Wastewater Treatment Plant Operator Certification Training

Module 16: The Activated Sludge Process Part II

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The Pennsylvania State Association of Township Supervisors (PSATS)
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Unit 1 – Process Control Strategies

Learning Objectives

- List the key monitoring points within the activated sludge process and explain what to look for at those points.
- List five key process control parameters and for each parameter, explain what it is, why it is used and how it is calculated.
- List the daily process control tasks that need to be accomplished and explain how to do them.

Plant Influent

Effect of Influent Characteristics

Changes in the influent flow rate and strength will affect the efficiency of an activated sludge treatment plant and may ultimately affect the plant's discharge.

Large Flow Increase

- In general, activated sludge treatment plants are designed to handle peak flow rates.
- There may be times, however, when the plant's hydraulic capacity is exceeded, which can result in reduced detention time in the aeration tank and the loss of activated sludge bacteria from the secondary clarifiers. This would ultimately result in a turbid final effluent that may exceed discharge limits. Typical discharge limitations for activated sludge plants will be discussed later in this module.
- Excessive influent flow may be due to stormwater infiltration or unusual industrial discharges.
- A switch from the conventional activated sludge treatment process to step feed aeration may help avoid the loss of activated sludge bacteria from the secondary clarifiers.

Large Influent Solids Increase

- If the influent solids loading exceeds the plant's design capacity, the amount of mixed liquor volatile suspended solids (MLVSS) may need to be adjusted. The plant's design capacity can be determined from the plant's design engineer.

Mixed Liquor Volatile Suspended Solids (MLVSS) is the organic or volatile suspended solids in the mixed liquor of an aeration tank. This volatile portion is used as a measure or indication of the microorganisms present.

- If the influent solids are primarily organic and result in increased Biochemical Oxygen Demand (BOD) loading, then you may need to increase the MLVSS in the aeration tank by reducing the sludge wasting rate.

Biochemical Oxygen Demand (BOD) is the rate at which organisms use the oxygen in water or wastewater while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation. BOD measurements are used as a measure of the organic strength of wastes in water.

- A shock load of Influent solids that are primarily inert may result in a decrease in the MLVSS-to-MLSS ratio. The typical optimum MLVSS-to-MLSS ratio in activated sludge plants is between 0.7 and 0.8.

Mixed Liquor Suspended Solids (MLSS) is the suspended solids in the mixed liquor of an aeration tank.

- Under this scenario, it may be tempting to increase the sludge wasting rate to remove inert solids from the aeration system, but this may actually worsen the problem by wasting too much volatile suspended solids. Instead, try changing to step feed aeration to retain more solids in the aeration tank.

Monitor Treatment Plant Capacity

- Typical wastewater parameters that are used to characterize influent loadings are flow, biochemical oxygen demand (BOD), total suspended solids (TSS), ammonia, total Kjeldahl nitrogen (TKN), and phosphorus.

- The processes of nitrification and carbonaceous oxidation in the aeration tank impart an oxygen demand. For example, if the influent ammonia loading exceeds the plant's capacity while the BOD loading does not, there may not be enough oxygenation capacity to accommodate carbonaceous oxidation and still meet the effluent ammonia limit.

- Another example would be when an influent phosphorus load exceeds the plant's chemical feed system capacity, resulting in an effluent phosphorus limit violation.

Primary Clarifier

Biochemical Oxygen Demand (BOD)/Chemical Oxygen Demand (COD)

- Well designed and operated primary clarifiers should remove from 24 to 40 percent of BOD. Poor performing clarifiers will result in the discharge of excess solids and BOD to the secondary treatment system, which may result in effluent permit limit violations.

- Excessive hydraulic loads resulting in reduced detention times in primary clarifiers may sweep the solids out of the clarifier and into the aeration tank. Bring offline clarifiers, if available, online to increase the detention time. Flocculants can be added to the primary clarifier influent to reduce the required detention time for effective settling.

Flocculants are chemicals that promote the agglomeration of smaller particles into large, settleable particles.

- A change in influent particle size characteristics from heavy, rapidly settling particles to smaller, colloidal particles may result in decreased clarifier performance. In this situation, the addition of flocculants can be used to improve the BOD and TSS removal efficiencies.

- Malfunctioning or improperly operated sludge removal equipment, such as the sludge scraping mechanism and sludge draw off pump, may be responsible for poor clarifier performance. If sludge removal equipment is not working properly, the sludge layer accumulating on the bottom of the clarifier may continue to increase in thickness until solids are washed out of the clarifier through the effluent weir to the secondary treatment system. Check the sludge scraping mechanism and the sludge draw off pumps regularly to make sure they are operating properly.

Total Suspended Solids (TSS)

- In general, well designed and operated primary clarifiers should remove from 50 to 70 percent of TSS. The reasons for poor TSS removal in the primary clarifier and the recommendations for improvement are the same as described above for BOD.

Nutrients

- In addition to an adequate carbon source, activated sludge bacteria require adequate amounts of nutrients, such as nitrogen and phosphorus, to function properly.

- The general rule of thumb is that the ratio of BOD-to-nitrogen-to-phosphorus in the primary clarifier effluent be approximately 100:5:1.

Aeration Tank

Operational Control Parameters

Monitoring the following operational control parameters will enable an operator to optimize the biological treatment process.

- MLSS/MLVSS
  The mixed liquor suspended solids (MLSS) concentration is a measure of the total concentration of solids in the aeration tank and includes both inert and organic solids. Typical MLSS concentrations for conventional activated sludge plants range from 2,000 to 4,000 mg/L. Mixed liquor volatile suspended solids (MLVSS) is an indirect measure of the concentration of microorganisms in the aeration tank and should be between 70 and 80 percent of the MLSS.

- Residual Dissolved Oxygen
  The microorganisms in the aeration tank require oxygen to oxidize organic waste. It is critical to monitor the residual dissolved oxygen (DO) concentration in the aeration tank to ensure that there is adequate oxygen available. A DO concentration between 2 to 4 mg/L is usually adequate to achieve a good quality effluent.

- pH and Total Alkalinity
  Like the residual DO concentration, pH and total alkalinity are important parameters that can affect the well-being of activated sludge microorganisms. In general, the optimum pH level for bacterial growth ranges between 6.5 and 7.5. Low pH values may inhibit the growth of nitrifying organisms and encourage the growth of filamentous organisms. The optimum pH range for nitrification is 7.2 to 9.0.

Nitrification is a process in which *Nitrosomonas* bacteria oxidize ammonia to nitrite and *Nitrobacter* bacteria oxidize nitrite to nitrate.

- Specific Oxygen Uptake Rate

The **specific oxygen uptake rate** (SOUR) is a measure of the quantity of oxygen consumed by microorganisms and is a relative measure of the rate of biological activity. As microorganisms become more active, the SOUR increases and vice versa.

The SOUR is determined by taking a sample of mixed liquor, saturating it with oxygen, and measuring the decrease in oxygen with a DO probe with time. The result of that test, the oxygen uptake rate (OUR), measured in mg O_2/L-min, is divided by the MLVSS to yield the SOUR, measured in mg O_2/g MLVSS-hr.

Research has shown that the SOUR and final effluent COD can be correlated. Therefore, changes in the SOUR can be used to predict final effluent quality. If SOUR increases it is an indication of an increase in the MLSS respiration rate and may require additional oxygen to stabilize.

Color

- If there is white, crisp foam present on the surface of the aeration tank, decrease the sludge wasting rate.

- A thick, dark brown or gray, greasy foam indicates the presence of a slow-growing filamentous organism, usually of the *Nocardia* genus. The causes and treatment options for *Nocardia* foaming will be discussed later.

Microscopic Examination of Biomass (Mixed Liquor)

- Recording observations, such as size and nature of floc particles and the type and number of organisms, will enable you to make qualitative assessments.

- This subject will be covered in more detail in Unit 3.

Secondary Clarifier

Sludge Blanket Level

- The high volume of flocculant solids in the secondary clarifier results in the formation of a sludge blanket. The thickness of the sludge blanket varies and may become so thick that biomass will be washed out of the clarifier and into the final effluent. The optimum sludge blanket level must be determined by experience and must provide adequate settling depth and sludge storage. Typically, secondary clarifiers allow for 2-3 feet of depth for thickening, 3 feet for a buffer zone between the thickened sludge and the clarification zone, and 8 feet for clarification.

- The operator should keep good records of the sludge blanket levels in order to avoid the loss of biomass from the clarifier. The sludge blanket level can be monitored manually or automatically.
  - *Manual – Sludge Judge*
    The sludge blanket level can be measured manually using a clear plastic tube with a check valve on the bottom (e.g., Sludge Judge®). This device is simply lowered slowly into the clarifier until it hits the bottom of the clarifier. A check valve on the bottom of the tube traps the solids and water inside the tube as the tube is raised out of the tank. The tube has markings spaced one foot apart so that the location of the top of the sludge blanket can be determined.

Figure 1.1 Sludge Judge®[1]

- *Automatic*

  A more sophisticated (and more expensive) method for monitoring sludge blanket level is to use an automatic sludge blanket monitor. These devices come in a variety of different configurations and use different technologies to sense the interface between the clear water and the sludge blanket. These devices can monitor both the depth of the sludge blanket and the solids concentrations in the clarifier in real time.

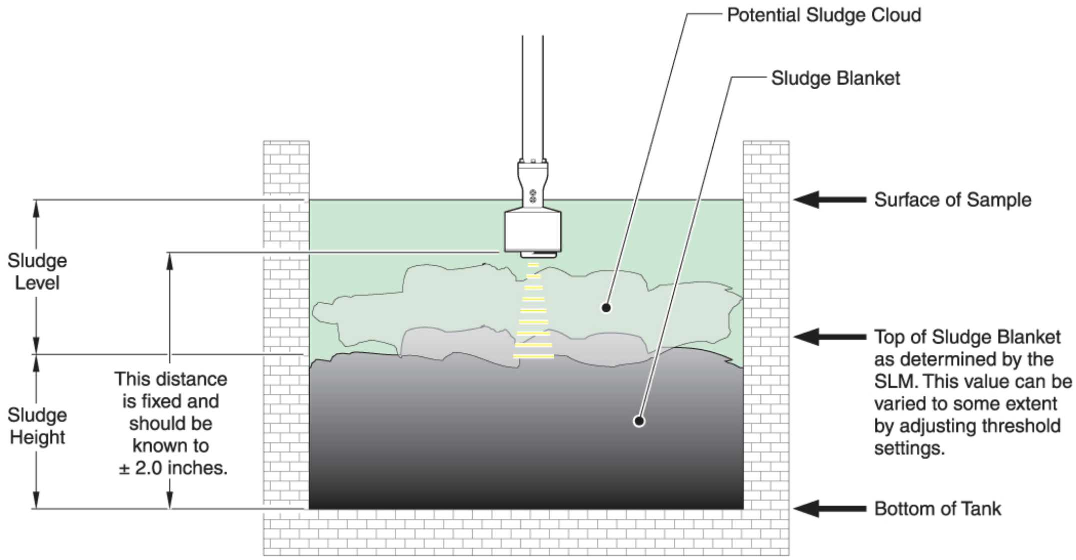

Figure 1.2 Example 1 of an Ultrasonic Automatic Sludge Blanket Monitor[2]

