

SECONDARY TREATMENT – ACTIVATED SLUDGE

Activated sludge is another biological process used to remove organics from wastewater. Like the trickling filter, activated sludge processes are used to grow a biomass of aerobic organisms that will breakdown the waste and convert it into more bugs. This is accomplished in large aerated tanks instead of the trickling filter's fixed media. These tanks are called aeration basins. Activated sludge processes return settled sludge to the aeration basins in order to maintain the right amount of bugs to handle the incoming "food". Activated sludge processes have higher removal efficiencies (95-98%) than trickling filters (80-85%).

ACTIVATED SLUDGE TERMINOLOGY

MLSS/MLVSS - The biomass of critters that is responsible for removing the BOD make up a large portion of the solids that are contained in the process. They are the "active" part of activated sludge. The solids under aeration are referred to as the Mixed Liquor Suspended Solids or MLSS. The portion of the MLSS that is actually eating the incoming food is referred to as the Mixed Liquor Volatile Suspended Solids or MLVSS. The inventory of the biomass is calculated as pounds of microorganisms based on the volume of the tanks and the concentration of the MLVSS.

RAS/WAS - As the mixed liquor moves to the secondary clarifier, the activated sludge settles to the bottom of the tank and is removed. This sludge is not as thick as primary sludge. The solids concentrations will normally be between 0.5-0.8% or 5,000-8,000 mg/L. One of two things will happen to the settled sludge. Most of it will be returned to the aeration basins to keep enough activated solids in the tanks to handle the incoming BOD. This is known as the Return Activated Sludge or RAS. A small portion of the sludge will be removed from the system as the MLSS inventory grows. It is referred to as Waste Activated Sludge or WAS.

Detention time - Detention time, or the length of time the MLSS are under aeration, differs with each type of activated sludge process. RAS flows can be used to manipulate the detention time in the aeration tanks. Increasing the RAS flow at night will help maintain the proper detention times as influent flows drop.

F:M Ratio - One of the process parameters used to control activated sludge solids inventory is known as the Food-to-Microorganism ratio or F:M ratio. It is a baseline established to determine how much food a single pound of organisms will eat every day. A pound of bugs will eat between 0.05-0.6 pounds of food per day depending on the process.

MCRT/Sludge Age - Another control parameter is the length of time the bugs stay in the process. If a system wastes 5% of the solids in the system every day, then MLSS would only remain in the system an average of about 20 days ($100\% / 5\% \text{ per day} = 20 \text{ days}$). This is known as the Mean Cell Residence Time or MCRT. Some operators also refer to this number as Sludge Age.

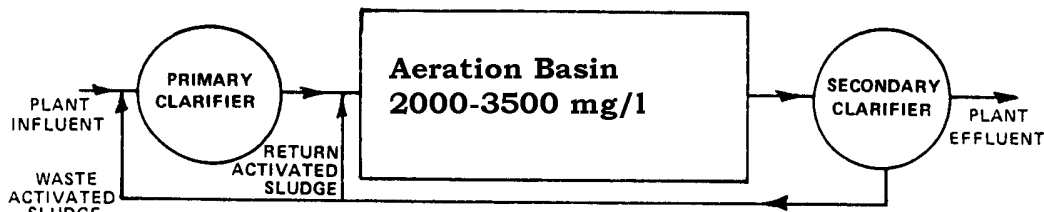
SVI - The sludge volume index or SVI is a measurement of how well the activated sludge settles in the clarifier. Sludge settleability in a large part depends on the condition of the organisms. Good settling sludge will have an SVI between 80 and 120. As the sludge becomes lighter and the settled volume increases the SVI will also increase.

ACTIVATED SLUDGE PROCESSES

There are basically three types of activated sludge processes. They all accomplish the biochemical reduction of organics using aeration basins and return and waste sludge systems. The detention times, MLSS, and F:M loadings are different in each case. The one control parameter that they all share is the dissolved oxygen requirement of 2.0-4.0 mg/L. The fact that aerobic conditions exist in the aeration basin means that the mixed liquor should have a light earthy odor that is not objectionable. Dissolved oxygen levels are maintained by aeration equipment using blowers and diffusers or mechanical aerators.

