Lesson 18:

The Activated Sludge Process

Objective

In this lesson we will learn the following:

- How the activated sludge process treats wastewater.
- The importance of ensuring the proper microorganisms exist for waste reduction.
- Variations of the activated sludge process.

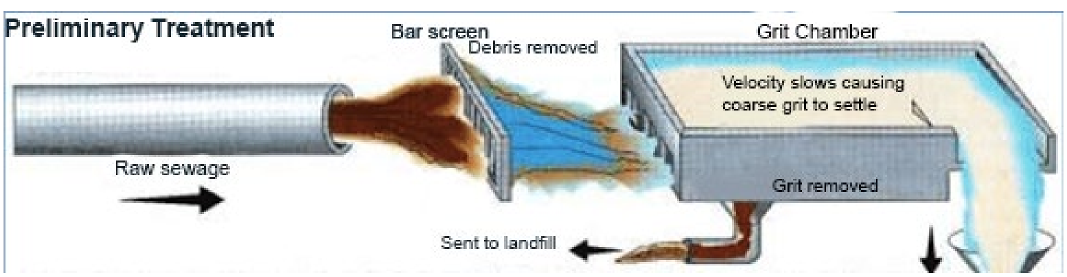
Reading Assignment

Read the online lecture.

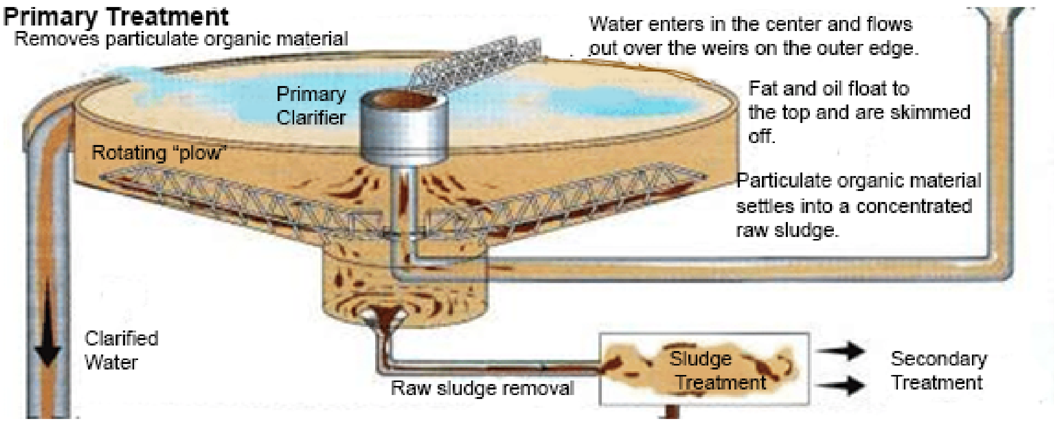
Lecture

Introduction

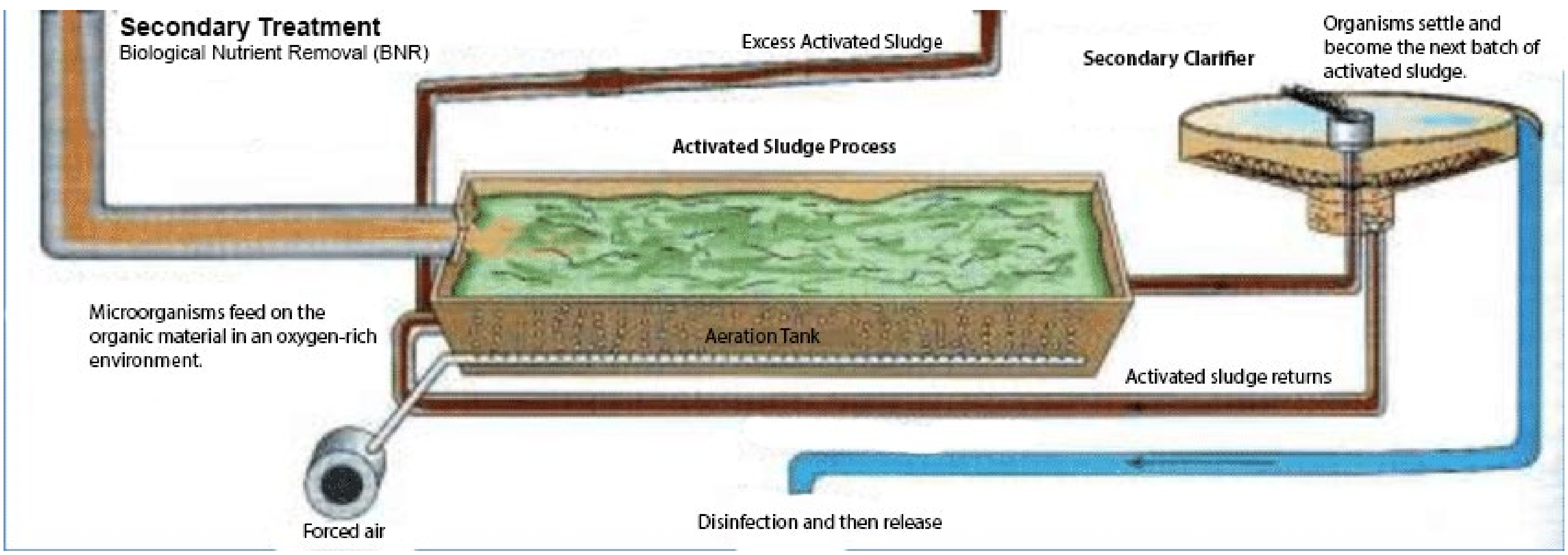
Let's do a quick recap of the processes covered so far. First, the waste stream undergoes preliminary treatment by removing grit and debris.



Next, it enters the primary clarifier for particulate organic material removal.



The next step of treating wastewater is *secondary treatment*, where the rest of the organics are removed. This step is also known as **biological nutrient removal**.



The **activated sludge process** is the most commonly used method of reducing the organic load of the wastewater stream after primary treatment. When the concentration of organic pollutants is reduced, the oxygen demand placed on the receiving waters is also reduced. This process is also able to oxidize ammonia, reduce the Carbonaceous Biochemical Oxygen Demand (CBOD) and also remove nitrogen and phosphorus from the waste stream.

So, what is BOD and CBOD? BOD stands for Biochemical Oxygen Demand and it represents the amount of oxygen required by microbes to biochemically oxidize organic and inorganic contaminants in the waste stream. The BOD must be reduced before the wastewater is released into the receiving water. This ensures that an excessive oxygen demand will not be placed on the receiving water body, which could cause fish kills or algal blooms.

Total BOD represents the total oxygen demand caused by both carbonaceous BOD (CBOD) and nitrogenous BOD (NBOD), which all play a role in the treatment of wastewater. *Carbonaceous BOD (CBOD)* reflects the oxygen demand created by the oxidation of *organic* carbon substances (sugars, fats and proteins). *Nitrogenous BOD* measures the oxygen demand created by the oxidation of *inorganic* nitrogen compounds, like ammonia and nitrite.

Using the activated sludge process to remove nutrients like nitrogen or phosphorus is referred to as *tertiary treatment*. The main goal is to remove CBOD to the following EPA established limits (based on 30 day average):

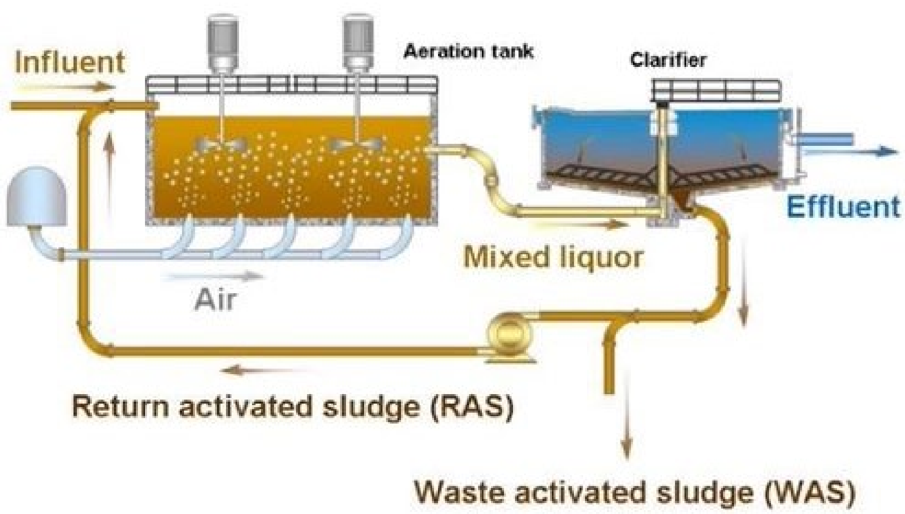
BOD: ≤ 30 mg/L
CBOD ≤ 25 mg/L

The composition of the wastes stream and the NPDES limits for the utility will determine the removal requirements and mode of operation for each treatment plant. The parameters will change between a conventional plant and one that utilizes tertiary treatment, which is just an added step of treatment after conventional primary and secondary treatment.