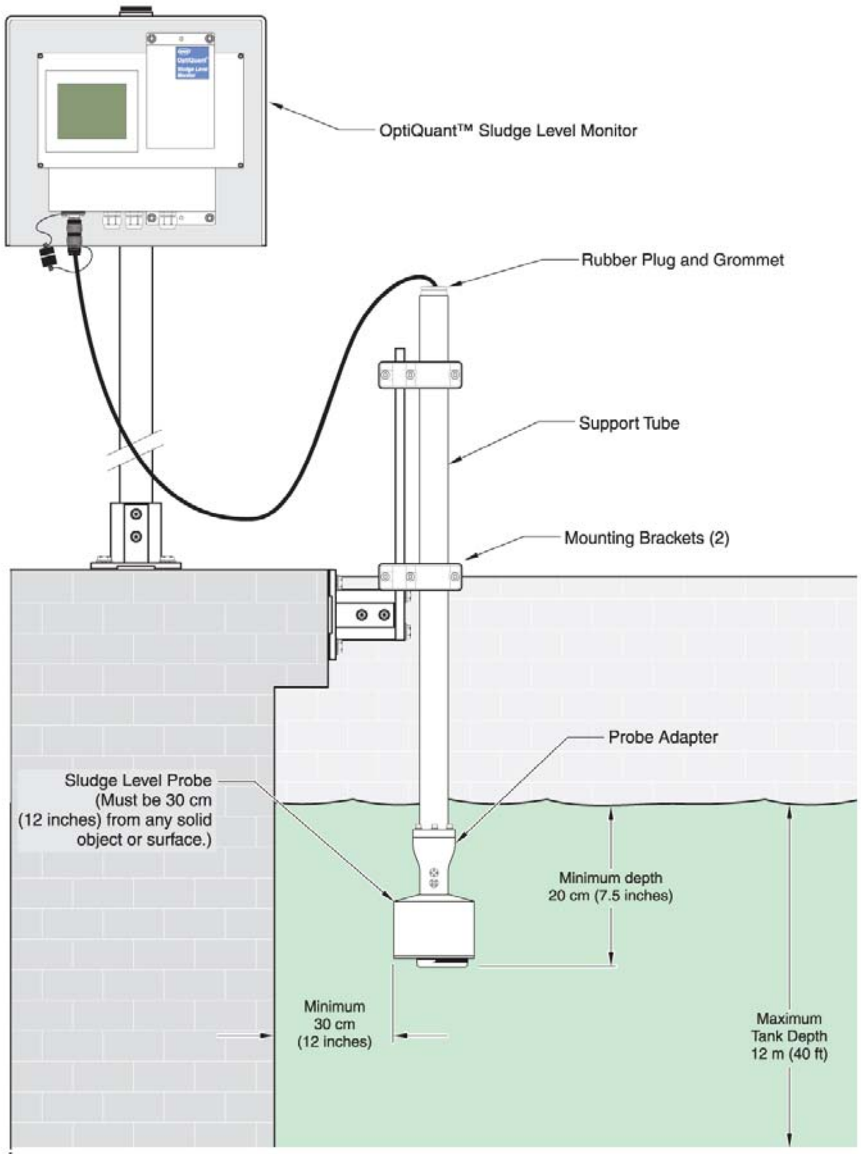

Figure 1.3 Example 2 of an Ultrasonic Automatic Sludge Blanket Monitor[3]

Sludge Return Rate

- The sludge return rate or return activated sludge (RAS) rate is important in controlling and maintaining an adequate MLSS concentration in the aeration tank to achieve the desired degree of treatment.
- RAS pumping rates are typically 50 to 100 percent of the wastewater flow rate for large plants and up to 150 percent of the wastewater flow rate for small plants.
- Inadequate RAS pumping rates can result in a rising sludge blanket. However, a rising sludge blanket can occur despite an increase in RAS flow due to reduced detention times caused by increased influent flow.
- The return-sludge flow rate should be adjusted to maintain the sludge blanket as low as possible.

Floating Solids on Clarifier Surface

- Floating solids on the clarifier surface are an indication of a problem called “rising sludge.”
- This problem occurs when the DO concentration in the secondary clarifier drops resulting in an anoxic, or oxygen deficient, condition. Under anoxic conditions, nitrifying bacteria convert nitrate to nitrogen gas. The nitrogen gas bubbles adhere to floc particles, causing them to rise up to the surface.

Internal Plant Recycles

Supernatant from anaerobic digesters or sludge holding tanks and the clarified water from sludge dewatering process (e.g., belt press) or thickening processes are typically recycled back to the primary clarifiers.

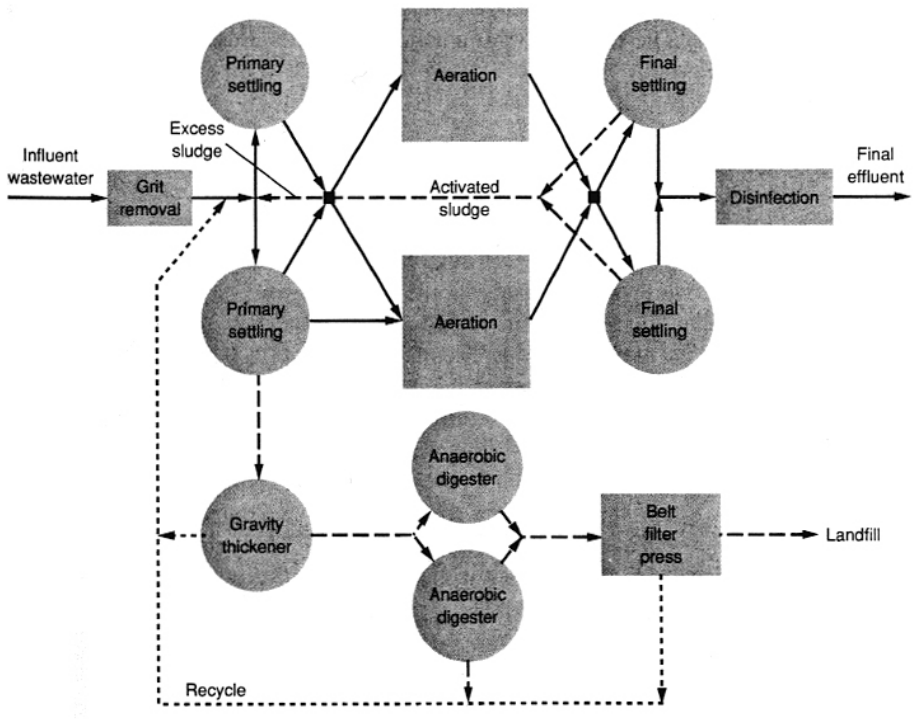

Figure 1.4 Process Flow Diagram Showing Typical Internal Plant Recycles [4]

Plant Effluent

The purpose of the activated sludge treatment plant is to provide an effluent quality that meets or exceeds the NPDES permit discharge limitations. Therefore, it is critical to monitor the plant effluent.

Turbidity

Turbidity is a measure of the cloudiness of the wastewater.

- A turbidimeter measures the amount of light scattered by the suspended particles in a wastewater sample, yielding a measurement that gives a qualitative measure of the TSS concentration.
- Turbidimeters can be installed to give real-time data or bench-top units can be used to test grab samples. Turbidity is measured in units of nephalometric transfer units (NTU).

NPDES Permit Requirements

Your NPDES permit will require that you sample your plant influent and effluent frequently and have the samples analyzed for a variety of parameters.

Table 1.1 Typical Permit Parameters

Parameter	Typical Discharge Limitation
flow rate	varies
BODs	30 mg/L monthly avg., 45 mg/L weekly avg.
TSS	30 mg/L monthly avg., 45 mg/L weekly avg.
pH	6.0 to 9.0
total residual chlorine	0.038 mg/L daily max., 0.08 mg/L weekly avg.
fecal coliform	400#/100 mL daily max.
total recoverable metals	varies
hardness (as $CaCO_3$)	no limit, just monitor
total phosphorus	1 mg/L monthly avg
ammonia nitrogen	no limit, just monitor
acute whole effluent toxicity (WET)	Toxic Unit – Acute (TU_a) must be <1
chronic WET (must be negative) Relative	Toxic Unit – Chronic (rTU_c) must be <1

- The EPA has established the following minimum national standards for secondary treatment for all activated sludge treatment plants:

Table 1.2 Minimum National Standards

Parameter	Units	30-day Average Concentration	7-day Average Concentration
BOD_5	mg/L	30	45
Suspended Solids (TSS)	mg/L	30	45
pH	pH units	must be between 6.0 and 9.0	
$CBOD_5$	mg/L	25	40

- Discharge limitations for the other typical NPDES parameters vary widely and are determined on a case-by-case basis. Your NPDES permit may have more or fewer parameters.

☑ Exercise

1. What are the six key monitoring points within the activated sludge process?

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2. For each of the monitoring points listed above, explain what key characteristics a TPO should look for.

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Mean Cell Residence Time (MCRT)

What Is MCRT?

The Mean Cell Residence Time (MCRT) or solids retention time, is an average measure of how long the microorganisms remain in contact with the substrate (food source). MCRT is also known as solids retention time (SRT).

Why Is It Used?

- Like the F/M ratio, the MCRT is another process control parameter used to control the mass of MLVSS in the aeration tank. Either the F/M ratio or the MCRT can be used to control the amount of sludge in the aeration tank as the two parameters are related. Just stick with one method to be consistent.
- Control of the plant using the MCRT is accomplished by adjusting the sludge wasting and return rates to achieve the desired MCRT. Increasing the wasting rate and decreasing the return rate with decrease the MCRT and decreasing the wasting rate and increasing the return rate will increase the MCRT.

How Is It Calculated?

- The MCRT can be calculated two ways depending on the volume used for the volatile suspended solids in the system. Either method can be used, but select a method and use it consistently.

$$\theta_c = \frac{V_r X}{Q_w X_w + Q_e X_e}$$

where θ_c = mean cell-residence time based on the aeration tank volume, d
V_r = aeration tank volume, Mgal (m^3)
X = concentration of volatile suspended solids in the aeration tank, mg/L $(g/m)^3$
Q_w = waste sludge flowrate, Mgal/d (m^3/d)
X_w = concentration of volatile suspended solids in the waste sludge, mg/L (g/m^3)
Q_e = treated effluent flowrate, Mgal/d (m^3/d)
X_e = concentration of volatile suspended solids in the treated effluent, mg/L (g/m^3)

Figure 1.5 Calculation Based on Aeration Tank Volume[7]

$$\theta_{ct} = \left[\frac{X_t}{(Q_w X_w + Q_e X_e)}\right]\left[\frac{1}{8.34 \text{lb/Mgal} \cdot (\text{mg/L})}\right] \quad \text{U.S. customary units}$$

Figure 1.6 Calculation Based on Total System Volume[8]

where θ_{ct} = mean cell residence time based on the total system
X_t = total mass of volatile suspended solids in the system, including the solids in the aeration tank, in the settling tank, and in the sludge return facilities, (lb)

Sample Calculation

Calculate the MCRT assuming the following:

Aeration Tank Volume is 1,000,000 gal
Wastewater flow to aeration tank is 4.0 mgd
Sludge wasting rate = 0.075 Mgd
MLVSS = 2,000 mg/l
Waste sludge VSS = 6,200 mg/l
Final effluent VSS = 10 mg/l

$$\theta c = \frac{1 \text{ Mgal} \times 2{,}000 \text{ mg/l}}{(0.075 \text{ Mgd} \times 6{,}200 \text{ mg/l}) + (4 \text{ Mgd} \times 10 \text{ mg/l})}$$

$$= 3.96 \text{ days}$$

Calculation

Calculate the MCRT assuming the following:

Aeration Tank Volume is 250,000 gal
# of aeration tanks = 4
Wastewater flow to each aeration tank = 1.25 Mgd
Sludge wasting rate = 0.1 Mgd
MLVSS = 2,000 mg/l
Waste sludge VSS = 8,000 mg/l
Final effluent VSS is negligible

Typical Values

- MCRTs ranging from 3 to 15 days are typical for conventional activated sludge plants. MCRTs less than 3 days will produce a sludge that is young and slow settling and produce a turbid effluent.