CONVENTIONAL ACTIVATED SLUDGE PROCESSES

Conventional activated sludge has an aeration basin detention time of 4-6 hours. During this time the microorganisms will completely stabilize the BOD before the mixed liquor leaves the basins. The MLSS concentrations usually run from 2000-3500 mg/L. F:M ratios should be between 0.2-0.5. MCRT or sludge age varies from 5-15 days.



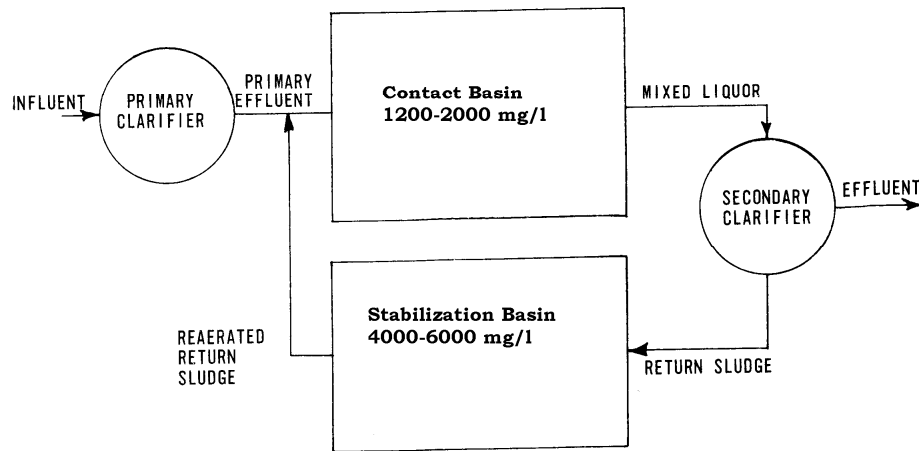
Conventional Activated Sludge

CONTACT STABILIZATION PROCESSES

Contact stabilization uses two separate aeration processes. The primary effluent enters the contact chamber where the bugs begin to break down the BOD and increase the overall settleability of the organics that are not yet oxidized. The raw organics and MLSS settle out in the clarifier just like conventional activated sludge. But instead of returning the RAS to the contact basin, it is pumped to another aeration basin called a stabilization basin. Here the RAS is aerated until the organics have been eaten or stabilized by the bugs. The effluent from the stabilization basin is returned to the contact basin, to maintain the MLSS there, and the process begins again.

The main advantage of the contact stabilization process is that most of the solids and BOD reduction happens off-line from the main flow. This prevents massive solids loss during hydraulic shocks on the system and reduces recovery time since the bulk of the biomass is kept in the stabilization basin.

The detention time in the contact basin is from 0.5-2.0 hours. The detention time in the stabilization basin is from 4-8 hours, about the same as conventional processes. The MLSS concentrations will run from 1200-2000 mg/L in the contact chamber and will be 4,000-6,000 mg/L in the stabilization chamber (the same as the RAS). Contact stabilization has the highest F:M ratios. The F:M ratio can run as high as 0.6.