The table below shows typical removal requirements and operational mode for CBOD and suspended solids removal:

Removal Requirement	Conventional Plant	Tertiary Treatment
Effluent CBOD	5-15 mg/L	<5 mg/L
Effluent SS	15 mg/L	<5 mg/L

There are many different variations of the activated sludge process, even though they all have the same basic characteristics, including:



- **Biological Reactor (Aeration Tank):**
  This is where all the magic happens: where the microbes do their work in the aeration basin. The contents of this basin are referred to as Mixed Liquor (MLSS), since it is comprised of several components, such as soluble, colloidal and suspended material both biodegradable and non-biodegradable in nature. The **organic** portion of the MLSS is called **Mixed Liquor Volatile Suspended Solids (MLVSS)** and makes up approximately *70-80% of the MLSS*.

- **Oxygen Source:**
  The microbes in the reactor are aerobic, which means they need oxygen to thrive and treat waste. This is supplied in different ways, including mechanical aeration, blowers and diffusers.

- **Mixing Mechanism:**
  Each basin must have a way to keep the microbes in suspension so they are able to come into contact with as much waste as possible. This is achieved through mixing mechanisms, which also ensures sufficient dissolved oxygen (DO) is distributed throughout the basin.

- **Clarifier:**
  After spending adequate contact time in the biological reactor (aeration basin), the mixed liquor flows to a clarifier where the solids are separated from the liquid. The clarified liquid flows over the effluent weir to the next process, while the solids

collect on the bottom of the clarifier for removal.

- **Sludge Collection System (Return Activated Sludge (RAS)):**
  The sludge collection system moves the settled sludge to a common point where it can be pumped back to the aeration tank for further treatment, or sent to the solids handling facility for disposal.

- **Sludge Wasting System (Waste Activated Sludge (WAS)):**
  While the microbes are in the aeration tank they reproduce very quickly, becoming overpopulated and starving with the amount of wastewater being treated. It is important to maintain a desired microbial population for process control, which is done through sludge wasting. This is linked with the *Mean Cell Residence Time (MCRT)*, which is the amount of time microbes are in the process.

Biochemical Reactions

In the activated sludge process, the BOD and suspended solids are reduced through a variety of biochemical reactions. In the first step, carbonaceous BOD (CBOD) is reduced through a **chemoheterotrophic aerobic reaction**:

$$\text{Organic matter} + O_2 + \text{nutrients} + \text{microbes} \rightarrow \text{new microbes} + CO_2 + H_2O$$

When the organic matter, nutrients and microbes in the aeration basin are given oxygen, it produces new microbes, water and carbon dioxide as a byproduct. These new microbes are either wasted (WAS) or returned (RAS) to do more work in the aeration basin.

The second reaction that occurs helps to reduce the nitrogenous BOD (NBOD) in the waste stream. This occurs through a **chemoautotrophic aerobic reaction** known as **nitrification**. Nitrification is an aerobic process in which ammonia-oxidizing bacteria, known as *Nitrosomonas*, change the ammonia (NH_4) and organic nitrogen in the wastewater into oxidized nitrogen, usually nitrate (NO_2).

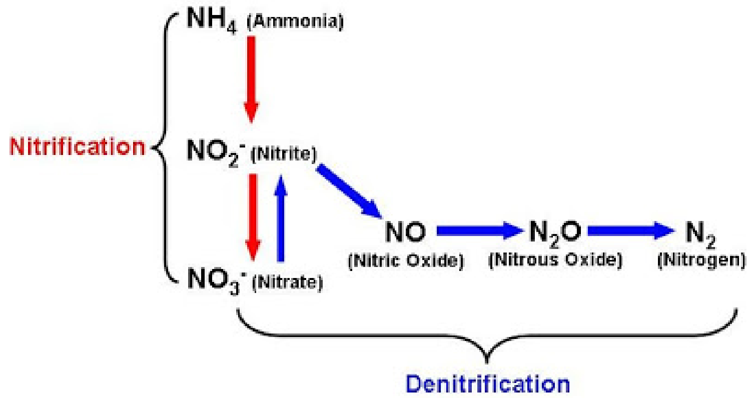
Complete nitrification of ammonia (90% removal) will require more oxygen than a non-nitrifying conventional plant designed to remove CBOD only. **The amount of oxygen required for nitrification to occur is 4.6 kg for every kg of ammonia-nitrogen that is oxidized to nitrate.** This may account for 25% of the total oxygen required to treat for CBOD and ammonia nitrification.

The operator must ensure that the basin environment is maintained within the desired parameters for nitrification to occur:

DO	2-3 mg/L
pH	6.5-8.5
Alkalinity	50 mg/L as $CaCO_3$
MCRT	> 4 days, > 10 days
Temperature	15-30°C

To complete the removal of nitrogen from the waste stream, **denitrification** must occur. This is achieved by having an unaerated zone at the beginning of the reactor (basin) where the RAS combines with the MLSS recycle flow.

The nitrite is further converted into nitrate (NO_3) by *Nitrobacters*, or nitrite-oxidizing bacteria.



The last biochemical reaction to occur in the activate sludge process is a **chemoheterotrophic anoxic reaction** with creates **denitrification** in the system. Denitrification is an *anoxic* (low oxygen) process that occurs when nitrite or nitrate ions are reduced to nitrogen gases and bubbles. The bubbles attach to the biological floc in the process and float it to the surface of the secondary clarifiers. This condition is often the cause of rising sludge in the secondary clarifier.

Denitrification removes 85-95% of nitrogen from the waste stream by reducing nitrate to nitrogen gas in the absence of dissolved oxygen and the presence of an organic carbon source. **Denitrification increases the alkalinity at a rate of 3.6 mg $CaCO_3$ for every mg of nitrate that is denitrified.**

The microorganisms that populate the aeration basin include:

- Flocculated bacteria
- Fungi
- Protozoa
- Rotifers

These biochemical reactions show the flexibility of the activated sludge treatment process. Conditions within the basin can be altered to encourage the appropriate microbial population for maximum treatment. Some of the parameters that can be controlled include the *dissolved oxygen and nutrient levels*, *MCRT*, and the *hydraulic residence time* (HRT). This is basically how much oxygen the microbes need, amount of time in the basin and how fast the waste stream has to move to accomplish this. Controlling *these* parameters is the primary function of the treatment operator.

Activated Sludge Process Variations

One way to classify an activated sludge plant is to evaluate the loading rate. This process can be classified as high-rate, conventional, or low-rate.

Loading Rate Classification				
Loading Range	**MCRT (days)**	**Volumetric Loading (lb BOD/1,000 ft^3)**	**F:M (lb:lb/day)**	**BOD Removal**

Hight rate	1-3	100-1,000	0.5-1.5	50-95%
Conventional	5-15	20-40	0.2-0.5	85-95%
Low rate	20-30	10-25	0.05-0.15	75-95%

*Notice how the MCRT and F:M ratio are *inversely* related. As the time spent in the process (MCRT) goes up, the F:M ratio goes down.

As well as classifying the process as high rate, conventional or low rate, the *configuration* will also distinguish one plant from another. Each configuration will adjust the dissolved oxygen, HRT, MCRT and RAS to remove BOD, ammonia, nitrogen and phosphorus from the waste stream.

