycled water, and disinfected tertiary recycled water. Undisinfected secondary recycled water is the lowest level of treatment and therefore has limited application uses. It can be used for orchards or vineyards where the recycled water does not come into contact with the edible portion of the crop. It can also be used for ornamental nursery stock and non food bearing trees as longs as no water is applied to the plants for 14 days prior to harvesting, retail sale, or allowing access by the general public.

Disinfected secondary 23 and 2.2 differ in the level of disinfection. The 23 and 2.2 is referring to results from the Most Probable Number (MPN) test used to determine the effectiveness of the disinfectant. An MPN of 2.2 is the lowest level of detection for the test and therefore a lower chance of pathogenic organisms existing in the sample. As the wastewater goes through higher levels of treatment it can be used for more non-restrictive uses. Disinfected secondary-23 recycled water can be used for irrigation purposes but only in areas where there is a limited chance of the water coming in contact with the general public. For example, it can be used to water freeway landscaping, cemeteries, and golf courses with restricted access. Disinfected secondary 2.2 recycled water can be used for irrigation of food crops where the edible portion is produced above ground and not contacted by the recycled water.

Disinfected tertiary recycled water is highest level of treatment defined by Title 22 and can be used for pretty much any type of irrigation. It can be used on food crops where the recycled water does come into contact with the edible portion of the crop. It can be used to irrigate parks, playgrounds, school yards, and residential landscaping. Disinfected tertiary recycled water can also be used for other purposes such as flushing toilets, industrial processes, fire fighting, decorative fountains, and car washes.

Indirect Potable Reuse

Title 22 also regulates using recycled water for indirect potable reuse. It outlines two ways to do this, either by surface application or subsurface application of groundwater replenishment. Surface application is when the recycled water is sent to a percolation basin. The water is forced by gravity through the voids in the soil which adds an extra layer of filtration as the water enters a groundwater aquifer. The water is then pumped out of the aquifer and sent to a water treatment facility where it is further treated and ultimately is used for potable water.

Subsurface application is when the water is pumped directly from the treatment plant discharge to the groundwater aquifer. Since this method does have the added treatment benefit of the water percolating through the soil, additional advanced treatment methods are needed at the wastewater treatment facility. The tertiary treated wastewater will typically go through reverse osmosis membrane filtration prior to being injected into the groundwater aquifer.

CHAPTER 5: SOLIDS HANDLING PROCESSES

Learning Outcomes:

- Understand where solids from the wastewater treatment are generated
- Compare the different ways to thicken wastewater solids

Biosolids

For many years the solids leaving the wastewater treatment plant was referred to as sludge. The term sludge is still used but typically refers to the untreated raw sludge leaving the primary clarifiers or the waste activated sludge (WAS) leaving the secondary clarifiers. However, once the sludge has been treated in can be converted to biosolids. Biosolids can be used for many beneficial purposes such as compost, fertilizer, and landfill cover. In the liquid portion of wastewater treatment the goal was reduction of organic matter. Much of that organic matter ends up in the sludge. In biosolids it's that organic matter that can be used for composting. There is also an ample amount of nitrogen and phosphorus which are key components in fertilizer. That organic matter has a lot of potential energy. During the digestion treatment stages this energy can be captured and used to power other portions of the treatment process.

Primary Treatment Sludge Thickening

Gravity thickening is commonly used to thicken primary solids. The purpose of thickening is to reduce the water content. This makes a more concentrated sludge that will require smaller digesters in the next treatment stage. Gravity thickening works very similarly to primary sedimentation. However, instead of starting with raw wastewater we are starting with concentrated sludge. In the primary sedimentation tank the raw wastewater will increase from around 1% solids to up to between 4% and 6% solids. Starting with the higher percent solids concentration and putting it through the similar treatment process can further increase the solids concentration to 10% or greater. By increasing the percent solids the sludge becomes thicker. It's getting thicker because the water is being removed.

Similar to the sedimentation process gravity thickeners rely on the heavy solids in the sludge to settle by gravity to the bottom of the thickener. As the solids settle the water will be separated out. The tank will become stratified with larger amounts of solids on the bottom of the tank and layer of water with less solids on top. The top layer is referred to as the supernatant and the bottom layer is called subnatant. To optimize the performance of a gravity thickener it's critical to have "fresh" primary sludge. Sludge that is becoming or has already gone septic will not settle as easily as newer sludge. Therefore, controlling the rate of pumping from the primary sedimentation tank to the gravity thickener must be closely watched. If the sludge is going septic in the primary tanks then the pumping rate will need to be increased. This will lower the detention time a keep the sludge from going septic. However, if it's pumped to quickly then the percent solids might be decreased which is also not optimal. Another way to deal with septic sludge is to add chlorine to reduce the biological activity.