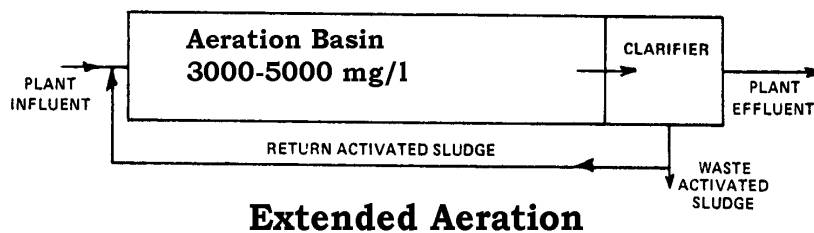
Contact Stabilization



**Contact Basin solids on the left and
Stabilization Basin solids on the right.**

EXTENDED AERATION PROCESSES

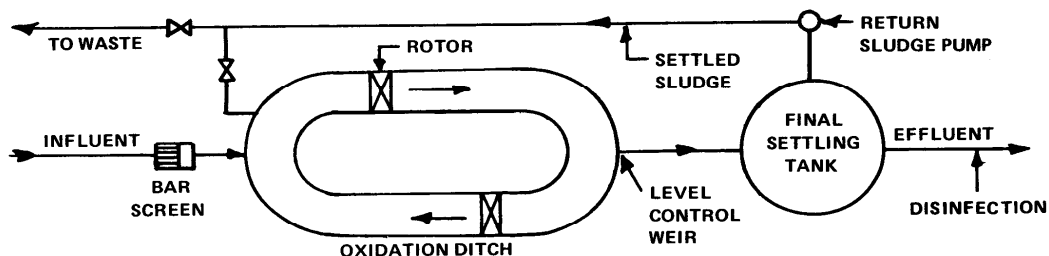
Extended aeration systems are designed to completely stabilize all of the organic material in the aeration basins. The detention times range from 16-24 hours and MLSS ranges run from 3000-5000 mg/L. They have the lowest F:M ratios of any of the activated sludge processes, usually 0.05-0.2. The only solids that remain are in the form of inert ash. Extended aeration plants normally have pretreatment but not primary clarifiers. RAS is returned to the headworks and waste sludge is sent to an aerobic digester.



OXIDATION DITCHES

An oxidation ditch is a form of extended aeration activated sludge. The aeration basin is a large oval shaped tank that resembles a racetrack. Wastewater enters the ditch and is circulated around the track by means of a large horizontal brush/rotor. The rotor assembly is partly submerged in the ditch. As it rotates it pushes the mixed liquor around the "track". The rotor also provides the needed aeration to maintain a DO level of about 2 mg/L in the basin. The BOD loading for oxidation ditches can vary between 10-50 lbs/1000 cu ft/day. The oxidation ditch effluent passes to the secondary clarifier and RAS is returned to the ditch.

The velocity and DO levels can be adjusted by changing the rotor speed and operating depth. The effluent weir is a slide gate that can be raised and lowered to change the water level in the ditch. This also changes how deep the rotor is submerged in the mixed liquor. When it runs deeper it aerates better. The proper velocity for an oxidation ditch should be about 1 foot/sec. If the velocity falls below 1 fps, there is a possibility that sludge will settle in the corners of the ditch. This will result in septic conditions and odors.



Oxidation Ditch Activated Sludge

Some ditches are designed with a concrete wedge at the exit of each bend. As the flow comes "out of the turn", the wedge forces the water at the outside to the inside as it comes down the "straightaway". This helps mix the flow and creates turbulence where settling is most likely to occur. Oxidation ditches, as with other extended air systems, do not have primary treatment. Pretreatment may be limited to barscreens. This means that grit will not be removed until it settles out in the oxidation ditch. The grit buildup in the ditch can result in odors and loss of detention time. It should be removed anytime the unit is drained for service.



**Activated sludge oxidation
ditch treatment plant**

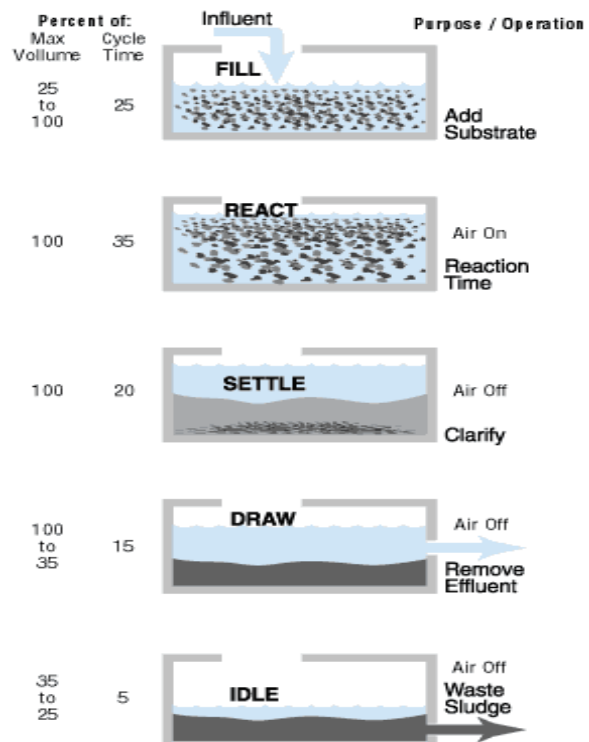


**Aerator rotor assembly
provides DO and keeps solids**

SEQUENCED BATCH REACTOR (SBR)

A sequenced batch reactor is a process that is used in small package plants. It is not a continuous flow process. The reactor basin is filled and then aerated for a certain period of time, usually 1-3 hours. After the aeration cycle is complete, the reactor is allowed to settle and effluent is decanted from the top of the unit.