Some of the most common configurations utilized include:

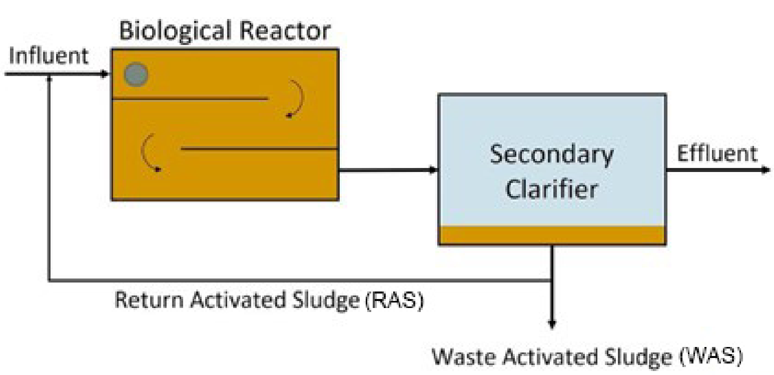
- Plug-flow
- Sequencing batch reactor (SBR)
- Oxidation ditch
- Contact stabilization
- Step-feed
- Use of Selectors before the reactor
- High purity oxygen system
- Biological Nutrient Removal

The above configurations vary in how the waste stream is added and how the oxygen is introduced to the basin. These adaptations are designed to remove nitrogen only, phosphorus only or removal of both.

The biological removal of phosphorus is similar to that of nitrogen, except that the unaerated zone should be completely *anaerobic* (No dissolved oxygen (DO) or chemically bound oxygen in the form of nitrates). The **anaerobic** environment allows phosphorus-accumulating organisms (PAOs) to gain the advantage over other microbes in BOD assimilation.

Let's dive in a little deeper and learn about the different configurations that can be used

Plug Flow

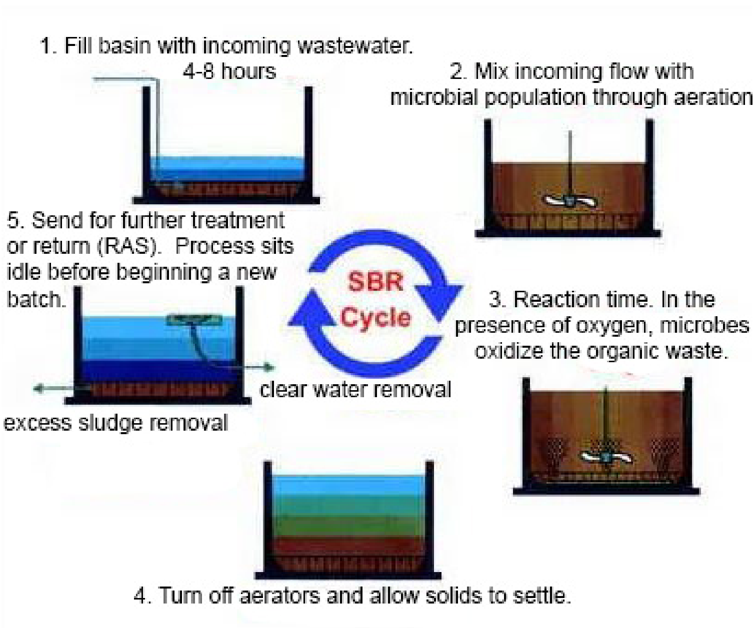


In the plug flow configuration, the waste stream enters the biological reactor, or aeration basin, on one end and exists the opposite end. As the waste stream flows through the basin, the BOD will deplete while the suspended solids will increase. This activated sludge configuration provides the highest BOD removal rate.

Sequencing Batch Reactor (SBR)

In the sequencing batch reactor (SBR) configuration, all treatment and clarification takes place in the same tank. The wastewater is treated in batches and is used in systems with low waste stream flows ranging at 1 MGD or less.

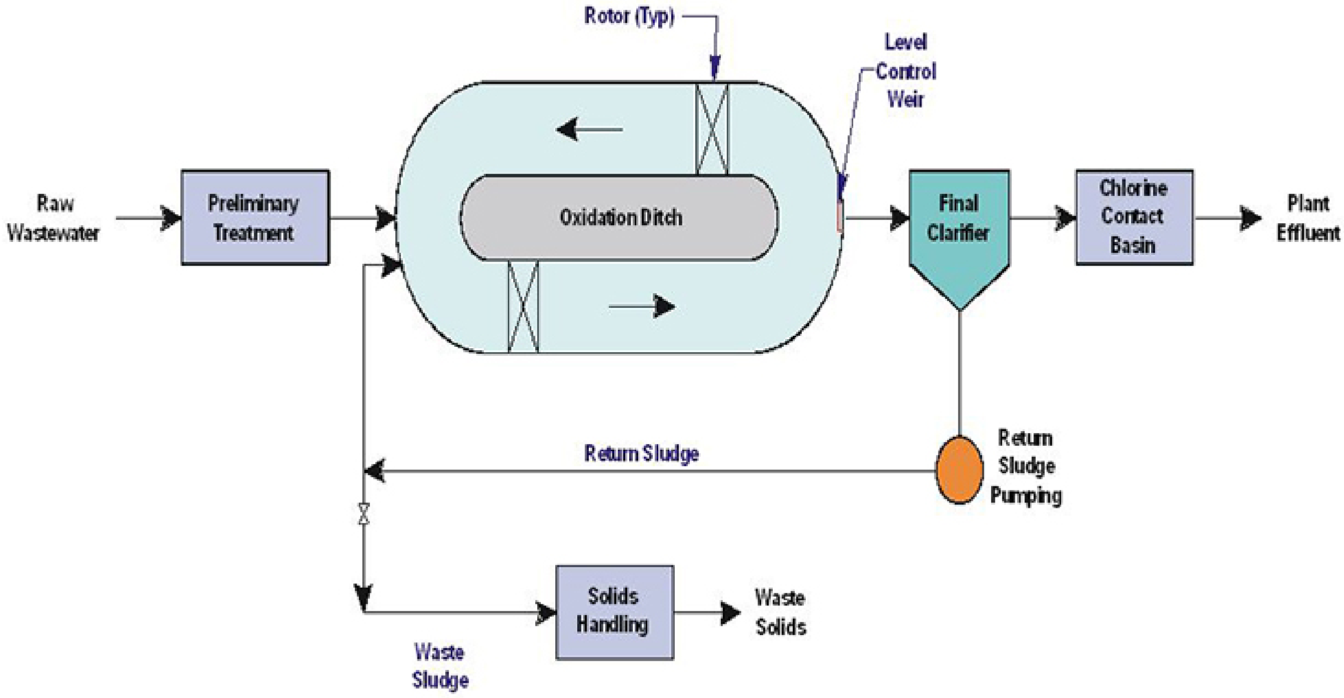
The tank, which contains thickened activated sludge, is filled with raw wastewater and then aerated for a period of time. The aeration system is cycled on and off every 2 hours while filling the basin, which takes a total of 8 hours for complete fill. The solids are then allowed time to settle while the treated water is transferred from the upper level of the tank.



The SBR process can be controlled to imitate many of the activated sludge process variations listed above. This is done by changing the sequence and time of the feed and aeration process. The SBR can effectively simulate the following variations:

- Plug flow
- Step-feed
- Contact stabilization
- Biological Nutrient Removal (BNR) systems

Oxidation Ditch



The oxidation ditch configuration is a low rate process with a high hydraulic retention time (HRT). The waste stream is circulated by mechanical aerators that are placed on each side of the ditch. This configuration is used in small to medium sized applications and is very stable because of the low F/M and high MCRT.

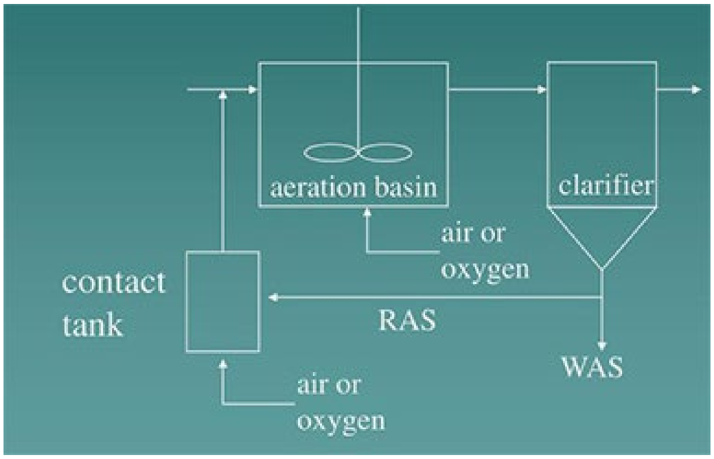
The raw wastewater flows into the basin, which contains mixed liquor that has not had primary settling. For this configuration, sometimes bar screens and comminutors are the only pretreatment of the wastewater before it enters the ditch. The flow speed of the wastewater allows the grit to settle out in the ditch. The dissolved oxygen level is dependent upon the water depth in the oxidation ditch. The deeper the water level, the deeper the rotors can go into the stream, creating more oxygen.