Food/Microorganism Ratio (F/M Ratio)

What Is F/M Ratio?

The food-to-microorganism (F/M) ratio is a measure of the mass of substrate (food) available in the primary effluent per unit mass of MLVSS per unit time and has units of lb BOD or COD/lb MLVSS-day.

- The concentration of MLVSS represents the concentration of organisms in the aeration tank. Operators often use COD instead of BOD because COD test results are available four hours after sample collection instead of five days for BOD test results. The five day wait for test results is too long when troubleshooting problems that are potentially occurring now.

Why Is It Used?

- The F/M ratio is a process control parameter that can be used to control the concentration of MLVSS in the aeration tank. For example, if you have a design F/M ratio that must be maintained and you know what the primary effluent COD and aeration tank detention time are, you can calculate the required MLVSS concentration. You can use this method to calculate new MLVSS concentrations that are required for changes in the primary effluent COD load.
- To maintain a MLVSS concentration, the sludge wasting rate will need to be adjusted.
- To calculate the sludge wasting rate, the following information is needed:
  - The MLVSS concentration.
  - Concentration of the volatile solids in the sludge in the secondary clarifier.
  - The desired mean cell residence time (MCRT).
- Calculation of the sludge wasting rate will be discussed in further detail later in this unit.

The F/M ratio is a parameter that is also used to characterize conditions favorable or deleterious to filamentous organisms.

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How Is It Calculated?

$$F/M = \frac{S_o}{\theta X}$$

where F/M = food-to-microorganism ratio, d^{-1}
S_o = influent BOD or COD concentration, mg/L (g/m^3)
θ = hydraulic detention time of the aeration tank = V/Q, d
V = aeration tank volume, Mgal (m^3)
Q = influent wastewater flowrate, Mgal/d (m^3/d)
X = concentration of volatile suspended solids in the aeration tank, mg/L (g/m^3)

Figure 1.7 F/M Calculation[6]

Sample Calculation

Calculate the required MLVSS concentration given the following:

Influent flow rate = 10 mgd
F/M ratio = 0.75 lb COD/lb MLVSS-day
Primary effluent COD = 200 mg/l
# of aeration tanks in parallel = 4
Aeration tank dimensions:
Depth of water = 20 ft
Length = 120 ft
Width = 24 ft

Step 1:

$$\theta = \frac{V}{Q}$$

$$\theta = \frac{20\ ft \times 120\ ft \times 24\ ft \times 4\ tanks}{10 \times 10^6\ gal/day} \times \frac{7.48\ gal}{ft^3}$$
$$= 0.17\ days$$

Step 2:

$$X = \frac{S_o}{(F/M)\theta} = \frac{200\ mg\ COD}{l} \times \frac{mg\ MLVSS\ day}{0.75\ mg\ COD} \times \frac{1}{0.17}$$

X = 1,568 or 1,600 mg MLVSS/l

Typical Values

Table 1.3 Typical F/M Ratios

Activated Sludge Process	F/M Ratio (lb COD/lb MLVSS-day)
High-Rate	>1.0
Conventional	0.5 to 1.0
Extended Aeration	<0.2

Sludge Volume Index (SVI)

What Is SVI?

The **sludge volume index (SVI)** is the volume in mL occupied by one gram of MLSS after 30 minutes of settling in a 1,000 mL graduated cylinder and has units of mL/g. The SVI is a measure of the settleability of the activated sludge in a secondary or final clarifier. Lower values of the SVI indicate better sludge settleability.

Why Is It Used?

- The SVI is used to characterize the settleability of activated sludge.
- The optimal SVI for your plant must be determined by experience and occurs when the plant is generating its best quality effluent regarding solids and BOD removals. Since the SVI depends on the characteristics of the sludge and the MLSS concentration at your plant, it is not advisable to use SVI values from the literature or other plants as a target.
- The SVI can be used as one of several methods to control the sludge return rate. The following formula can be used to determine the required sludge return rate (as a percentage of the plant influent flow), given a desired MLSS concentration:

$$Qr = \frac{Q}{[100/(Pw \times SVI) - 1]}$$

where

Qr = sludge return flow rate
Q = plant influent flow rate
Pw = MLSS concentration (%) = MLSS (mg/L) / 10,000
SVI = sludge volume index

How Is It Calculated?

- The SVI is determined by collecting a sample of sludge from the effluent of the aeration tank and pouring it into a 1,000 mL graduated cylinder.
- The sample is allowed to settle for 30 minutes and the volume of settled solids is recorded.
- The first step in the calculation is to calculate the percentage of settleable solids by dividing the formula given below to calculate the SVI:

$$SVI = \frac{\%\ \text{settleable solids} \times 10{,}000}{\text{MLSS (mg/L)}}$$

Calculation

Calculate the SVI for an activated sludge sample given the following:

30-minute settleable solids volume = 200 mL
MLSS = 2,000 mg/L

Typical Values

- The preferable range for the SVI is 50 to 150 mL/g.

Specific Oxygen Uptake Rate (SOUR)

What is SOUR?

The **specific oxygen uptake rate** (SOUR) is a measure of the quantity of oxygen consumed by microorganisms and is a relative measure of the rate of biological activity. As microorganisms become more active, the SOUR increases and vice versa.

Why Is It Used?

- Research has shown that the SOUR and final effluent COD can be correlated. Therefore, changes in the SOUR can be used to predict final effluent quality.

How Is It Calculated?

- The SOUR is determined by taking a sample of mixed liquor, saturating it with oxygen, and measuring the decrease in oxygen with a DO probe with time.
- The result of that test, the oxygen uptake rate (OUR), measured in mg O_2/L-min, is divided by the MLVSS to yield the SOUR, measured in mg O_2/g MLVSS-hr.
- Refer to Method 2710 B. "Oxygen-Consumption Rate" in Standard Methods for the Examination of Water and Wastewater for details on SOUR determination.

Typical Values

- The SOUR is highly dependent on the type of plant, influent wastewater characteristics, and sludge characteristics. There are no published "typical values" of SOUR.

Sludge Wasting

Sludge wasting is an integral process in activated sludge treatment. Solids in waste activated sludge (WAS) come from two sources. The primary source of WAS is from the growth of new bacterial cells in the aeration tank. In simplistic terms, bacteria in properly functioning aeration tanks use available energy, carbon, and nutrient sources to grow and reproduce. The second source is from organic and inorganic solids in the raw wastewater that pass through the primary clarifiers.

Why Is Sludge Wasted?

- Sludge is wasted to maintain the desired mass of microorganisms in the aeration tank. It is typically wasted when the actual MCRT or sludge age is higher than the target value.

How Is Sludge Wasted?

- Typical secondary clarifiers at activated sludge plants thicken the activated sludge to three to four times the concentration in the aeration tank. This can result in WAS (and return activated sludge, RAS) MLSS concentration from 2,000 to 10,000 mg/l (0.2 to 1.0 percent).

- It is important not to make sudden drastic changes to the WAS rate since biological systems respond better to gradual changes. The preferred method is to waste sludge on a continuous basis, changing the WAS rate as needed by no more than 10 to 15 percent from one day to the next.

- High-rate activated sludge plants typically generate 0.75 pounds of activated sludge per pound of BOD removed while conventional plants typically generate 0.55 pounds of sludge per pound of BOD removed. Extended aeration plants generate less sludge at 0.15 pounds of sludge per pound of BOD removed.

Primary Clarifier

- The sludge produced in the bottom of primary clarifiers has a lower water content than the WAS produced in the bottom of the secondary clarifiers. Therefore, discharging the WAS to the primary clarifier is a method to reduce the water content of the sludge prior to further processing in a digester. The primary clarifiers must have the solids loading capacity to accept WAS if WAS is to be wasted in this manner.

Solids Thickeners

- Another method to waste activated sludge is to direct the WAS to a solids thickener. The purpose of the thickener is to reduce the water content of the sludge prior to further processing in a digester. There are several types of thickeners used for this purpose: gravity, belt, and flotation thickeners. The type of thickener used generally depends on the design engineer's familiarity and/or preference.

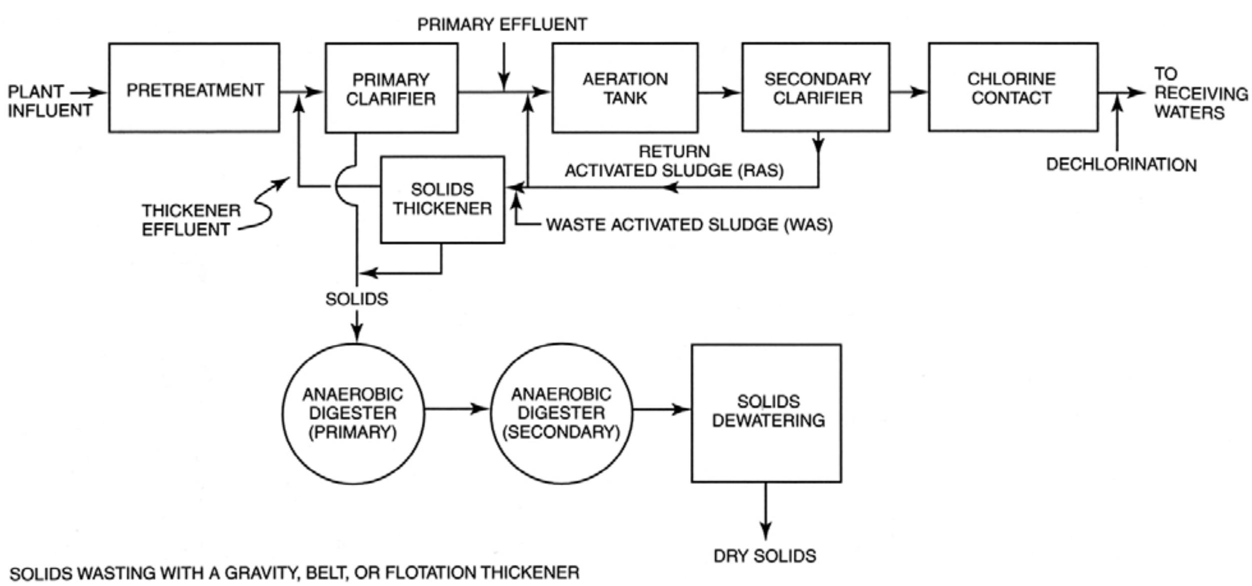

Figure 1.8 Solids Wasting[9]

Calculating the Sludge Wasting Rate

Calculating Based on F/M

- If you use the F/M ratio to control the activated sludge process, you calculate a target MLVSS based on the desired F/M ratio and influent wastewater COD.

- To maintain the target MLVSS concentration, the WAS rate needs to be varied accordingly, remembering not to subject the system to rapid changes (i.e., no more than a 10 to 15 percent change in WAS flow rate per day).

- If the actual MLVSS is too high, the WAS rate should be increased and vice versa.

- The following formula should be used to calculate the additional pounds of sludge that must be wasted per day to reduce the MLVSS concentration to the target level:

  $P_x = (X_1 - X_2) \times V_r \times 8.34$, where:

  P_x = additional sludge to be wasted per day (lb/day)
  X_1 = current MLVSS (mg/L)
  X_2 = target MLVSS (mg/L)
  V_r = volume of aeration tank (Mgal)
  8.34 = conversion factor (lb-L/Mgal-mg)

- Use the following formula to convert the mass of additional wasted sludge to a volumetric flow rate:

  $$Q'w = \frac{P_x}{(X_w \times 8.34)}$$

  Where

  Q'w = additional sludge to be wasted per day (mgd)
  X_w = VSS of WAS (mg/L)
  8.34 = conversion factor (lb-L/Mgal-mg)

Sample Calculation

You have determined that your desired MLVSS concentration is 1,600 mg/L based on a target F/M ratio of 0.75 day^{-1} (see example MLVSS calculation under Food/Microorganism Ratio Section). The actual MLVSS at this instant is 2,000 mg/L, the aeration tank volume is 1.7 Mgal, the WAS VSS is 8,000 mg/L, and the current WAS flow rate is 0.5 mgd.