Secondary Treatment Sludge Thickening

When thickening secondary sludge or a mixture of secondary and primary sludge, a dissolved air flotation thickener (DAFT) is commonly used. A DAFT works by taking a portion of the clear subnatant leaving the DAFT and pressurizes the water with an air compressor. The water is then conveyed back into the DAFT where it is exposed to atmospheric pressure. The difference in pressure causes lots of tiny air bubbles to be released, just like opening a soda bottle. The tiny air bubbles will float to the top of the DAFT. The incoming sludge will not be able to settle to the bottom because of the rising air bubbles. Therefore, the solids remain on the top layer and the bottom layer is clearer water. The solids will be skimmed off and sent to a hopper where it will be pumped to the next stabilization treatment stage. The clearer water on the bottom will be sent back to the headworks to be further treated in the liquid portion of the treatment process.

A DAFT can typically create a solids concentration between 4% and 8%. The return water is pressurized between 40 and 70 psi. A key parameter to a well operated DAFT is the air to solids ratio. A common air to solids ratio is around 0.02 to 0.04. If not enough air is supplied to the tank then the solids will settle to the bottom. Other operational parameters are the speed of the skim arm. Operators should set the speed to slowly skim the thickened sludge into a hopper. If the skim arm speed is set to high it will thin out the solids and reduce the percent solids concentration. There should be about a 1 to 3 foot blanket of thickened sludge on the DAFT. Polymer is often added to aid the coagulation of solids. This also the solids to bind together and make larger particles that will more easily float to the top of unit.

CHAPTER 6: BIOSOLIDS STABILIZATION

Learning Outcomes:

- Compare and contrast the various sludge stabilization methods
- Understand the different biological processes to stabilize wastewater solids
- Describe the different types of bacteria used during anaerobic digestion at different temperatures

Sludge Stabilization

Once the solids have been thickened they are ready to be stabilized. At this point the solids have only been thickened and they are the waste products of the liquid portion of the treatment process. There is a large amount of volatile organic material that needs to be stabilized. Stabilization will also help reduce odors and destroy pathogens. There are several different methods to achieve this. Digestion is the most common but stabilization can also be achieved by adding chemical or thermal stabilization by heating the sludge.

Aerobic Digestion

Aerobic decomposition is very similar to the aeration tanks discussed earlier in the activated sludge systems. The primary and/or secondary sludge is digested aerobically, meaning that aerobic bacteria will break down the organic matter. The digesters can either be rectangular or round. The bacteria are aerobic so air must be applied to the digester.

One major difference between the aeration tank in the activated sludge tanks and the aerobic digester is that there is not a continual supply of fresh BOD_5. In the digester there is no fresh wastewater coming in only the settled solids. In the digester the aerobic bacteria will be able to breath but with no food source they will undergo endogenous respiration. In this state the bacteria begin to breakdown their own cell mass and thus reduce the amount of volatile suspended solids. Aerobic digesters will have a longer detention time, typically on the order of 30 days or more. Common volatile solids reduction can be around 45% to 70%

Anaerobic Digestion

Recall that anaerobic means the environment has no free or combined sources of oxygen. Bacteria must find a different source of respiration. Anaerobic digestion is a two-step biological treatment process. The first step is done by a group of bacteria that breakdown solids to form volatile acids. The second step is another group of bacteria breaking down those volatile acids to form methane, carbon dioxide, and water.

When checking the operation of a digester, pH is a critical parameter. The first step of the digestion process is to create volatile acids. Excessive acids will cause a drop in pH. A pH between 6.6 and 7.6 is considered an acceptable range. If the pH drops below this then that is a sign there are not enough methane forming bacteria to breakdown the volatile acids. Another way to examine this is by looking at the volatile acid to alkalinity ratio. Large amounts of alkalinity in the sludge will be able to buffer drastic changes in pH. If there isn't enough alkalinity the pH could drop significantly and adversely affect the bacteria in the digester.

Mixing is also an important design and operation requirement. Good mixing will distribute the sludge evenly throughout the tank. This allows the bacteria to come in contact with the raw sludge and aid the digestion process. Proper mixing will also prevent separation of grit and other inert solids. It will also prevent the development of a scum layer at the top of the digester.