If the oxidation ditch develops a crisp, white foam the operator should reduce the sludge wasting because it indicates a young sludge age or that the wastewater isn't spending enough time in the basin (low Mean Cell Residence Time (MCRT)). A dark foam indicates old foam and indicates the sludge wasting volume should be increased so it doesn't stay in the basin longer than needed. Allow several days for the process to stabilize before tweaking the parameters again. The operator is shooting for a waste stream that is medium to dark brown, which occurs if the sludge age is greater than 10 days.

The following parameters are the normal operating range for an oxidation ditch:

- Flow = 0.8 - 1.2 fps
- MLVSS = 2,000 - 6,000 mg/L
- DO = 0.5 - 2 mg/L
- MCRT = ≥ 10 days
- F/M = 0.03 - 0.1 lb BOD/day/lb MLVSS

Contact Stabilization



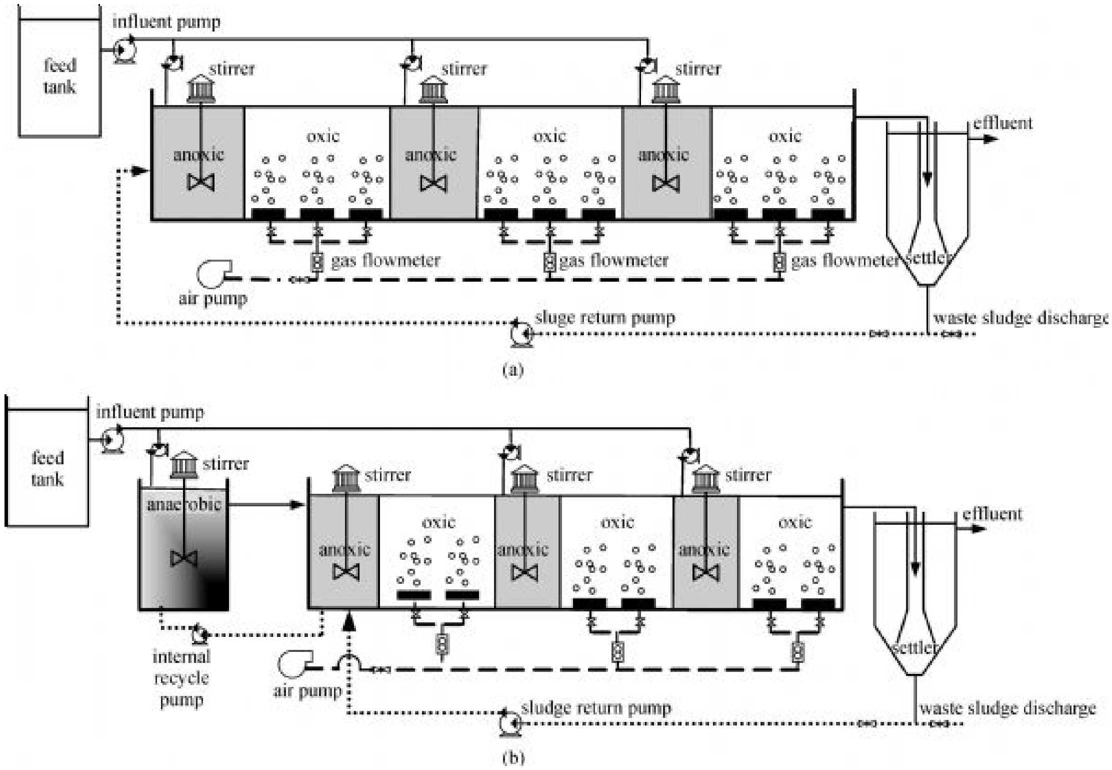
This configuration relies on biosorption, which is a physiochemical process that occurs naturally in certain biomass. The process allows it to passively concentrate and bind contaminants onto its cellular structure, which uses the BOD in the wastewater. Let's watch a short video that explains what occurs in this configuration.

The waste stream enters the aeration basin and stays approximately 30 minutes to 1 hour while biosorption takes up the BOD present in the wastewater. The Solids Retention Time (SRT) which is similar to MCRT, ranges from 3 to 15 days. The returned sludge (RAS) is usually 40-70% of the flow, with the balance being wasted (WAS).

In the contact tank microbes stay for hours to stabilize before going back to the influent and re-enter the aeration basin. The majority of the solids are in the contact tank, so it doesn't effect the outgoing effluent as much.

Step-Feed

The step-feed activated sludge configuration can be operated as the conventional process, step-feed process or the contact stabilization process. Another type of step-feed configuration has a compartmentalized biological reactor.

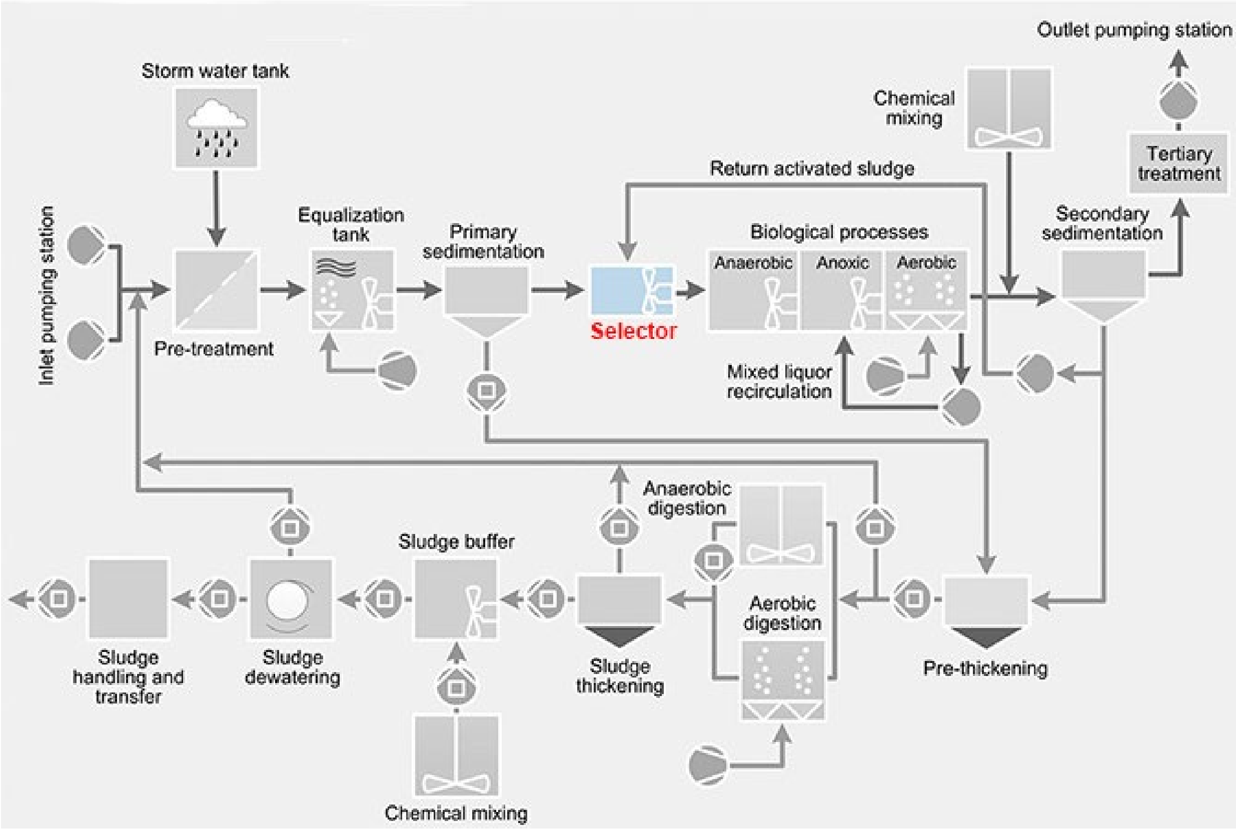


**Anoxic = no oxygen; Oxic = oxygen*

As you can see in the first configuration, the waste stream enters the system at three different locations. In the second configuration, there are two points of entry, but the reactor is compartmentalized.