Step 1: Calculate the additional pounds of sludge to be removed:

$$Px = (2{,}000 - 1{,}600) \times 1.7 \times 8.34$$
$$= 5{,}671 \text{ lb/day}$$

Step 2: Convert the mass rate to a volumetric flow rate:

$$Q'w = \frac{5{,}671}{(8{,}000 \times 8.34)}$$
$$= 0.08 \text{ mgd}$$

Step 3: Calculate the total volumetric sludge wasting rate:

$$Q'w = 0.5 + 0.08$$
$$= 0.58 \text{ mgd}$$

Calculating Based on MCRT

If you use the MCRT to control the activated sludge process, you can use the target MCRT, the volume of the aeration tank, the MLVSS concentration, the plant effluent flow rate, and the VSS concentration in the final effluent to calculate the desired WAS rate according to the following formula:

$$Qw = \frac{\left[\frac{V_r X}{\Theta_c}\right] - Qe\,Xe}{X_w}$$

Where

Qw = WAS flow rate (mgd)
V_r = aeration tank volume (Mgal)
X = MLVSS (mg/L)
Qe = plant effluent flow (mgd)
Xe = VSS in plant effluent (mg/L)
X_w = VSS in WAS (mg/L)
Θ_c = MCRT (days)

Calculation

Calculate the required WAS rate given the following:

Volume of aeration tank = 1.7 Mgal
MLVSS = 1,600 mg/L
plant effluent flow = 10 mgd
VSS in effluent = 10 mg/L
MCRT = 5 days
VSS in WAS = 8,000 mg/L

Record Keeping

Raw data such as meter readings and visual observations are typically recorded in some type of operator's log book. Lab results are typically kept in a separate file. The raw data recorded in the log book and the lab files can be used to create summary data sheets like the following:

MONTHLY LAB DATA FOR EXAMPLE ACTIVATED SLUDGE PLANT

Date	Day	Flow, MGD	BOD		COD	Suspended Solids		Suspended Solids		Volatile Solids		Total Vol, lbs[b]	F/M Ratio	Waste, lbs[c] / day	Air, MCF[d] / day	SVI
			Infl, mg/L	Effl, mg/L	Infl, mg/L	Infl, mg/L	Effl, mg/L	Reaer, mg/L	Aer,[a] mg/L	Reaer, %	Aer,[a] %					
1	W	19.9	440	8	992	446	8	8060	2150	83	82	95786	.43	44298	80.2	270[e]
2	T	22.3	430	11	957	540	18	8860	2160	80	80	98453	.66	50544	80.2	384
3	F	29.2	580	9	1420	682	11	9830	2510	81	80[f]	109930	.38	59929	64.8	295
4	S	24.0	270	12	838	542	27	7930	2170	77	74	87353	.60	53041[g]	51.2	248
5	S	18.8	280	10	770	586	16	8880	2380	73	72	98932	.17	39474	39.0	109
6	M	20.0	360	12	894	456	12	9470	2140	72	72	91818	.38	59156	56.6	98
7	T	20.0	380	8	992	502	26	6090	3050	71	72	85877	.56	36112	61.8	125
8	W	21.7	350	6	881	476	11	8690	2180	74	77	91710	.75	50152	72.5	92
9	T	20.0	340	8	770	380	14	8370	1750	75	79	83716	.44	42931	66.3	–
10	F	25.0	360	9	846	430	16	6070	2040	76	78	74570	.56	24350	68.2	98
11	S	19.9	400	6	710	476	16	8580	2390	76	79	97214	.38	33130	43.7	106
12	S	17.1	210	6	650	380	6	7820	1790	77	75	80672	.25	21131	32.0	156
13	M	21.3	380	9	930	424	6	8220	1990	76	78	87313	.45	23720	65.8	106
14	T	21.2	400	9	920	430	8	8960	2160	78	82	94866	.47	38335	72.4	113
15	W	20.9	440	16	1000	472	21	8720	2680	80	67[h]	98913	.49	44798	77.5	101
16	T	19.1	380	8	927	450	12	8410	2080	81	84	96448	.43	46362	75.3	135
17	F	16.3	350	6	907	428	11	7070	1950	82	87	86835	.38	34965	66.0	133
18	S	16.5	320	5	720	418	14	6120	1830	84	89	79820	.31	23785	42.0	131
19	S	15.4	200	6	620	360	11	5460	1800	84	85	72937	.25	15665	36.4	138
20	M	16.3	400	9	1040	470	8	5430	1590	82	84	67433	.54	13812	51.5	151
21	T	15.4	460	14	1080	416	8	6300	1940	84	86	81982	.50	20176	71.4	155
22	W	15.8	420	6	986	432	9	6620	2120	85	86	88288	.37	28213	69.4	189[e]
23	T	15.1	400	6	888	418	12	6410	1990	85	85	83811	.33	29510	62.2	347
24	F	14.8	360	8	848	414	13	5940	1900	86	90	81395	.21	22689	57.5	289
25	S	16.2	220	8	797	400	14	5490	1800	85	84	73218	.30	15567	42.0	183
26	S	14.2	260	8	700	396	14	5850	1710	84	85	74451	.22	14442	38.4	292
27	M	20.3	420	16	1010	489	14	6330	1510	83	93	75674	.54	18530	58.9	152
28	T	20.4	440	7	961	428	12	6960	1770	85	88	84673	.52	25889	82.1[i]	158
29	W	20.3	480	7	1120	438	8	7180	1810	86	85	86398	.63	30360	94.2	138
30	T	20.8	500	8	1200	616	7	7870	1880	86	88	93977	.54	40300	97.1	144
31	F	21.9	410	7	952	320	10	7710	1870	87	91	74545	.60	38709	92.0	128
Avg		19.4	375	9	914	455	13	7410	2035	81	82	86536	.44	33551	63.5	172

[a] Middle of three aeration tanks.
[b] Multiply lbs x 0.454 to obtain kg.
[c] Multiply lbs/day x 0.454 to obtain kg/day.
[d] Multiply MCF/day x 0.0283 to obtain Million cu m/day.
[e] Filamentous growths. Increase chlorine dose to return sludge.
[f] Drop in percent volatile matter due to storm.
[g] Carefully decrease solids wasting rate due to storm.
[h] Lab error.
[i] Increased air requirements and increased solids wasting due to industrial dump of methanol.

Figure 1.9 Example 1 of Monthly Data Sheet[10]

CLEANWATER, U.S.A.
WATER POLLUTION CONTROL PLANT

MONTHLY RECORD ________ 19__ OPERATOR: ____________

DATE	DAY	WEATHER	FLOW – MGD	RAW WASTEWATER TEMP.	RAW WASTEWATER pH	RAW WASTEWATER SETT. SOLIDS	RAW WASTEWATER B.O.D.	RAW WASTEWATER SUSP. SOLIDS	PRIM. EFF. B.O.D.	PRIM. EFF. SUSP. SOLIDS	PRIM. EFF. D.O.	FINAL EFFLUENT pH	FINAL EFFLUENT B.O.D.	FINAL EFFLUENT SUSP. SOLIDS	FINAL EFFLUENT D.O.	FINAL EFFLUENT CL2 RES.
1	S	CLEAR	1.782	75	7.2	14			118	84	0.6	6.9	19	18	0.9	2.7
2	M	CLEAR	2.347	74	7.3	13	218	150	156	84	0.3	6.8	19	15	1.0	2.8
3	T	CLEAR	2.165	74	7.3	8			109	66	0.8	6.8	14	9	1.2	8.8
4	W	CLEAR	2.012	74	7.3	12			135	74	0.5	6.8	16	14	0.8	4.4
5	T	CLEAR	2.483	74	7.2	13	189	138	134	62	0.3	6.8	9	11	1.7	5.2
6	F	CLEAR	2.386	74	7.2	13			112	60	0.4	6.8	18	6	2.6	6.0
7	S	CLEAR	2.131	75	7.3	13			89	66	0.7	6.9	14	7	1.2	4.4
8	S	CLEAR	1.867	76	7.4	12	174	134	84	74	0.9	6.9	9	15	0.8	4.2
9	M	CLEAR	2.634	75	7.3	14			117	68	0.3	6.9	11	11	1.6	3.5
10	T	CLEAR	2.307	76	7.3	18			120	66	0.3	7.1	8	8	1.5	6.6
11	W	CLEAR	2.198	76	7.3	18	192	142	111	68	0.4	7.0	9	10	1.1	6.6
12	T	CLEAR	2.202	76	7.3	11			99	72	0.4	7.0	11	9	2.0	3.8
13	F	CLEAR	2.178	77	7.3	11			81	58	0.6	7.0	15	18	3.5	4.0
14	S	CLEAR	2.006	78	7.3	12	155	156	105	76	0.3	6.9	12	8	3.1	3.8
15	S	CLEAR	1.942	78	7.2	12			113	74	0.4	6.9	9	9	1.3	4.4
16	M	CLEAR	2.464	78	7.2	11			128	74	0.3	6.9	10	10	1.8	3.0
17	T	CLEAR	2.321	78	7.1	8	168	144	110	64	0.4	6.8	10	11	1.9	6.6
18	W	CLEAR	2.611	78	7.3	15			105	64	0.2	6.9	11	7	2.2	4.4
19	T	CLEAR	2.457	78	7.3	12			87	72	0.5	6.9	10	7	2.9	6.2
20	F	CLEAR	2.498	79	7.3	11	193	118	105	66	0.7	6.9	18	12	3.1	4.4
21	S	CLEAR	2.213	76	7.1	12			109	76	0.6	7.1	10	9	1.2	4.2
22	S	CLEAR	1.878	76	7.3	12			131	78	0.4	6.9	14	10	0.5	4.2
23	M	CLEAR	2.901	77	7.3	12	187	142	133	89	0.2	6.9	13	13	0.3	2.5
24	T	N.M. CLEAR	2.340	78	7.3	13			114	56	0.3	6.9	14	10	2.2	4.2
25	W	CLEAR	2.421	78	7.3	13			89	56	0.4	7.0	12	8	2.8	4.0
26	T	CLEAR	2.562	79	7.3	12	212	170	143	87	0.6	7.0	10	6	1.7	4.3
27	F	CLEAR	2.428	79	7.3	10			128	84	0.5	6.8	15	10	0.5	3.8
28	S	CLEAR	2.149	78	7.3	12			84	66	0.9	6.9	16	5	0.6	3.5
29	S	CLEAR	1.862	79	7.3	7	176	102	117	60	0.5	6.9	14	8	0.5	3.9
30	M	CLEAR	2.746	79	7.3	13			107	73	0.2	6.8	8	8	1.6	3.5
31																
MAX			2.901	79	7.4	18	218	170	156	89	0.9	7.1	19	18	3.5	8.8
MIN			1.782	74	7.1	7	155	102	84	56	0.2	6.8	8	5	0.5	2.5
AVG			2.283	77	7.3	12	186	139	112	70		6.9	12	10	1.6	4.4