When the decanting cycle is complete, the reactor is again filled with raw sewage and the process is repeated. These processes are popular because entire process uses one tank. Most plants do not have clarifiers or RAS systems. A large equalization basin is required in this process, since the influent flow must be contained while the reactor is in the aerating cycle.



BIOLOGICAL GROWTH RATE

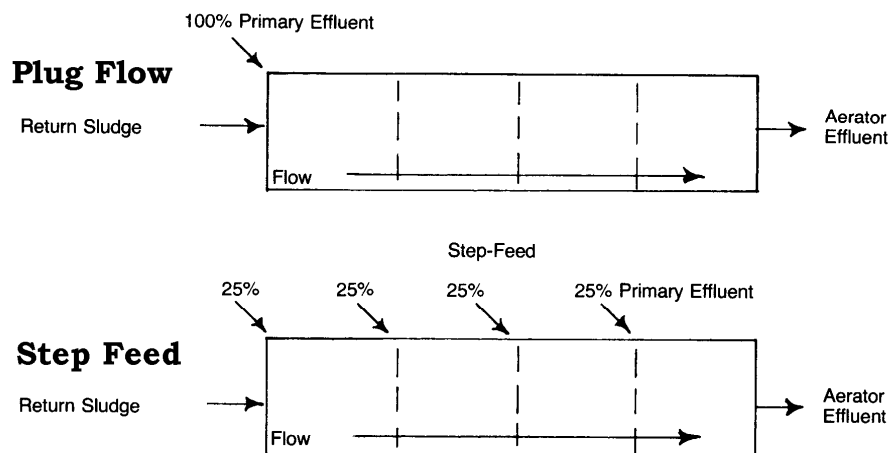
The respiration rate or metabolism level of the biomass will dictate how much food each pound of bugs can eat every day and how fast the biomass grows as a result. The goal is to achieve what is known as "endogenous respiration". At this level of metabolism the bugs are working at maximum efficiency. The oxygen uptake rate (OUR) is used to determine if endogenous respiration is being achieved. The oxygen uptake rate is determined by measuring the amount of DO that is depleted from a sample of mixed liquor in 15 minutes. The uptake rate is obtained by multiplying the 15-minute depletion by four to get a value in mg/L per hour. Most cases, endogenous levels of respiration are achieved when the oxygen uptake rate is between 15-30 mg/L per hour.

If they were left in the aeration basins all of the time they would literally suffer burnout, much like an athlete, from operating at such a high level of activity. When they pass to the clarifier they get a chance to rest and digest their food. Just about the time that they start getting hungry again, they should be returned to the aeration basins to eat. This cycle keeps the biomass at its optimum activity level. The growth rate of the biomass is dependent upon the available oxygen, F:M ratio and temperature. When the temperature of the water drops 10° C, the bioactivity drops by about 50%.

INFLUENT FLOW PATTERNS

Most treatment plants put the entire influent flow in one end of the process and take it out the other. This type of flow pattern is called "plug flow". Plug flow patterns put a high organic load in the front stages of the process and the BOD drops off in each consecutive stage. Since the amount of air needed is directly related to BOD loading, this means that a great deal more oxygen is needed in the first stages than in the latter ones. Problems maintaining DO levels can occur. The system is also subject to upset if an organic shock load hits.

Activated Sludge Flow Patterns



Another flow pattern that is used in some plants is called "step feed". In a step feed process the influent flow is split and sent to the first three stages of the process. Each stage receives a portion of the raw BOD and the remainder of the BOD from the previous stages. This allows for more even air loading on each stage and makes shock loads easier to handle.