Selectors

By placing selectors before the biological reactor, the operator can create conditions that favor one microorganism over another. This does NOT include filamentous bacteria since they create bulking and foaming. You want sufficient oxygen and nutrients to favor the good settling bacteria. Organic loading is very high, which favors the good settling bacteria. In these selectors, the hydraulic retention time (HRT) is usually 10-30 minutes and the DO level is above 1 mg/L.



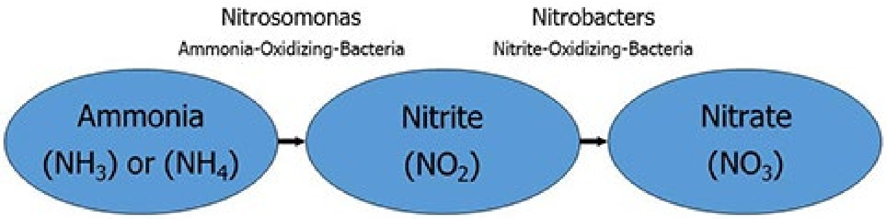
The diagram above illustrates using selectors on modified plug collectors. This type of configuration has baffles added to the basin to create different compartments, for different DO levels (aerobic, anaerobic and anoxic).

Other Modifications: Nitrogen and Phosphorus Removal

Nitrification Process

As mentioned above, the nitrification process occurs through a **chemoautotrophic aerobic reaction**. Nitrification is a two-step process. Bacteria known as *Nitrosomonas* convert ammonia and ammonium to nitrite. Next, bacteria called *Nitrobacter* finish the conversion of nitrite to nitrate. Biological nitrification is the process in which *Nitrosomonas* bacteria oxidize ammonia to nitrite and *Nitrobacter* bacteria oxidize nitrite to nitrate. This process results in the overall conversion of ammonia to nitrate.

These microorganisms are autotrophic, which means they derive their carbon source from inorganic carbon, such as carbon dioxide and bicarbonate. Most other types of organisms in activated sludge are heterotrophic, which means they derive their carbon source from the organic matter in the wastewater. Environmental conditions of pH, alkalinity, temperature, dissolved oxygen concentration and organic loading affect the nitrification process in activated sludge plants.



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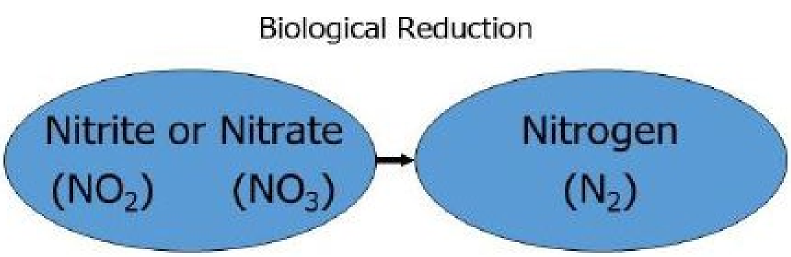
Denitrification Process

In review, the denitrification process occurs through a **chemoheterotrophic anoxic reaction** in the system. Denitrification is an *anoxic* (low oxygen) process that occurs when nitrite or nitrate ions are reduced to nitrogen gases and bubbles. The bubbles attach to the biological floc in the process and float it to the surface of the secondary clarifiers. This condition is often the cause of rising sludge in the secondary clarifier. Dissolved oxygen inhibits denitrification. As DO increases, denitrification rate decreases. Maintain DO below 0.3 mg/L in the anoxic zone to achieve denitrification.



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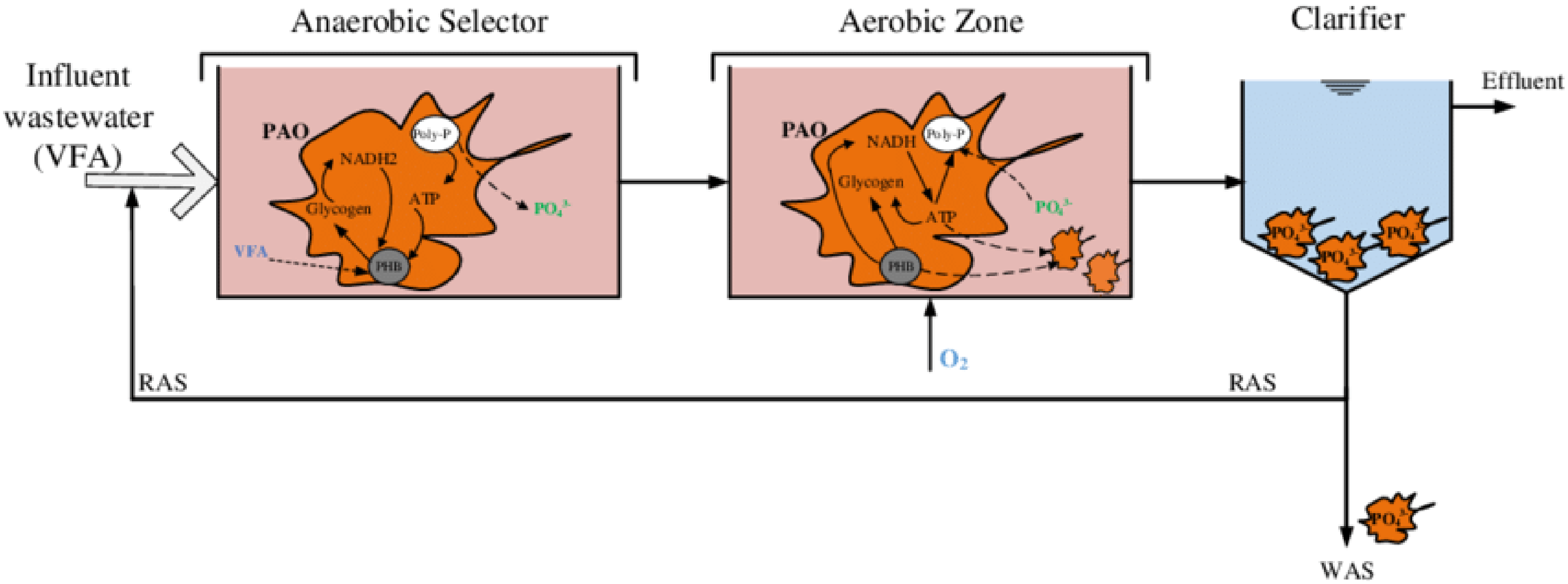
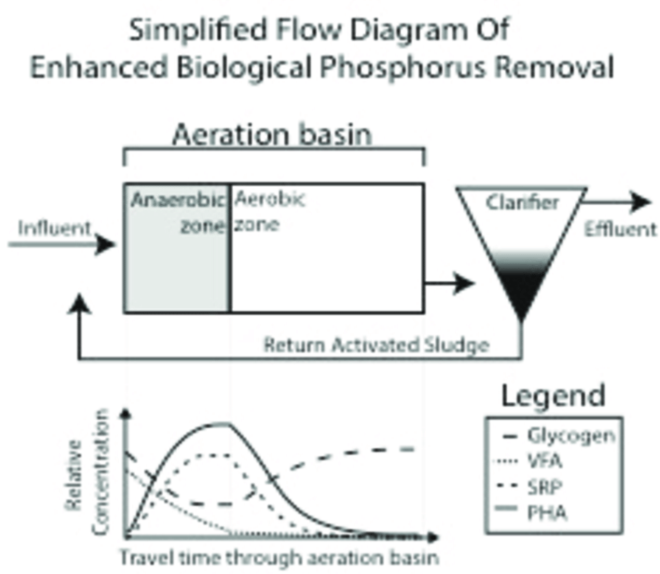
Biological Phosphorus Removal



In biological nutrient removal the system is engineered to favor the growth of aggressive **phosphate accumulating organisms (PAOs)**. These organisms absorb more phosphorus than required for their life processes, so it is stored in their cells for later use. This is done by having an anaerobic zone (negative redox potential without nitrate/nitrite present) along with soluble organics (preferably volatile fatty acids (VFAs)). This system usually has the influent entering into the anaerobic chamber because under *anaerobic* conditions, the PAOs release the stored phosphate yielding enough energy to accumulate soluble organics as their food source. In this step we see an increase in soluble phosphate.