DATE	AERATION SYSTEM LBS. VOL. SOLIDS	SUSP. SOLIDS	% VOL.	30 MIN. SETT.	S.V.I.	D.O.	RETURN SUSP. SOLIDS	RETURN-MGD	WASTE GAL. X 1000	WASTE LBS./DAY
1	6746	2036	78.9	150	73	2.5	5961	0.702	70	3480
2	6859	2078	78.6	150	72	1.4	4683	0.711	72	2812
3	7224	2211	77.8	170	76	2.1	6625	0.708	71	3922
4	7305	2213	78.6	180	81	2.0	6641	0.712	70	3877
5	7014	2106	79.3	170	80	2.6	6098	0.722	78	3966
6	6754	2069	79.0	160	77	3.5	5862	0.700	80	3911
7	6296	1905	78.7	150	78	2.6	5564	0.706	80	3712
8	7057	2138	78.6	180	84	0.9	6758	0.703	72	4058
9	6767	2037	79.1	160	78	2.5	6022	0.712	70	3515
10	6119	1861	78.3	170	91	2.8	6135	0.705	64	3274
11	7035	2123	78.9	200	94	1.7	6183	0.700	70	3609
12	6352	1954	77.4	190	97	3.0	6027	0.704	70	3518
13	6313	1937	77.6	170	87	4.8	5542	0.689	72	3327
14	6335	1929	78.2	160	82	4.3	4856	0.703	70	2834
15	6873	2090	78.3	180	86	2.2	5753	0.711	73	3502
16	7082	2162	78.0	200	92	2.5	6852	0.723	76	4343
17	6215	1937	76.4	190	98	2.8	6654	0.698	74	4106
18	6227	1923	77.1	190	98	3.3	5767	0.717	83	3992
19	4844	1534	75.2	170	110	4.5	4762	0.721	25	992
20	5846	1822	76.4	190	104	4.1	5123	0.719	0	0
21	6892	2096	78.3	200	95	2.6	5928	0.706	35	1730
22	7518	2263	79.1	260	114	1.8	3894	0.703	35	1136
23	8388	2541	78.6	310	121	1.9	8396	0.741	70	4901
24	7962	2409	78.7	230	95	3.6	8824	0.700	71	5225
25	7688	2332	78.5	230	98	4.1	7382	0.713	72	4432
26	6697	2047	77.9	210	102	2.6	6867	0.698	70	4008
27	6923	2103	78.2	200	94	1.2	7436	0.702	64	3969
28	7169	2180	78.3	200	91	1.7	8412	0.706	68	4770
29	7852	2397	78.0	230	95	1.0	7117	0.700	66	3917
30	7688	2335	78.4	220	94	2.9	7735	0.713	70	4515
31										
MAX	8388	2541	79.3	310	121	4.8	8824	0.741	83	5225
MIN	4844	1534	76.4	150	72	0.9	4683	0.698	0	0
AVG	6868	2092	78.1	192	91	2.6	6328	0.708	65	3511

SUMMARY DATA		
% REMOVAL	B.O.D.	S.S.
INF – PRI	39.7	49.6
INF – EFF	93.5	.92.8

SLUDGE DATA	
% SOLIDS — AVG.	5.6
LBS. DRY SOLIDS / DAY	5579
% VOL. SOLIDS — AVG.	79.8
LBS. VOL. SOLIDS / DAY	4452
LBS. VOL. SOL./1000 FT^3/DAY	67.5
GALS. SLUDGE TO BEDS	28,000
CU. YDS. CAKE REMOVED	63
FT^3 GAS / LB. VOL. SOLIDS	6.8
FT^3 GAS / LB. MG FLOW	14,286

COST DATA	
MAN DAYS 63 PAYROLL	2,325.78
POWER PURCHASED	520.32
OTHER UTILITIES (GAS, H_2O)	NONE
GASOLINE, OIL, GREASE	108.56
CHEMICALS AND SUPPLIES	547.25
MAINTENANCE	238.48
VEHICLE COSTS	NONE
OTHER	NONE
TOTAL	$ 3,740.39
OPER. COST/MG TREATED	$ 54.62
OPER. COST/CAPITA/MO.	$ 0.158

FLOW METER: LAST 222046; 1st 153549; TOTAL 68.497 MG

ELECTRIC METER: LAST 7838; 1st 5670; TOTAL 2168; MULT 40 X 2168 = 86,720 KWH

RAW SLUDGE: LAST 798324; 1st 432984; STROKES 365340; TOTAL 365340 X 1.0 = 365,340 GALS

GAS METER: LAST 2181110; 1st 1265230; TOTAL 915,880 FT^3

RETURN SLUDGE: LAST 67635048; 1st 67613800; TOTAL 21.248 MG

WASTE SLUDGE: LAST 134251; 1st 132560; TOTAL 1961 x 1000 MG

Figure 1.10 Example 2 of Monthly Data Sheet[11]

- Plotting certain process parameters vs. time using a spreadsheet program can help you to visualize trends.

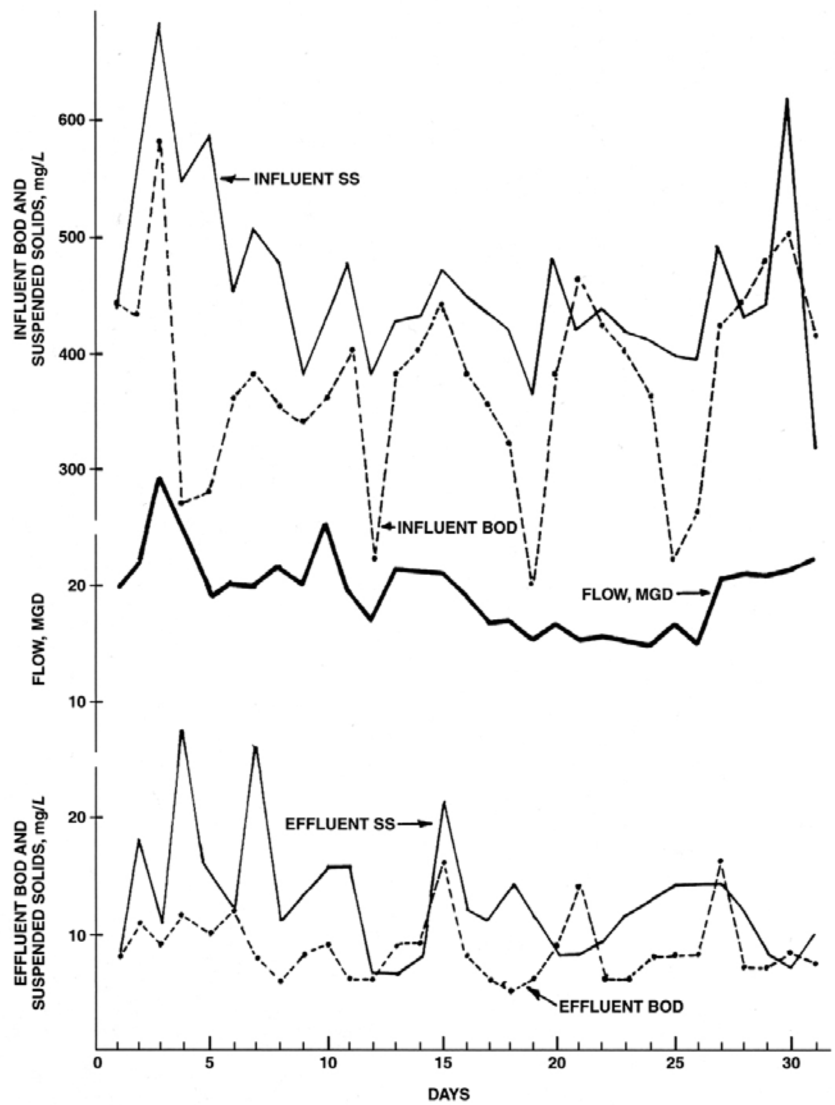

Figure 1.11 Example 1 of Process Parameter Plot[12]

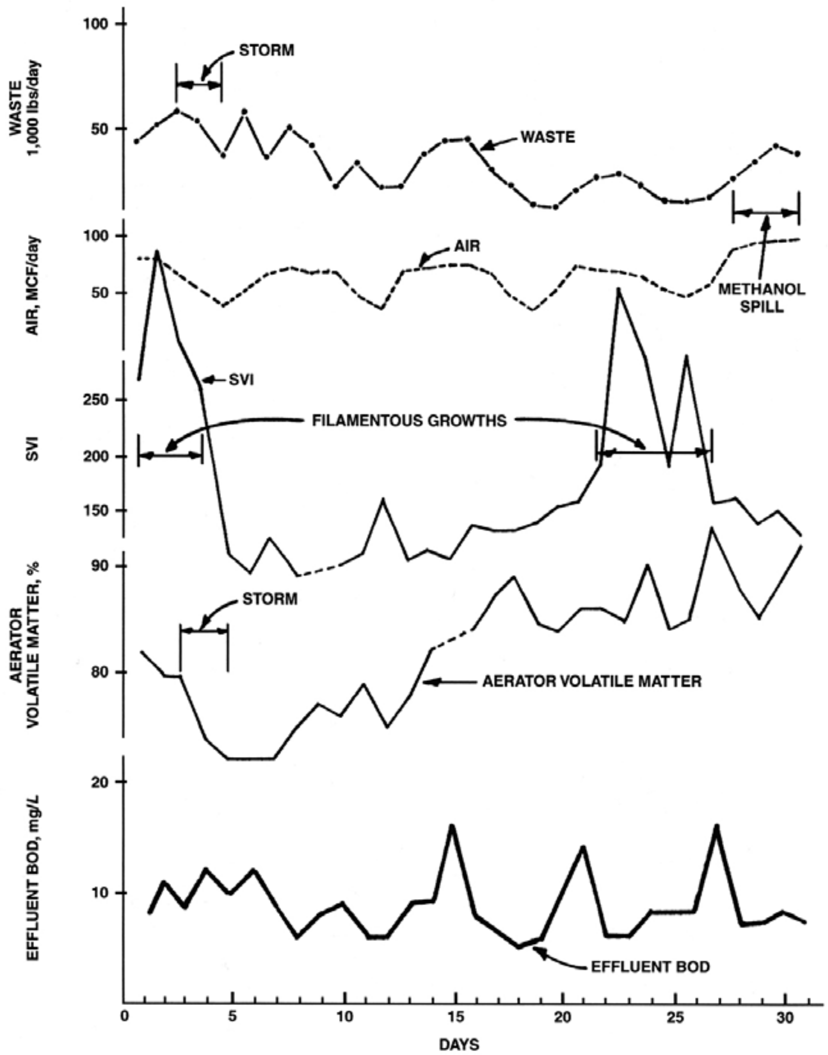

Figure 1.12 Example 2 of Process Parameter Plot[13]

- Notice that these plots are “stacked” on top of a common time axis. This allows you to see how the process parameters are affected when changes to the system are made.

Process Parameters

The following process parameters should be measured and recorded daily in an operator's log book and/or data sheet to characterize the performance of the plant.

TSS and VSS

- The total suspended solids (TSS) concentration should be monitored at the following locations:
  - plant influent
  - primary clarifier effluent
  - aeration tank
  - return sludge
  - final clarifier effluent
  - plant effluent
- The volatile suspended solids (VSS) concentration should be monitored in the aeration tank. This will enable you to calculate the MLVSS-to-MLSS ratio in the aeration tank. This ratio should be in the 0.8 to 0.9 range for well-operating plants.

BOD, COD, or TOC

- Biological oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC) are parameters used to measure the organic "strength" of the wastewater.
- Use of COD is recommended because the results from a COD test are available much sooner than results from a BOD test (i.e., four hours vs. five days). When dealing with a potential plant-upsetting condition, waiting five days for a BOD result is unacceptable. Note that you will probably have to analyze your plant influent and effluent samples for BOD in accordance with your NPDES permit.
- It is possible to correlate COD results with BOD results if you have a sufficient database of historical COD and BOD sample results for your wastewater. This can be helpful because it allows you to "predict" the BOD concentration based on the COD result.
- BOD, COD, or TOC should be monitored at the plant influent, primary effluent and the final clarifier effluent.