There are three different types of anaerobic digestion based on what the operating temperature of the digester is. They are classified by the type of bacteria that is most abundant at the specified temperature ranges. The most common type is mesophilic, which operates between 85°F and 100°F. This is the same type of anaerobic digestion that occurs in human stomach. Psychrophilic digesters will operate between 50°F and 68°F. The advantage of this type of digester is external heating systems are not needed to raise the temperature. However, at these colder temperatures the bacteria are not as active. Therefore, psychrophilic digester will require a longer detention time to achieve stabilization of the solids. Going hotter than mesophilic is thermophilic. These digesters operate between 120°F and 135°F . At these higher temperatures, a detention time of 5 to 12 days can sufficiently stabilized the solids. However, there is an added cost to heat the sludge to these higher temperatures.

Chemical Stabilization

Chemical stabilization is achieved by adding calcium hydroxide, $Ca(HO)_2$. It's also commonly known as slaked lime. Adding the lime will raise the pH of sludge to the point where biological activity is drastically reduced. This is much different from digestion because the organic matter is not reduced. The lime temporarily halts the biological activity and thus stabilizing the sludge. The sludge is then disposed of to a landfill. Chemical stabilization is not as common due to the high costs, regulations, and environmental impacts of handling chemicals.

CHAPTER 7: BIOSOLIDS TREATMENT

Learning Outcomes:

- Compare and contrast the different methods of biosolids dewatering
- Understand the limits of different biosolids dewatering methods
- Compare the energy and labor requirements of different biosolids dewatering methods

Sludge Dewatering

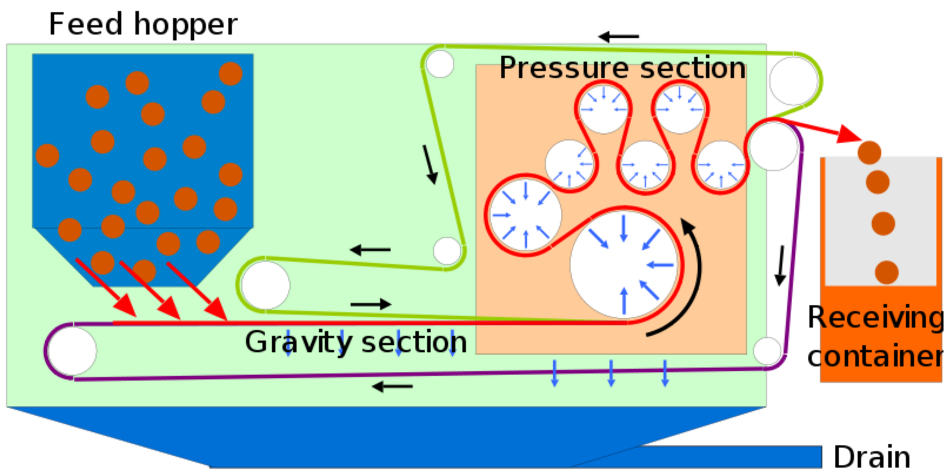
Sludge dewatering is exactly what it sounds like. At this point the sludge has been stabilized by reducing the amount of volatile organic material. It's almost ready for disposal which usually means it will need to be transported somewhere. This can be very expensive because the sludge is still mostly water. Dewatering removes a lot of the water and increases the percent of solids. This will make transporting the dewatered biosolids much more cost effective.

Drying Beds

The simplest and cheapest way to dewater sludge is by drying beds. The sludge is sent to the drying beds where the sun heats it up and evaporates the water. This process can take several weeks or even months to achieve the desired percent solids. Also, the process is dependent on weather. In colder months it can take even longer. There are some adaptation to increase the process. Some drying beds will be slightly sloped with sand in the middle. There is an underdrain system beneath the sand. With sand beds the water is being evaporated by the sun but is also being directed towards the sand and filtered through to the underain system where it is then sent back to the headworks of the treatment plant. There are also vacuum assisted drying beds. Similar to sand drying beds but instead of relying on gravity for the water to drain a vacuum is created to force the water out. Drying beds are efficient and cost effective for smaller systems and where land is available.