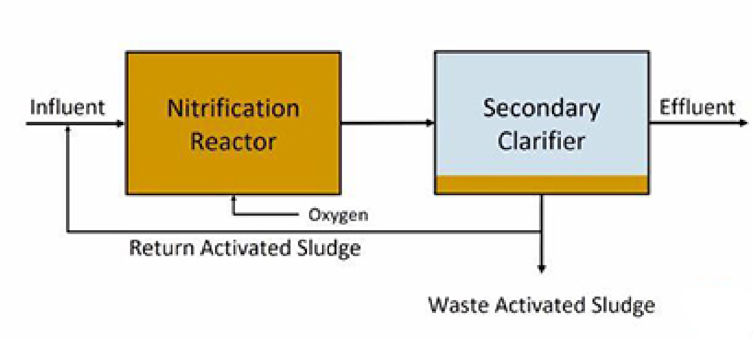


After reacting with the organics in the influent anaerobic zone, the PAOs enter the aerobic portion of the system. With abundant oxygen, the microbes digest the accumulated organics and use some of the energy to uptake soluble phosphorus. As the organisms are exposed to repeated cycles of anaerobic/aerobic conditions, the system should favor the growth of microbes that have the ability to uptake carbon as their food in the anaerobic zone. With excess phosphate in the water, a number of the microbes should be PAO bacteria.

The phosphorus is finally removed during the wasting process (WAS).

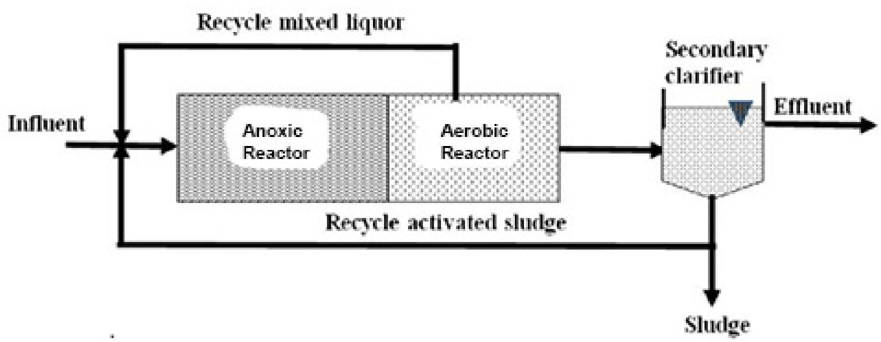
Carbonaceous Nitrification

This type of configuration reduces the carbonaceous biological oxygen demand (CBOD) and ammonia levels in the waste stream while increasing the nitrate levels. Nitrogen is not removed in this process and a higher residence time (MCRT) is required than a conventional activated sludge system.

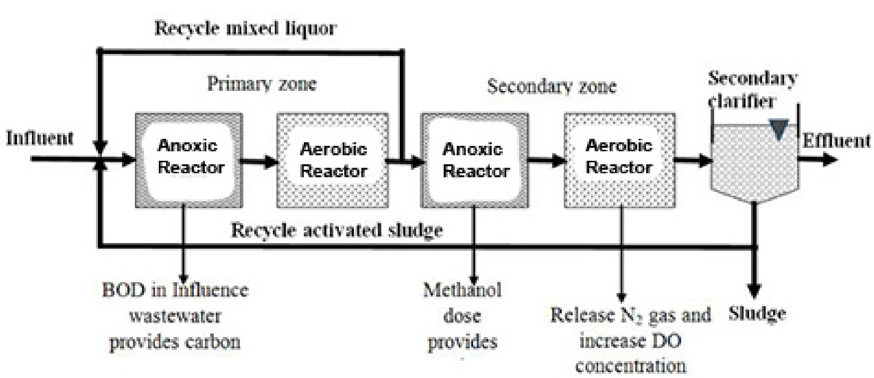


Nitrogen Removal

Nitrogen can be removed from the system using a single bacteria species moving from an *anoxic* zone to an *aerobic* zone. In the aerobic zone nitrification occurs. As the waste stream moves into the anoxic zone, denitrification occurs before being sent to the secondary clarifier for further treatment. The zones can be swapped around if desired.



Nitrogen can also be removed from the wastewater in a four-stage Bardenpho™ process rotating between anoxic and aerobic zones. The returned sludge (RAS) is sent to the first anoxic zone from the secondary clarifier. The second aerobic tank is used to strip the nitrogen gas and phosphorus. This type of configuration is more efficient at removing nitrogen than the above configuration.



Process Control

There are different methods an operator can use to control the activated sludge process, including proper MLVSS levels, adequate dissolved oxygen and control of the clarifier.

Maintaining the optimum quantity of solids in the biological reactor is one of the most important functions of an operator. The solids inventory will be feeding on the incoming organic waste and will reduce the CBOD of the wastewater. There are several parameters you can use to monitor and maintain the appropriate level of solids to meet the treatment objectives required by the NPDES permit. The process control parameters include:

- **F:M:**
  The Food to Microorganism Ratio (F:M) will be different at each plant. This ratio is calculated by dividing the pounds of CBOD entering the aeration basin by the pounds of MLVSS already in the basin.

  $$\text{F/M Ratio} = \frac{\text{BOD}_5\text{, lb/day}}{\text{MLVSS, lb}}$$

  Typical F:M values will vary depending on the treatment objectives and plant classification:

  Hight rate: 0.5 - 1.5
  Conventional: 0.2 - 0.5
  Low rate: 0.05 - 0.015

  The F:M variable that the operator can control is the pounds of MLVSS in the basin. By maintaining the proper returned and wasted sludge rates, the operator can maintain a fairly constant F:M that is ideal for their plant.

- **MCRT:**
  The Mean Cell Residence Time (MCRT) is a theoretical period of time that an individual organism remains in the system, treating the incoming waste stream. The MCRT is calculated by dividing the total pounds of solids (MLSS) in the basin by the pounds of solids (MLSS) leaving the system each day. Solids can leave the system by being wasted or flowing over the effluent weir.

  $$\text{MCRT, days} = \frac{\text{Solids in aeration system, lbs}}{\text{Solids leaving the system, lb/day}}$$

  Just like the F:M ratio, the control variable is the amount of solids kept in the process. Once the ideal MCRT is calculated, the formula above can be used to determine the appropriate wasting rate to maintain that MCRT value. The MCRT has an inverse relationship with the F:M ratio. As MCRT goes up, F:M goes down. Typical MCRT values will vary depending on treatment objectives and plant classification.

  High rate: 1-3 days
  Conventional: 5-15 days
  Low rate: 20-30 days

Loading Rate Classification			
Loading Range	MCRT (days)	Volumetric Loading (lb BOD/1,000 ft³)	F:M (lb/lb.day)
High rate	1-3	100-1,000	0.5-1.5
Conventional	5-15	20-40	0.2-0.5
Low Rate	20-30	10-25	0.05-0.15

- **SRT and Sludge Age:**
  The Solids Retention Time (SRT) and sludge age are two other ways of expressing essentially the same thing as MCRT. Even though SRT is calculated with a different formula, it is still a means of determining how long a microbe will stay in the process. Regardless of the formula used, consistency in the calculations is most important.

Controlling Dissolved Oxygen

Most plants that use *atmospheric air* as their oxygen source should maintain a dissolved oxygen (DO) level around 2 mg/L in the aeration basin to favor good settling bacteria over filamentous bacteria, which thrive in low DO environments and will cause sludge settling issues if allowed to dominate the bacteria population.

In pure oxygen systems, the DO levels are usually in the range of 4-10 mg/L. Operators should monitor the basin for populations of low-DO bacteria, such as *S. natans*, type 1701 and *H. hydrossis*. An indication of low DO conditions can come from a high effluent turbidity as well as the activated sludge turning dark and emitting foul odors.

Many plants have online monitoring equipment that continuously measures and records DO levels at specific points within the aeration basin. Whether the data is automatically generated or taken manually, regular monitoring is necessary to ensure the environment is one that favors good-settling organisms rather than filaments.