The third type of flow pattern is called "complete mix". This flow pattern usually occurs in extended aeration plants. The influent enters the center of a single stage aeration basin and leaves at the edge. The location of the aerators and mixers is designed to create uniform MLSS loading

PROCESS CONTROL

There are three parameters that are adjusted to maintain efficient operation of an activated sludge process. They are dissolved oxygen levels, RAS flows, and WAS flows. When diffuser type aerators are used, the DO levels are established by controlling the amount of airflow to each basin. If DO levels are too high the flow can be throttled using valves on the air header pipes. In most cases the air system is branched to each tank. Throttling the flow to one tank will increase the flow to others. When the diffusers get clogged the airflow will drop dramatically. The diffusers can be "bumped" with a sudden burst of air to help clear them. Balancing the airflow between the basins, to maintain the proper DO levels, is an important part of maintaining an efficient operation.

Return activated sludge flows are important because the microorganisms must be returned to the aeration tanks before they run out of dissolved oxygen. They spend about two hours in the clarifier during average flows. During that time they will use up the 2-4 mg/L of DO that they had when they entered the clarifier. If they are not returned to the aeration basin in time their metabolism rate (how fast they eat food) will drop off and they won't be hungry when they get there. The longer they go without air the longer it will take for them to build up their metabolism rate to the endogenous levels needed to meet the F:M ratio. Return sludge pumping capacity should be sufficient to almost match the daily average flow rate at night. As the flows drop at night, the detention time in the clarifiers gets longer. To compensate, the RAS flows are increased to reduce the detention time in both the aeration basin and the clarifiers. Increasing the RAS flow will also reduce the depth of the sludge blanket in the clarifier.

Wasting sludge is how the F:M ratio is maintained. As the biomass eats the organics it creates more bugs. The excess must be removed to keep the MLSS levels constant. WAS flow rates are usually 1-2% of the influent flow. When MLSS levels rise the sludge age increases. This older sludge will not settle as well and can result in ashing and solids carryover out of the clarifier. When this occurs, the wasting rate should be increased to remove more solids from the system. When light tan colored straggler floc is going over the weirs, it is usually an indication that the sludge age has decreased. The wasting rate should be reduced to increase the sludge age or MCRT.

Care should be taken when changing wasting rates. A sudden increase in the WAS flow can lead to an upset of the process. WAS should be removed continuously and changes in flows should be made in 1-2% increments each day to minimize the impact on the process. It is important to remember that it takes a long time to see results from process changes. A startup may take up to 60 days and 1 to 2 MCRT to see the results from wasting changes.

ACTIVATED SLUDGE MICROORGANISMS

Most of the BOD reduction is a result of the activity of the aerobic bacteria that are present. But an entire food chain develops as a result of the bioactivity. Protozoa that are large enough to be seen with a microscope occupy the upper regions of the food chain. There are five categories of these activated sludge "bugs". The predominance of one or more of these groups over the others can give an indication of the age and condition of the sludge. They are listed below in order of appearance:

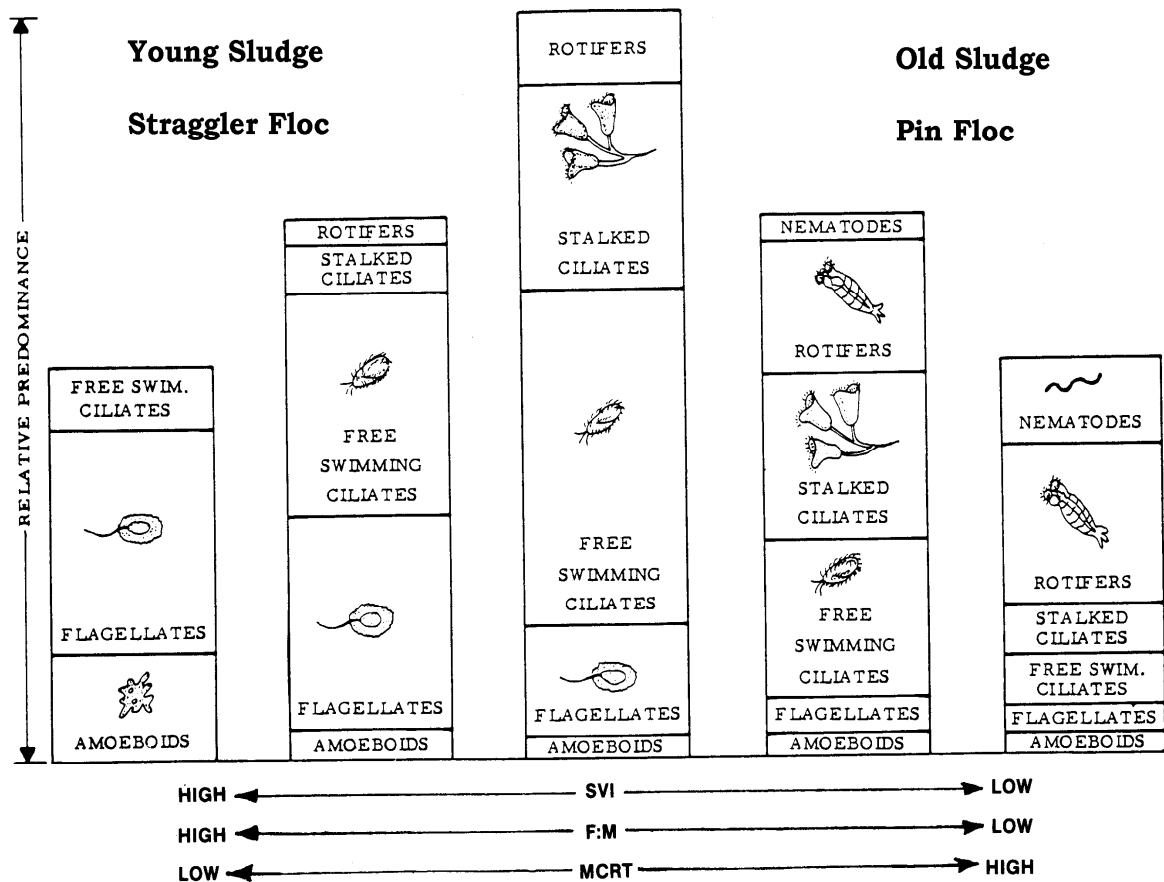
ACTIVATED SLUDGE MICROORGANISMS

Amoeboids
Flagellates
Free Swimming Ciliates
Stalked Ciliates
Rotifers

An amoeba is a single celled organism that is the first to develop in the sludge. They are found in sludge regardless of sludge age. If they are predominant the sludge is very young. Flagellates are the next bugs to develop. They have a large single cell body with a whip like appendage called a flagellum. They are predominant, with the amoeboids, when the sludge is very young. Young sludge has a poor settleability and a high SVI. Brown straggler floc in the effluent is another indicator of young sludge age. As the sludge age increases the number of flagellates drops.

Free swimming ciliates are small oval shaped bugs with tiny hairs or cilia. These cilia move in a wave-like motion to propel them in the water and bring food to them. Their numbers increase as the sludge reaches maturity and achieves its peak settleability, and then drop off as the sludge age continues to increase. Stalked ciliates look like a cluster of flowers attached to a sludge particle. Their tulip shaped bodies have cilia at the "mouth" to bring food to them. They are the predominant bugs in some contact stabilization processes. The free swimmers and stalks are the predominant groups in good settling sludge and they both decline as the sludge ages.

Rotifers are the most complex organisms of the group. They have nine cells and are larger than the other organisms. They have a long telescoping body and move by attaching to a particle and stretching out to another one, much like a caterpillar. They are first seen in sludge as straggler floc disappears with increasing sludge age. Their numbers continue to increase as the sludge ages. They are predominant in old sludge. Another indicator of old sludge is the appearance of very small pin floc in the effluent.



THE "BUG" CHART

SLUDGE PROBLEMS

Sludge blanket problems manifest themselves in several different ways. Straggler floc is common in young sludge. It can be eliminated by reducing wasting so the sludge ages. Pin floc problems occur as the sludge becomes too old. It can be remedied by increasing wasting rates to reduce the sludge age.

Filamentous bacteria are long stringy bacteria that are present in sludge of all ages. They are beneficial in small numbers. They help stick sludge particles together. In large numbers they bridge the particles and reduce the settleability of the sludge. When this occurs "bulking" sludge problems can develop. Bulking sludge is dark brown in color and can also be accompanied by dark, oily foam accumulation in the aeration basins. *Nocardia* is a type of filament that is known to cause bulking and foaming problems in activated sludge. They are long cylindrical organisms that cluster in groups like broom bristles. They appear in older sludge and thrive when the pH drops below 6.0 and oxygen levels drop below 1.0 mg/L. Adding 1.0-1.5 mg/L of chlorine to the RAS flow is often used in wastewater systems to control filaments.