DO

- You should maintain a DO residual in your plant's final effluent to minimize the impact to the organisms in the receiving stream and to monitor the performance of a reaeration basin if applicable.

- DO should be monitored at the aeration tank, secondary or final clarifier effluent (inside the effluent weir) and the final effluent.

Settleable Solids/SVI

- Settleable solids is a measure of the quantity of solids in a given sample volume in the wastewater that will settle out of solution.

- Settleable solids can be determined on a volume-to-volume (mL/L) or mass-to-volume basis (mg/L). The sludge volume index (SVI) is used to a measure of the settling characteristics of the mixed liquor from the aeration tank.

- Settleable solids should be monitored at the plant influent and digester supernatant.

Temperature

- Temperature affects biological and chemical processes and should be monitored at the plant influent, aeration tank and the final effluent.

- The optimum temperature range for biological activity is about 25 to 35 °C, which will seldom be achieved in the aeration tank. The solubility of oxygen in water decreases with increasing water temperature, so the aerators will have to work harder during the warm summer months to maintain a certain DO concentration.

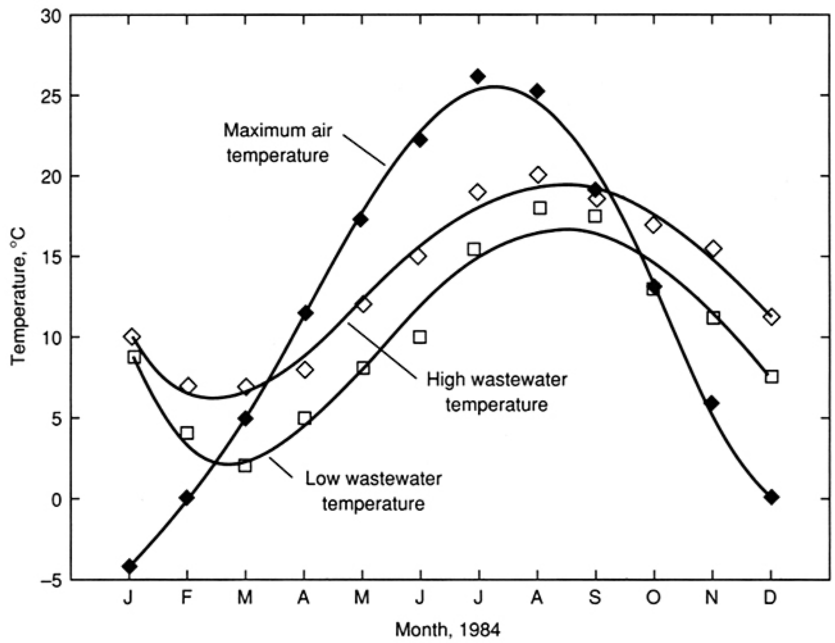

Figure 16.13 Typical Ranges in Influent Wastewater Temperature Throughout the Year[14]

pH

- Like temperature, pH affects biological and chemical processes.

- The optimum pH level for bacterial growth ranges between 6.5 and 7.5. Low pH values may inhibit the growth of nitrifying organisms and encourage the growth of filamentous organisms. The optimum pH range for nitrification is 7.2 to 9.0.

- pH should be monitored at the plant influent, primary effluent, aeration tank and final effluent.

Clarity

- The clarity of the supernatant in the final clarifier should be checked to assess the solids separation process. Clarity can be measured with either a Secchi disc or a turbidimeter.

- A Secchi disc is a flat white disc that is lowered into the water until it is just barely visible. The depth of the disc at this point is recorded as the Secchi disc transparency.

- A turbidimeter measures the amount of light scattered by suspended particles. An in-line turbidimeter provides "real time" turbidity (measured in units of nephelometric transfer units (NTU)) by sending a constant sidestream of water to a flow-through cell, where the turbidity is measured. A bench-top turbidimeter measures the turbidity of a grab sample.

- Clarity can be measured using either method, just stick with one method to be consistent.

Chlorine Demand

- Chlorine demand is the amount of chlorine that must be added to reach a desired residual level. This parameter is only applicable if chlorine is used to disinfect the final clarifier effluent.

- The chlorine demand at the final clarifier effluent should be monitored to regulate the chlorine dose.

- The chlorine demand for your plant will depend on the levels of readily oxidizable substances, such as ferrous iron, manganese, hydrogen sulfide, and organic matter and the amount of ammonia- and organic-nitrogen in the final clarifier effluent. A typical chlorine dose for an activated sludge plant effluent is 2-8 mg/L, while the typical desired chlorine residual is 0.5 mg/L. See Module 5 for more information on the chlorination process.

Coliform Group Bacteria

- Coliform group bacteria should be monitored in the final effluent in accordance with your NPDES permit.

- The analytical method depends on your regulatory agency's requirements. The two primary methods are the multiple-tube fermentation technique and the membrane filter technique.

- Typical NPDES permits limit the amount of total coliforms in the final effluent to 400 MPN/100 mL. MPN refers to the Most Probable Number, which is a statistical estimate of the concentration of coliforms per 100 mL using the multiple-tube test method, not the actual number of organisms.

Meter Reading & Calculations

In addition to the process parameters just mentioned, the equipment meter readings listed below must also be recorded and monitored.

- Daily influent flow.
- Return sludge pumping rate.
- Waste sludge pumping rate.
- Air flow to diffused air system or hours operated at specific motor speeds for mechanical aeration.

These meter readings along with the process parameters previously mentioned are used to determine the following process parameters:

- Pounds of solids under aeration = (MLSS, mg/L) x (aeration tank volume, Mgal) x 8.34
- BOD or COD load to aeration tank (lb/day) = (BOD or COD in primary effluent, mg/L) x (plant influent flow, mgd) x 8.34
- Solids leaving plant (lb/day) = (TSS in plant effluent, mg/L) x (plant effluent flow, mgd) x 8.34
- MCRT or F/M ratio (see Unit 1)
- Solids load to digester (lb/day) = (TSS of waste sludge, mg/L) x (waste sludge pumping rate, mgd) x 8.34
- Solids in digester supernatant (lb/day) = (TSS of digester supernatant, mg/L) x (supernatant flow rate, mgd) x 8.34

Observations

The following areas should be examined and any unusual observations should be recorded.

- **Inspect the color and flow of the plant influent.**

  Fresh, untreated domestic wastewater should have a light brownish-gray color. Untreated wastewater residing in the collection system for extended periods of time may become septic. You will notice a gradual change in the color of the wastewater from gray to dark-gray and eventually to black. The presence of septic wastewater will create more odors at the headworks of the plant. Some industrial discharges can affect the color of the influent wastewater. A quick check of the water level in the primary flow measurement device (e.g., weir or flume) will tell you if you have extremely high or low flow conditions.

- **Look for the presence of scum and odor on the surface of the primary clarifier.**

  The same comments regarding plant influent color apply to the color of the wastewater in the primary clarifier.

- **Examine the level of turbulence, color and thickness of surface foam and scum of the aeration tank.**

  A properly functioning aeration system will generate highly turbulent conditions to promote the transfer of oxygen from the gas phase to the aqueous phase. You should see a “rapidly boiling” surface for diffused-air systems in the aerobic zones. If the surface looks relatively still with little bubbling present, there may be a problem with the blowers or the diffusers. The presence of thick, dark brown foam on the surface of the aeration tank could be an indication of *Nocardia* growth. See Unit 2 for more information on *Nocardia* foam.

- **Check the clarity of the effluent and the type of solids on the surface of the secondary clarifier.**

  The secondary clarifier effluent should be relatively clear and free of visible activated sludge flocs. The presence of activated sludge flocs in the secondary clarifier effluent could be an indication of sludge bulking. Sludge bulking will be discussed later. The surface of the clarifier should be clear and free of floating debris and foam. Thick, dark brown foam on the surface of the clarifier could be an indication of *Nocardia* growth. See Unit 2 for more information on *Nocardia* foam. The presence of gas bubbles and rising sludge masses on the surface of the clarifier is an indication that denitrification is occurring in the clarifier. See Unit 2 for more information on rising sludge.

- **Inspect the color and odor of the return activated sludge.**

  RAS should have a light brownish color. RAS should not be allowed to become septic, which would be indicated by a dark-gray to black color and a foul odor.

- **Examine mechanical equipment and motors for excessive vibrations, noises and temperature.**

Review Log Book

The operator should review the log book at the start of every shift. Every operator on every shift should follow the same operational strategies to maintain consistency. This will ensure that consistency is maintained and that everyone is up to date on the status of the plant.

- A review of the log book will tell you what the status of the plant is, whether any operational changes have been made, and the reason for the changes.
- Review the log book for the following:
  - Unusual occurrences. Check to see if any corrective action was taken to address the unusual occurrence and whether the problem has been corrected.
  - Status of the return and waste sludge pumps.
  - DO level in aeration tanks. A DO level of 1 to 3 mg/L should be maintained at all times.
  - Chlorine dose rate. If chlorine is added to the return sludge line to control filamentous growths, check the dose rate in pounds of chlorine added per day.

Review Lab Data

- In addition to reviewing the log book, review the lab data and/or summary data sheets for the following:
  - Pounds of volatile solids under aeration (MLVSS). Check the MLVSS concentration in mg/L and the MLVSS/MLSS ratio.
  - Sludge wasting rate. Adjust the sludge wasting rate to maintain the desired MLVSS concentration.
  - Air usage. Check the airflow requirement in millions of cubic feet per day (Mcf/d) to maintain the desired aeration tank DO concentration. The air usage is an indicator of influent BOD loading.

Key Points for Unit 1 – Process Control Strategies

- Biochemical Oxygen Demand (BOD) is the rate at which organisms use the oxygen in water or wastewater while stabilizing decomposable organic matter under aerobic conditions.

- Flocculants are chemicals that promote the agglomeration of smaller particles into large, settleable particles.

- The Mean Cell Residence Time (MCRT) or solids retention time, is an average measure of how long the microorganisms remain in contact with the substrate (food source).

- MCRTs ranging from 3 to 15 days are typical for conventional activated sludge plants.

- Sludge is wasted to maintain the desired mass of microorganisms in the aeration tank. It is typically wasted when the actual MCRT or sludge age is higher than the target value.

- It is important not to make sudden drastic changes to the WAS rate since biological systems respond better to gradual changes.

- Biological oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC) are parameters used to measure the organic "strength" of the wastewater.

- You should maintain a DO residual in your plant's final effluent to minimize the impact to the organisms in the receiving stream and to monitor the performance of a reaeration basin if applicable.

- Use of COD is recommended because the results from a COD test are available much sooner than results from a BOD test (i.e., four hours vs. five days).

- pH should be monitored at the plant influent, primary effluent, aeration tank and final effluent.

- RAS should have a light brownish color. RAS should not be allowed to become septic, which would be indicated by a dark-gray to black color and a foul odor.

Exercise for Unit 1 – Process Control Strategies

1. List the nine process parameters that require record keeping and briefly explain why:

   a. ____

   ____

   b. ____

   ____

   c. ____

   ____

   d. ____

   ____

   e. ____

   ____

   f. ____

   ____

   g. ____

   ____

   h. ____

   ____

   i. ____

   ____

[1] Source: www.geneq.com/catalog/en/sludge_judge.htm

[2] OptiQuant™ Sludge Level Monitor Instrument Manual (Loveland, CO: The Hach Company, 2002), p. 20.

[3] OptiQuant™ Sludge Level Monitor Instrument Manual (Loveland, CO: The Hach Company, 2002), p. 31.

[4] p. 183 M & E

[5] L.J. Thibodeaux, *Chemodynamics: Environmental Movement of Chemicals in Air, Water, and Soil*, (New York, NY: John Wiley & Sons, 1979).