Controlling the Clarifier

There are certain control parameters to be concerned with to efficiently operate the secondary clarifier, including MLSS, flow, returned flow, clarifier surface area and sludge settleability. The solids loading rate (SLR) includes four of these five control parameters. Maintaining the SLR within an acceptable range allows easy control of the clarification process. The solids loading rate should not exceed 35 lb/day/ft^2 of clarifier surface area. The SLR should be reduced if the sludge is not settling well in the secondary clarifier.

Controlling the Sludge Blanket

It is important to maintain an adequate sludge blanket in the clarifier to thicken the returned sludge, ensuring the volume of secondary effluent water returned to the aeration basin is minimized. The operator must balance thickened sludge with the possibility of denitrification occurring in the secondary clarifier. If the sludge remains in the clarifier too long, the nitrogen gas bubbles caused by denitrification could cause the sludge to float and carry over the effluent weir. By regularly checking the sludge blanket depth, the operator can ensure that the target blanket depth for the plant is maintained. The optimal depth for the sludge blanket is 1-2 feet to ensure an adequate RAS/WAS flow rate.

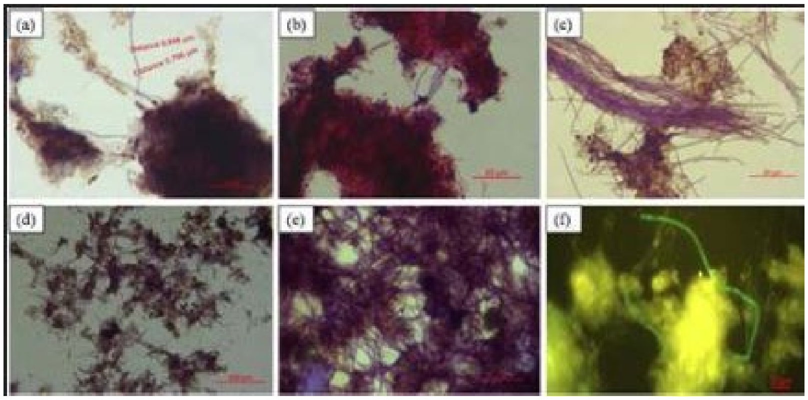
Controlling the Returned Activated Sludge (RAS) Flow

It is very important to maintain a proper sludge blanket in the clarifier. This can be accomplished by controlling the rate of activated sludge returned to the aeration basin for additional treatment. Typically, the return rate is set as a constant percentage of total plant flow. In high rate, or low MCRT systems, the RAS flow is traditionally 25-50% of the waste stream. Systems operating in the low rate, or high MRCT, may set the RAS flow in the range of 100-150% of the wastewater flow.

Microbial Populations and Settleability

The type of microorganisms present in the final clarifier greatly impacts how well the activated sludge will settle. The operator can control the microbial population by regulating the environmental conditions in which they grow and reproduce. You can tell a lot about the microbes present just by what happens in the basin. For example, sludge bulking and foaming in the aeration basin are caused by large amounts of unwanted bacteria. Even though filamentous bacteria are necessary to form good-settling floc, too many will cause sludge bulking, which will cause the sludge not to settle in the final clarifier.

Filamentous bacteria can be identified under the microscope, or they assume to exist if the Sludge Volume Index (SVI) is greater than 150 mL/g. This measurements gives the operator an indication of how well the sludge blanket is compacting in the secondary clarifier.



Conditions that lead to extreme filament growth are:

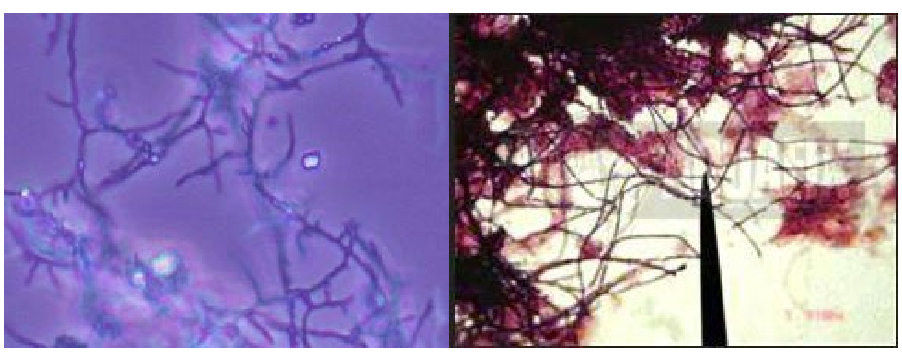
- Low DO
- Highly soluble, high-sugar waste
- Low pH

By increasing the DO and/or pH in the aeration basin will usually solve the problem. if the cause is due to a high-sugar content waste stream, the use of aerobic, anoxic, or anaerobic selectors may be used to limit the growth of the unwanted microbes.

Another short-term option is to apply chlorine to the return activated sludge (RAS), which kills the filamentous bacteria present. The application rate of chlorine to the aeration basin is traditionally 4 lb/day per 1,000 lb of MLSS.

Microbial Populations and Foam Control

The microbes responsible for foaming in the basin are branched filaments such as *Nocardia* or *Microthrix parvicella*.



Nocardia can be physically removed from the basin since most of the bacteria is in the foam. The operator can also maintain a low MCRT in the basin, since *Nocardia* is a slow growing bacteria. It can also be controlled by spraying chlorine directly to the foam on the surface (not to the RAS).

[Part 2: Activated Sludge Calculations]

Lesson 18:

The Activated Sludge Process Calculations

Objective

In this prat of the lesson we will learn how to calculate the following:

- Sludge Volume Index (SVI)
- Pounds of solids in the aeration basin
- Pounds of BOD applied per day
- Sludge age

Reading Assignment

Read the online lecture.

Lecture

Introduction

The biological reactor is where the microbial population reproduces and feeds on the incoming waste. The environment in the basin must be properly maintained to achieve the desired treatment results. The total solids concentration of the sludge being sent to the aerobic digester plays a key role in the process performance. Thickened sludge results in better volatile solids reduction in the digester. However, if the sludge is too thick, it can cause decanting problems. Typical organic loading is in the range of 0.f02 - 0.14 lb VSS/day/ft^3. If the loading is too high, it could cause anaerobic conditions due to insufficient oxygen transfer capacity, resulting in foul odors. Let's take a look at some of the parameters that need to be monitored during the activated sludge process.

Sludge Volume Index (SVI)

Sludge volume index (SVI) calculations will tell you whether the mixed liquor suspended solids (MLSS) in the aeration tank are settling at the right rate, or if they are hindering the performance of your facility. To calculate the SVI, you must first take a sample from the aeration tank. Let the sample settle for 30 minutes before beginning analysis. Analyze the sample and find out the concentration of suspended solids. this will be your MLSS concentration, represented in grams per liter (g/L). Divide the wet volume of the settled sludge (represented in mL/L) by the MLSS value from the last step. This calculation will give you your SVI value (represented in mL/g).

For this test, the settled solids are determined by doing a 30-minutes settleability test.

The typical SVI for a system that is operating as it should will be between 50 and 150 mL/g. If your SVI is outside this range, you may need to adjust the levels in your system. Looking at the characteristics of different samples will give you some clues as to what you can expect from your own system.

SVI Value, mL/g	Indications
Less than 100	Old biosolids, possible pin flow. Effluent turbidity increasing.
100 - 250	Normal operation, good settling. Low effluent turbidity.
Greater than 250	Bulking biosolids, poor settling. High effluent turbidity.

To increase the SVI, you will need to increase the waste sludge rate. This will result in a slower rate of settling, which in turn will trap more of the suspended solids in the mixed liquor, leading to a clearer effluent. If you need to decrease the SVI, do the reverse: reduce the waste rate. This results in a thicker sludge with heavier particles. As the density increases, so does the rate of settling, making the process more efficient.

The sludge volume index can be determined with the following equation:

$$\text{SVI, mL/g} = \frac{\text{Settled sludge volume (SSV), mL/L x 1000 mg/g}}{\text{MLSS, mg/L}}$$

Example:

Lab results for a wastewater treatment plant are listed below. The aeration tank volume is 0.4 MG. Determine the sludge volume index.