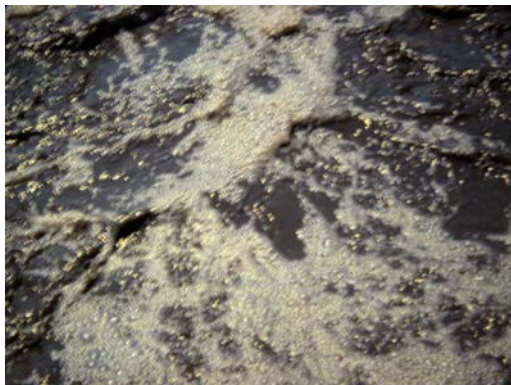
Hydraulic shock loading can cause a "wash out" of the sludge blanket. When the upward velocity in the clarifier exceeds the settling velocity of the sludge, the solids are blown out of the tank and over the weirs. Flow equalization basins are the only way to avoid hydraulic shock to the system when flow spike. Rising sludge occurs when the DO is depleted and portions of the sludge blanket become septic. Chunks of sludge will float to the surface as anaerobic gases are produced and trapped in the sludge blanket. Besides losing solids from the system, the septic conditions mean the bugs are also very sick and may not perform well when they are returned to aeration.



Hydraulic shock loading can cause a sludge blanket "wash out"

AERATION TANK FOAM

The bioactivity in the aeration basins will always result in some foam buildup in the basin. The color of the foam is an indicator of sludge age and condition. A crisp, white foam is indicative of young sludge. Rich medium tan foam is associated with good settling sludge. Dark brown, oily foam can be found in older sludge. It is common in aerobic digesters, but not a good sign in an aeration basin. It can also indicate filamentous bacteria problems.



Tan colored foam is a sign of good settling sludge

BASIC STUDY QUESTIONS

1. What are the differences in the three types of activated sludge processes?
2. What should the DO levels be in activated sludge aeration basins?
3. What are the components of an oxidation ditch?
4. What is the difference in the solids concentrations in primary and waste activated sludge?
5. What does the "F" in F:M ratio stand for?
4. Which of the following statements is not true about filamentous bacteria?
 - A. They are always present in MLSS
 - B. Too many can lead to bulking
 - C. They like a low pH
 - D. They indicate a young sludge age
5. Which of the following is a filamentous bacterium?
 - A. E. Coli
 - B. Nocardia
 - C. Nitrosomonas
 - D. Giardi

BASIC SAMPLE TEST QUESTIONS

1. What is the aeration basin detention time in conventional activated sludge processes?
 - A. 1-2 hours
 - B. 4-6 hours
 - C. 10-12 hours
 - D. 16-24 hours
2. What should the velocity be in an oxidation ditch?
 - A. 0.01 fps
 - B. 0.2 fps
 - C. 1.0 fps
 - D. 3.0 fps
3. What type of odor is associated with activated sludge processes?
 - A. A light earthy odor
 - B. A fruity odor
 - C. A rotten egg odor
 - D. An acrid odor

ADVANCED STUDY QUESTIONS

1. What is the main advantage of a contact stabilization process?
2. How do you determine sludge age or MCRT?
3. What are the differences in the three types of influent flow patterns for activated sludge processes?
4. Why should RAS flows be increased at night?
5. What are the F:M ratio ranges for each of the three types of treatment processes?

ADVANCED SAMPLE TEST QUESTIONS

1. What is the SVI range for good settling sludge?
 - A. 20-50
 - B. 60-70
 - C. 80-120
 - D. 130-210

2. Straggler floc would be found in:
 - A. Young sludge
 - B. Old sludge
 - C. Good sludge
 - D. Primary sludge

3. Wasting rates should never be changed by more than ____ at a time.
 - A. 1-1.5%
 - B. 5-10%
 - C. 20-30%
 - D. 50-60%

4. What type of microorganism is predominant in very old sludge?
 - A. Flagellates
 - B. Free swimming ciliates
 - C. Rotifers
 - D. Stalked ciliates

5. A white crisp foam indicates:
 - A. A young sludge
 - B. A mature sludge
 - C. An old sludge
 - D. A good beer