Belt Presses

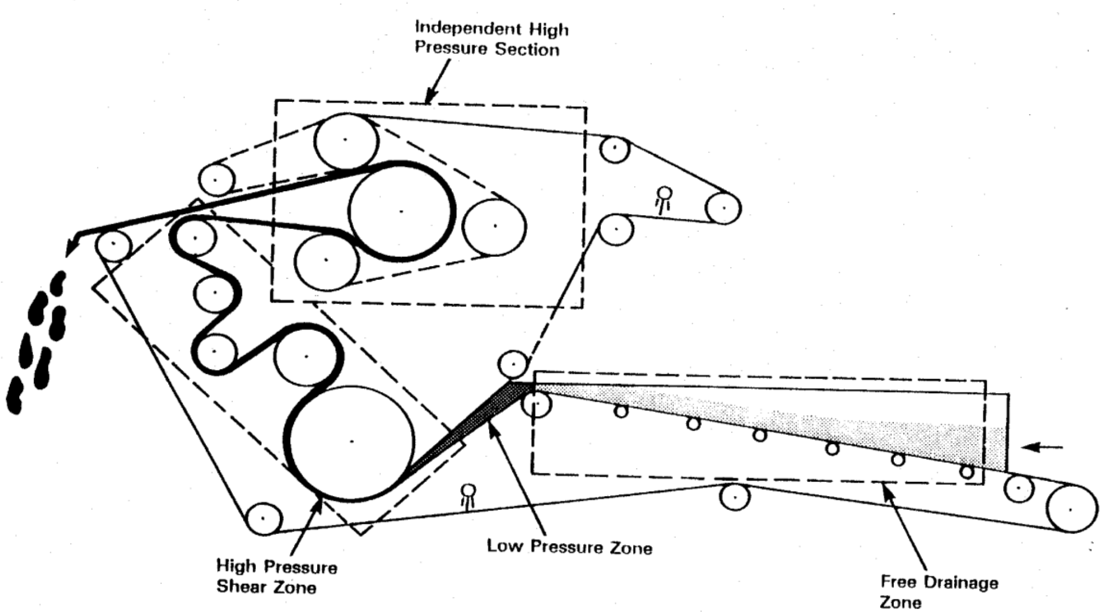
A belt filter press consists of two long filters. The sludge will be conveyed in between these two filters and then sent through progressively higher areas of pressure where water is squeezed through the filter and the solids are left behind. The first part of the belt filter press is the gravity zone. Here the digested sludge is mixed with polymer and begins to coagulate the solids. The solids are then conveyed and sandwiched between the other filter. There is then a low pressure section where water is forced between the filters and removed. The pressure then gradually increases as the filters are rolled through the belt press. This gradual increase allows more and more water to be removed. At the end of the belt press the two filters separate and the biosolids are scraped off and sent to a conveyor belt. Belt presses can achieve around 13% to 18% solids. Oftentimes belt presses are combined with drying beds to further increase the percent solids.



Belt Press - Image by Wikiwayman is licensed under CC BY-SA 3.0

Filter Presses

There are a couple of different types of filter presses. The most common is the plate and frame filter press. The unit consists of a series of filter plates. The plates are forced together with a hydraulic press and sludge is conveyed in between each of the plates. As the sludge is pumped into the filters the solids are trapped by the filter and the water passes through and is collected in a drain system. As more and more sludge is pumped into the filters the pressure will begin to increase. This extra pressure will cause even more water to be forced through the filters and out of the sludge. When the pressure reaches its maximum the operator will stop feeding sludge to the filters. The plates are then released from the hydraulic press and separated. As the plates separate the dried biosolids will fall off the filter plates and drop below to either a conveyor belt or often times to the bed of a dump truck. The biosolids will then be sent off for ultimate disposal. A well operated plate and frame press can achieve a solids concentration of 40% to 50%.



Filter Press - Image by the EPA is in the public domain

Another type of filter press is vacuum filtration. This consists of a circular drum with a filter material on the outside. The drum is submerged into a trough filled with the digested sludge. The drum slowly rotates while a vacuum is being created inside the drum. The vacuum pulls the water out of the trough. The solids are stuck on the outside of the filter while water is able to filter through and be sent to the drain system. By the time the drum does a full circle the percent solids has increased significantly and the biosolids are scraped off to a conveyor system where they are sent to a dump truck.

Waste Stream Recycling

The water being removed from the dewatering process needs to be sent back to the liquid portion of the treatment plant to be further treated. However, this water is often very high in ammonia and can overwhelm the bacteria in the activated sludge process. Some treatment plants will slowly pump this water back to the treatment plant so there isn't a large slug of ammonia going through the system. Others will only pump the water back during the night time hours when ammonia coming into the treatment plant is often lower. Some newer technologies will actually treat the water prior to being sent back to the headworks.

Sludge Disposal

Now that the sludge from the primary sedimentation and secondary clarifiers have been stabilized and dewatered we can call it biosolids. The biosolids need to either be be disposed of or reused. Biosolids are classified into two separate types by the EPA. Class B biosolids have been treated by the processes discussed in this chapter but can contain high levels of pathogenic organisms. Therefore, Class B biosolids have greater restrictions on land application and crop harvesting. Class A biosolids typically undergo a combination of the treatment processes discussed in this chapter to achieve lower levels of pathogens. Class A biosolids that meet EPA regulations can legally be resold as fertilizers.