MLSS	1600 mg/L
Mixed liquor volatile content	76%
Primary effluent BOD	130 mg/L
Primary effluent suspended solids	100 mg/L
Plant flow	2.1 MGD
30 minute settleable solids	190 mL/L

There are only two of the values given above that will be needed for SVI determination: MLSS and the 30 minute settleable solids measurement.

$$SVI, mL/g = \frac{Settled\ sludge\ volume, mL/L \times 1000\ mg/g}{MLSS, mg/L}$$

$$SVI, mL/g = \frac{190\ mL/L \times 1000\ mg/g}{1600\ mg/L}$$

$$SVI, mL/g = 119\ mL/g$$

Pounds of Solids in the Aeration Basin

In the activated sludge process it is important to control the amount of solids under aeration. The suspended solids in an aeration tank are called mixed liquor suspended solids (MLSS). To calculate the pounds of solids in the aeration tank, we need to know the MLSS concentration and the aeration tank volume. MLSS can be calculated using the following equation:

MLSS, lb = MLSS, mg/L x Volume, MG x 8.34 lb/gal

Example:

In a conventional activated sludge treatment plant the mixed liquor suspended solids were 2,300 mg/L. If the aeration basin is 120 feet long by 35 feet wide by 10 feet deep, how many pounds of solids are under aeration?

First, determine the volume of the aeration basin:

Volume = 120 ft x 35 ft x 10 ft x 7.48 gal/ft^3 *we add in the "7.48 gal/ft^3" equivalent to convert between cubic feet to gallons
Volume = 314,160 gal or 0.314 MG

Now we can determine the pounds of solids under aeration:

lb = Volume, MG x Concentration, mg/L x 8.34 lb/gal
lb = 0.314 MG x 2,300 mg/L x 8.34 lb/gal
lb = 6023 lb of solids in the aeration basin

Pounds of BOD Applied per Day

When determining BOD, it is necessary to have a population of microbes that can oxidize, or consume, the biodegradable organic matter present in the waste stream. When calculating the BOD loading on the aeration basin, loading on that process is usually calculated as lb/day using the "pounds" formula we have used before.

BOD, lb/day = Flow, MGD x BOD concentration, mg/L x 8.34 lb/gal

Example:

The BOD concentration of the wastewater entering the aeration basin is 180 mg/L. If the flow to the basin is 2.25 MGD, what is the BOD loading in lb/day?

BOD, lb/day = Flow, MGD x BOD concentration, mg/L x 8.34 lb/gal
BOD, lb/day = 2.25 MGD x 180 mg/L x 8.34 lb/gal
BOD, lb/day = 3,378 lb/day

Sludge Age

The sludge age is the amount of time, in days, that solids or bacteria are under aeration. It is also known as the mean cell residence time (MCRT). Sludge age is used to maintain the proper amount of activated sludge in the aeration tank. To calculate the sludge age, it is necessary to know the amount of suspended solids (pounds) that are in the aeration tank and the amount of suspended solids (pounds) that enter the aeration tank daily. The sludge age can be calculated by dividing the pounds of suspended solids, or MLSS, already in the aeration basin by the pounds of suspended solids that enter the aeration basin.

$$\text{Sludge age} = \frac{\text{Suspended solids in the aeration basin}}{\text{Suspended solids entering the aeration basin}}$$

Example:

Lab results for a wastewater treatment plant are listed below. The aeration tank volume is 0.4 MG.

MLSS	1600 mg/L
Mixed liquor volatile content	76%
Primary effluent BOD	130 mg/L

Primary effluent suspended solids	100 mg/L
Plant flow	2.1 MGD

We will need to do some pre-processing before we have the values needed to determine the sludge age. We can determine the suspended solids already in the aeration basin by:

Solids in the basin = Aeration basin volume, MG x MLSS, mg/L x 8.34 lb/gal
Solids in the basin = 0.4 MG x 1600 mg/L x 8.34 lb/gal
Solids in the basin = 5338 lb

Next we need to determine the solids that are entering the aeration basin from the primary clarifier:

Solids entering the basin = Flow, MGD x Suspended solids, mg/L x 8.34 lb/gal
Solids entering the basin = 2.1 MGD x 100 mg/L x 8.34 lb/gal
Solids entering the basin = 1751 lb/day

Now that we have all the information, we can plug those values into the sludge age formula:

$$\text{Sludge age} = \frac{\text{Suspended solids in the aeration basin}}{\text{Suspended solids entering the aeration basin}}$$

$$\text{Sludge age} = \frac{5338\ \cancel{\text{lb}}}{1751\ \cancel{\text{lb}}/\text{day}}$$

$$\text{Sludge age} = 3.05\ \text{days}$$

Summary

- Autotrophs use inorganic carbon as a food source.
- Heterotrophs use organic carbon as a food source.
- Microorganism selection in the activated sludge process is accomplished by controlling dissolved oxygen (DO) levels, nutrient levels, mean cell resident time (MCRT) and hydraulic retention time (HRT).
- Proper design and operation of the process can result in the removal or reduction of Carbonaceous BOD (CBOD), ammonia, nitrogen and phosphorus.
- Complete nitrification of ammonia (90% removal) will require more oxygen than a non-nitrifying conventional plant designed to remove CBOD only.
- Nitrification removes alkalinity from the waste stream.

- Denitrification adds alkalinity to the waste stream.
- The MCRT and F:M (Food to Microorganism ratio) are inversely related . As MCRT goes up, F:M goes down.
- The oxidation ditch process is normally operated as an extended aeration system that has an MCRT greater than 10 days.
- High purity oxygen processes are generally used when the waste stream has high levels of biochemical oxygen demand (BOD).
- Raw wastewater flows into an oxidation ditch without grit removal or primary settling.
- The F:M ratio is used as a primary process control parameter for activated sludge plants.
- Inadequate DO levels in the aeration basin can lead to the dominance of filamentous bacteria, which can result in poor sludge settling..
- Solids should not remain in the secondary clarifier longer than necessary since they deteriorate as long as they are in the clarifier.
- Activated sludge is used to remove dissolved and finely divided suspended solids from wastewater.
- Microorganisms in the mixed liquor reproduce at a rapid rate requiring a portion to be wasted (WAS) to maintain a constant population in the aeration basin.
- A brown leathery foam on the surface of an aeration tank indicates a high solids concentration that can be corrected by increasing the wasting rate.
- Causes of foaming in an aeration basin include a high solids retention time, over aeration, or excessive sludge wasting.
- The rotor in an oxidation ditch is used to keep the water flowing, the solids mixed, and to transfer oxygen to the mixed liquor.
- The secondary clarifier receives flow from the aeration basin and is used to separate the solids from the liquid.
- The activated sludge that is removed from the system is called waste activated sludge.
- The mixture of liquid, microorganisms, and solids in the aeration basin is called mixed liquor.
- Under normal operating conditions, activated sludge will have a light to medium brown appearance.
- Chemical Oxygen Demand (COD) is a relatively quick test that can be used to determine organic loading.
- Most of the “work” is performed by the bacteria in an activated sludge treatment plant.
- Phosphorus is removed prior to discharge to receiving waters since it is a nutrient that can cause excessive algae growth.
- A term used to describe the combined liquid and solids of the activated sludge process is mixed liquor.
- Primary treatment is not usually part of an extended aeration oxidation ditch process.
- DO in the aeration process of a small activated sludge package plant should be approximately 2 mg/L.
- For optimum water quality during the warm months of summer, the operator should waste approximately 5% of the solids in an extended aeration package plant.
- The DO level 15 feet upstream of the rotors in an oxidation ditch should be maintained at 2 mg/L during start up.
- The DO level 15 feet upstream of the rotors in an oxidation ditch should be maintained at 0.5 mg/L during normal operation.
- The MLVSS concentration is used to represent the microorganisms in the aeration basin available to treat incoming waste.
- Most algae are classified in the Protista kingdom.
- Bacteria are classified in the Monera kingdom.
- Acids and Alkali are corrosive and may interfere with biological treatment of wastewater.
- Essential nutrients for wastewater microorganism reproduction include nitrogen, phosphorus, and organic carbon.
- A good ratio of BOD to nitrogen to phosphorus is 100:5:1.
- Secondary sludges typically contain about 20-25 percent of non-volatile inorganic matter.

Assignment

Please complete the assignment for this lesson. You must be logged into Canvas to complete this assignment.

Quiz

Answer the questions in the lesson quiz.   You will need to log into Canvas to take the quiz. You may take the quiz 3 times, if needed, and an average will be taken from your attempts for final grade calculation.