[6] *Wastewater Engineering: Treatment, Disposal, Reuse*, 3rd Edition, (New York, NY: Irwin/McGraw-Hill, 1991), p. 532.

[7] *Wastewater Engineering: Treatment, Disposal, Reuse*, 3rd Edition, (New York, NY: Irwin/McGraw-Hill, 1991), p. 533.

[8] *Wastewater Engineering: Treatment, Disposal, Reuse*, 3rd Edition, (New York, NY: Irwin/McGraw-Hill, 1991), p. 533.

[9] John Brady, "Activated Sludge", in *Operation of Wastewater Treatment Plants: A Field Study Training Program*, Vol II, (Sacramento California: California State University, Sacramento Foundation, 1999), p. 56.

[10] Brady, p. 61.

[11] Brady, p. 141.

[12] Brady, p. 62.

[13] Brady, p. 63.

[14] *Wastewater Engineering: Treatment, Disposal, Reuse*, 3rd Edition, (New York, NY: Irwin/McGraw-Hill, 1991), p. 63.

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Unit 2 – Typical Operational Problems

Learning Objectives

- List six common process operational problems.
- List and explain possible plant changes that may result in process operational problems.
- Define sludge bulking, explain what causes it and identify possible solutions.
- Define septic sludge, explain what causes it and explain possible solutions.
- List five classifications of toxic substances and explain their effects on biological treatment systems.
- List and explain institutional, design and process controls that can be used to control toxic substances.
- Define rising sludge, explain what causes it and identify possible solutions.
- Explain what causes foaming/frothing and possible solutions.
- Explain the significance of the Process Trouble-shooting Guide.
- List and explain seven common equipment operational problems.
- Describe the maintenance required for surface aerators, air filters, blowers, the air distribution system and the air header/diffuser.

Plant Changes

High Digester Supernatant Solids

When the digesters are not functioning properly or are overloaded, the supernatant discharged to the primary clarifiers can contain elevated levels of solids. These solids can create several operational problems, such as:

- Digester solids can impart a high initial oxygen demand once in the aeration tank, requiring increased air input and increased MLVSS to treat the additional organic load.

- If the MLVSS are not increased in response to the supernatant solids, the mass of inert solids in the aeration tank will increase resulting in a reduction of the MLVSS-to-MLSS ratio.

If a plant operator decides to increase the sludge wasting rate based on an observed increase in MLSS due to digester supernatant solids, he may actually worsen the situation.

- The situation will likely degrade because by increasing the sludge wasting rate, the operator is also wasting valuable VSS, which is needed to build the MLVSS-to-MLSS ratio back up.

- Rather than increasing the wasting rate, the operator should decrease or cease wasting until the desired MLVSS concentration is reached. The plant may need to be changed to a step feed aeration process to accommodate the solids buildup in the aeration tank (see Module 17, Unit 2.)

Plant Influent Flow and Waste Characteristic Changes (BOD/COD, TSS)

Large increases in influent flow due to a storm will result in reduced detention times in the aeration basin and can result in the loss of volatile suspended solids through the secondary clarifiers. Shock loads high in COD/BOD from industrial sources will require an increase in MLVSS and air supply in the aeration tank. Toxic dumps may result in substantial bacterial die-off in the aeration tank.

- In general, the best control strategy to deal with these problems is to regulate the sludge wasting and return rates to retain as much of the volatile suspended solids in the aeration tank as possible. Encourage plant managers of industrial facilities discharging to your plant to notify you of planned or accidental slug loads and to discharge these loads slowly rather than all at once.

Temperature Changes

Temperature changes affect the rate of biological activity. Therefore, the optimal loading rates and typical air rates experienced during the summer will change during the winter.

- Activated sludge plants require more volatile suspended solids and less air flow in the winter.

- A temperature change does not significantly affect the activated sludge process unless it changes the wastewater temperature by more than 10°F (6°C).

Sampling Program Changes

In order to maintain a consistent, meaningful process database, it is critical to be consistent with regard to sampling locations and methods. When sample locations and collection methods vary widely, analytical results will be difficult to interpret. Changes in laboratory analytical methods can also result in widely varying sample results.

Sludge Bulking

Sludge bulking describes a condition in which activated sludge has poor settling characteristics and poor compatibility. When this occurs, the sludge blanket in the secondary clarifiers rises until solids eventually escape the clarifiers and are discharged from the plant.

Causes

- The presence of filamentous organisms is the predominant cause of sludge bulking. These organisms grow into long filaments from one floc mass to another and prevent the floc masses from effectively compacting during the settling process.

- The presence of excess water, or bound water, in the activated sludge bacteria cells, which effectively reduces the sludge density.

- Low pH, low DO and low nutrient concentrations have been linked to sludge bulking, but high F/M ratios (and low MCRTs) are the primary cause for repeated bulking. Microorganisms in a high F/M ratio environment tend to grow rapidly in a dispersed state rather than in clumps or flocs. When this occurs, activated sludge settling characteristics are poor and it is difficult to retain the sludge in the secondary clarifier without the addition of a chemical flocculant or by incorporating some other method to improve sludge settleability.

Solutions

- Increase the MCRT
  Carefully monitor plant records to ensure that the desired MCRT is achieved. Generally, increasing the MCRT may alleviate sludge bulking. Increasing the MCRT has the same effect as decreasing the F/M ratio. It is important to note that low F/M ratios (high MCRTs) can create conditions favorable to filamentous organisms, so compare your plant's F/M ratio or MCRT with the "typical" values published in the literature for properly functioning plants.

- Increase the DO
  Low DO levels in the aeration tank may create conditions favorable to filamentous organisms. As long as you have adequate aeration capacity, you should be able to maintain DO concentrations in the 2 to 4 mg/L range.

- Increase Hydraulic Detention Time in the Aeration Basin
  Sludge bulking caused by short hydraulic detention times in the aeration basin is either due to a design problem or an excessive return sludge pumping rate. You can increase the hydraulic detention time by decreasing the return sludge pumping rate. In order to maintain the same mass of activated sludge under aeration at a reduced return sludge pumping rate, you can add a chemical flocculant to the secondary clarifier to thicken the return sludge.

- Chlorinate the Return Sludge
  Chlorination of the return sludge can alleviate sludge bulking due to filamentous organisms in emergency situations or for a temporary solution. Chlorination will not address the root cause of the filamentous bulking. Chlorine is typically applied at a rate of 2 to 3 mg/L of Cl_2 per 1,000 mg/L of MLVSS. Secondary clarifier effluent turbidity may increase during chlorination due to the death of nitrifying bacteria.

- Add Flocculant
  The settling characteristics of a bulking sludge may be improved by the addition of a chemical flocculant to the secondary clarifier.

- Control sulfide ions entering the aeration tanks
  Check the concentration of sulfide ions in the aeration tanks and all streams entering the aeration tanks if you are experiencing sludge bulking. The bulking may be due to *Thiothrix*, which is a sulfur-reducing filamentous bacteria. Removing the sulfide ions will kill the *Thiothrix*.

Septic Sludge

Septic sludge is any sludge that has become anaerobic and is characterized by a foul odor. Anaerobic decomposition generates gases, which can cause the sludge to slowly rise to the surface of vessels, such as a primary or secondary clarifier.

Causes

- Sludge becomes septic when it is allowed to sit stagnant in a vessel or pipe long enough to deplete residual DO.
- Poorly designed or constructed sludge hoppers, wet wells, flow channels and pipe systems can cause activated sludge to turn septic if it is allowed to accumulate in pockets or “dead spots” for too long.
- Inadequate mixing in aeration tanks can result in activated sludge accumulating on the bottom and becoming septic.
- Sludge in a secondary clarifier may also become septic from return sludge rates being too low.

Solutions

- Completely mix the contents of the aeration tank.
- Maintain a flow velocity of at least 1.5 feet/second in sludge pipelines and channels to prevent sludge deposition.
- Increase return sludge rate to reduce the detention time of the sludge in the secondary clarifier.
- Make sure the clarifier collection mechanism is on so that solids are removed from the draw-off hopper.
- Make sure the sludge draw-off lines are not plugged.
- Make sure the return sludge pumps and valves are operating properly.

Rising Sludge

Rising sludge is the term used to describe sludge that slowly rises to the surface of secondary clarifiers. This phenomenon can occur when the sludge has good settling characteristics. Rising sludge is differentiated from sludge bulking by the presence of gas bubbles on the surface of the clarifier and usually produces a fine scum on the surface of the clarifier.

Causes

- Rising sludge is caused by the process of denitrification in the secondary clarifiers.

Solutions

- Increase the return sludge rate to decrease the detention time of the sludge in the clarifier.
- Decrease the flow rate of activated sludge to the problematic clarifier if the return sludge rate can not be increased.
- Increase the speed of the sludge collecting mechanism in the clarifier.
- Decrease the MCRT by increasing the wasting rate.

Foaming/Frothing

Foaming/frothing is the condition describing a buildup of foam or froth on the surface of the aeration tank. There are several different types of foam: thick, dark brown foam; light, white foam; unstable foams that come and go and are easy to treat; and stable foams that are more difficult to treat.

Causes

- Light, white foam is caused by a low MLSS.
- Unstable foams can be caused by nutrient deficiencies, solids recycled from dewatering processes, the presence of surfactants (detergents) in the plant's influent, over aeration and polymer overdosing.
- Persistent, stable foams are usually caused by the filamentous bacteria *Nocardia*, and are called *Nocardia* foam. *Nocardia* foam is thick, dark brown foam that can be caused by a low F/M ratio, high MLSS (high MCRT) due to insufficient wasting and reaerating activated sludge. The high air flow requirements to maintain high MLSS tend to expand *Nocardia* foam and worsen the problem.

Solutions

For control of detergent foam:

- Increase the MLSS concentration.
- Reduce the air supply during periods of low flow while maintaining residual DO level.
- Return digester supernatant slowly to the aeration tank during periods of low flow.

For control of *Nocardia* foam:

- Reduce the MCRT.
- Reduce air flow to decrease the thickness of the foam layer.
- Add a selector tank prior to the aeration tank to provide conditions; high F/M ratio, dissolved oxygen level between 2 and 5 mg/L and MCRT less than 5 days, unfavorable for *Nocardia* growth.
- Add a biological foam control agent consisting of bacterial cultures that will control *Nocardia*-produced biosurfactants.
- Chlorinate the return sludge.
- Spray chlorine solution or sprinkle calcium hypochlorite directly on surface of foam.
- Reduce the pH of the mixed liquor by chemical addition or initiating nitrification.

Toxic Substances

The EPA has developed a list of approximately 150 toxic substances, or "priority pollutants," based on their known or suspected carcinogenicity (cancer forming potential), mutagenicity (DNA altering potential), teratogenicity (potential for causing structural developmental defects during formation of individual organs), or high acute toxicity.

Categorical discharge standards, which are discussed below, are used to regulate the discharge of priority pollutants to publicly owned treatment works (POTWs) by commercial and industrial sources. Wastewater treatment plants discharging to surface waters are required to monitor their effluents for and comply with certain priority pollutant discharge limitations. The toxicity of wastewater treatment plant effluents is typically measured using the whole effluent toxicity (WET) test.

Classifications

Toxic substances in the priority pollutant list fall into the following classifications:

- Heavy Metals
  Heavy metals primarily originate from industrial sources. There are many industrial manufacturing processes that generate wastewater with heavy metals. Common metals found in untreated industrial wastewaters are:
  - Barium (Ba)
  - Cadmium (Cd)
  - Chromium (Cr)
  - Lead (Pb)
  - Mercury (Hg)
  - Silver (Ag)
  - Zinc (Zn)
  - Copper (Cu)
  - Nickel (Ni)
- Inorganic Compounds
  Sources of inorganic toxic compounds (non-metals) include arsenic from alloying metals and selenium from electronics manufacturing.

- Organic Compounds

The primary source of organic compounds is from industrial sources, for example, from the use of solvents in degreasing operations. Many of the organic compounds listed as priority pollutants are considered volatile organic compounds (VOCs).

VOCs are organic compounds that tend to evaporate easily. Generally, an organic compound is considered to be a VOC if its boiling point is less than or equal to 100°C and/or its vapor pressure exceeds 1 mm Hg at 25°C.

VOCs are a concern to wastewater treatment plant operators because they can be easily released to the atmosphere, especially at the headworks and in the aeration basin, presenting a health risk hazard.

Examples of priority pollutant VOCs are:

- Benzene (C_6H_6)
- Ethylbenzene ($C_6H_5C_2H_5$)
- Toluene ($C_6HC_5H_3$)

- Halogenated Compounds

Halogenated compounds are organic compounds with one or more halogen atoms (e.g., chlorine or bromine). They are commonly used as industrial solvents and pesticides, herbicides and insecticides. Halogenated organic compounds are extremely toxic and are not readily biodegradable.

Examples of chlorinated hydrocarbons commonly used in industry:

- Chlorobenzene (C_6H_5Cl)
- Chloroethene (CH_2CHCl)
- Dichloromethane (CH_2Cl_2)
- Tetrachloroethene (CCl_2CCl_2)
- Trichloroethene (C_2HCL_3)

- Pesticides, Herbicides and Insecticides
  Pesticides, herbicides, and insecticides are halogenated organic compounds that are toxic to most life forms and not readily biodegradable. These compounds are not generally found in domestic wastewater and may be found in surface runoff from agricultural and residential areas.
  The following are examples of these compounds:
  - Endrin (insecticide and fumigant)
  - Lindane (pesticide)
  - Methoxychlor (insecticide)
  - Toxaphane (insecticide and fumigant)
  - Silvex (herbicide, plant growth regulator)

Effects on Biological Treatment Systems

- In general, toxic organic compounds present in activated sludge plants may be removed, transformed, generated or passed through the system unchanged. These compounds are typically present at concentrations that are below levels that are toxic to activated sludge bacteria.

- Inorganic compounds, such as copper, lead, silver, chromium, arsenic, and boron cations (positively charged ions) can be toxic to microorganisms. A copper concentration of 100 mg/L, chromium and nickel concentrations of 500 mg/L, potassium and ammonium concentrations of 4,000 mg/L, and elevated concentrations of sodium can be toxic to bacteria in sludge digesters. Elevated levels of these cations have resulted in upset plant conditions.

Institutional Controls

Institutional controls are rules and regulations that govern the discharge of wastewater to POTWs. The purpose of institutional controls with regard to toxics is to prohibit or limit the amount of toxics that can be discharged to a POTW.

There are two types of institutional controls:

- **Prohibited Discharge Standards**
  Prohibited discharge standards apply to all commercial and industrial dischargers and restrict the discharge of pollutants that may cause fire or explosion hazards in collection or treatment systems, are corrosive (typically pH<5.0), block flow through sewers, upset the biological treatment process, or cause the temperature in the plant influent to exceed 40°C.

- **Categorical Standards**
  Categorical standards apply to specific commercial and industrial dischargers and restrict the amount of priority pollutants discharged.

Design Controls

Design controls are unit operations that are either specifically designed to remove toxics or have the ability to remove them.

There are many treatment technologies for the removal of toxics. The following are examples of the unit operations typically found in wastewater treatment.

- Carbon Adsorption
- Activated Sludge Powdered Activated Carbon
- Air Stripping
- Coagulation, Sedimentation & Filtration
- Chemical Oxidation / Treatment
- Conventional Biological Treatment

Process Controls

- In the event of an upset due to a toxic discharge and in the absence of design controls, reduce or cease sludge wasting and return all available sludge to the aeration tank.

☑ Exercise

1. List six process operational problems.

2. What is sludge bulking?

3. What is septic sludge?

4. List five classifications of toxic substances.

Process Troubleshooting Guide

One of the most important principles in process troubleshooting is to make only one process change at a time and to give the system adequate time to respond to the change before making another change. You will typically need to allow one week for the plant to stabilize after making a process change. As you gain more experience and become more familiar with your plant, you may be able to determine the effects of your process change within a few days.

Table 2.1 Process Troubleshooting Guide[1]

11.67 Process Troubleshooting Guide (adapted from *PERFORMANCE EVALUATION AND TROUBLESHOOTING AT MUNICIPAL WASTEWATER TREATMENT FACILITIES*, Office of Water Program Operations, US EPA, Washington, DC)

INDICATOR/OBSERVATION	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTION
1. Sludge floating to surface of secondary clarifiers.	1a. Filamentous organisms predominating in mixed liquor ("bulking sludge").	1a. SVI—if less than 100, 1(a) is not likely cause; microscopic examination can be used to determine presence of filamentous organisms.	1a. (1) Increase DO in aeration tank if less than 1.5 mg/*L* at effluent end of aerator. (2) Increase MCRT to greater than 6 days. (3) Increase sludge return rate and reduce or stop wasting. (4) Supplement deficiency of nutrients so that BOD to nutrient ratio is no more than 100 mg/*L* BOD to 5 mg/*L* total nitrogen, 1 mg/*L* phosphorus, and 0.5 mg/*L* iron. (5) Add 5-10 mg/*L* of chlorine to return sludge until SVI <150 (should be controlled within 2-3 days). Microscopically examine sludge to avoid destruction of beneficial organisms during chlorine application. (6) Increase pH to 7. (7) Add 50-200 mg/*L* of hydrogen peroxide to aeration tank until SVI <150.
	1b. Denitrification occurring in secondary clarifiers; nitrogen gas bubbles attaching to sludge particles; sludge rising in clumps.	1b. Nitrate concentration in clarifier influent; if no measurable NO_3^-, then 1(b) is not the cause.	1b. (1) Increase sludge return rate (will increase clarifier hydraulic load and reduce detention time). (2) Increase DO in aeration tank. (3) Reduce MCRT. (4) Reduce flow to offending unit if sludge return rate cannot be effectively increased.
2. Pin floc in secondary clarifier overflow—SVI is good but effluent is turbid.	2a. Excessive turbulence in aeration tanks.	2a. DO in aeration tank.	2a. Reduce aeration agitation (reduce blower CFM output or depth of submergence and RPM of mechanical aerator).
	2b. Overoxidized sludge.	2b. Sludge appearance.	2b. Increase sludge wasting to decrease MCRT.
	2c. Anaerobic conditions in aeration tank.	2c. DO in aeration tank.	2c. Increase DO in aeration tank to at least 1.0 to 1.5 mg/*L* in aerator effluent.
	2d. Toxic shock load.	2d. Microscopically examine sludge for inactive protozoa.	2d. (1) Re-seed sludge with sludge from another plant if possible; enforce industrial waste ordinances. (2) Stop wasting. (3) Return rate as high as possible to reestablish culture.

11.67 Process Troubleshooting Guide (continued) (adapted from *PERFORMANCE EVALUATION AND TROUBLE-SHOOTING AT MUNICIPAL WASTEWATER TREATMENT FACILITIES*, Office of Water Program Operations, US EPA, Washington, DC)

INDICATOR/OBSERVATION	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTION
3. Very stable dark tan foam on aeration tanks which sprays cannot break up. *NOTE:* If not causing a problem, do nothing.	3a. MCRT is too long.	3a. If MCRT greater than 9 days, this is probable cause.	3a. Increase sludge wasting to reduce MCRT. Increases should be at a modest rate and trends watched carefully.
4. Thick billows of white sudsy foam on aeration tank.	4a. MLSS too low.	4a. MLSS.	4a. Decrease sludge wasting to increase MLSS and MCRT.
	4b. Presence of a non-biodegradable surface active material.	4b. If MLSS level is appropriate, surfactants are probable cause.	4b. Monitor industrial discharges.
5. Aerator contents turn dark—sludge blanket lost in secondary clarifier.	5a. Inadequate aeration, dead zones, and septic sludge.	5a. Aeration basin DO and aeration rates (blower CFM output or mechanical aerator speed and depth).	5a. (1) Increase aeration by placing another blower in service. (2) Decrease loading by placing another aeration basin in service. (3) Check aeration system piping for leaks. (4) Clean any plugged diffusers or add more diffusers if possible. (5) Increase blower CFM output or mechanical aerator speed and depth.
6. MLSS concentrations differ substantially from one aeration basin to another.	6a. Unequal flow distribution to aeration tanks.	6a. Flow to each basin.	6a. Adjust valves and/or inlet gates to equally distribute flow.
	6b. Return sludge distribution unequal to aeration basins.	6b. RAS flow to each basin.	6b. Check return sludge flows and discharge points.
7. Sludge blanket overflowing secondary clarifier weirs uniformly.	7a. Inadequate rate of sludge return.	7a. Sludge return pump output.	7a. (1) If return pump is malfunctioning, place another pump in service and repair. (2) If pump is in good condition increase rate of return and monitor sludge blanket depth routinely. Maintain 1-3 foot (0.3-0.9 m) deep blanket. When blanket increases in depth, increase rate of return. (3) Clean sludge return line if plugged.
	7b. Unequal flow distribution to clarifiers causing hydraulic overload.	7b. Flow to each clarifier.	7b. Adjust valves and/or inlet gates to equally distribute flow.
	7c. Peak flows are overloading clarifiers.	7c. Hydraulic overflow rates at peak flows if >1,000 GPD/sq ft, this is a likely cause.	7c. (1) Install flow equalization facilities or expand plant. (2) Switch aeration mode to step-feed.
	7d. Solids loadings are too high on clarifier.	7d. Loadings should not exceed 1.25 lbs/sq ft/hr.	7d. Reduce MCRT if plant design does not allow step-feed.
8. Sludge blanket overflowing secondary clarifier weirs in one portion of clarifier.	8a. Unequal flow distribution in clarifier.	8a. Effluent weir.	8a. (1) Level effluent weirs. (2) Dye test clarifier for short circuiting and install baffles or deflectors if a problem.
9. In diffused aeration basin, air rising in very large bubbles or clumps in some areas.	9a. Diffusers plugged or broken.	9a. Visually inspect diffusers.	9a. Clean or replace diffusers; check air supply; install air cleaners ahead of blowers to reduce plugging from dirty air.
10. pH of mixed liquor decreases to 6.7 or lower. Sludge becomes less dense.	10a. Nitrification occurring and wastewater alkalinity is low.	10a. Effluent NH_3; influent and effluent alkalinity.	10a. (1) Decrease sludge age by increased wasting if nitrification not required. (2) Add source of alkalinity—lime or sodium bicarbonate.
	10b. Acid wastewater entering system.	10b. Influent pH.	10b. Determine source and stop flow into system.

11.67 Process Troubleshooting Guide (continued) (adapted from *PERFORMANCE EVALUATION AND TROUBLE-SHOOTING AT MUNICIPAL WASTEWATER TREATMENT FACILITIES*, Office of Water Program Operations, US EPA, Washington, DC)

INDICATOR/OBSERVATION	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTION
11. Sludge concentration in return sludge is low (<8,000 mg/*L*).	11a. Sludge return rate too high.	11a. Return sludge concentration, solids level (balance) around final clarifier, settleability test.	11a. Reduce sludge return rate.
	11b. Filamentous growth.	11b. Microscopic examination, DO, pH, nitrogen concentration.	11b. Raise DO, raise pH, supplement nitrogen, add chlorine (see item 1).
	11c. *Actinomycetes* predominate.	11c. Microscopic examination, dissolved iron content.	11c. Supplement iron feed if dissolved iron less than 5 mg/*L*.
	11d. Collector mechanism speed inadequate.	11d. Collector mechanism.	11d. Adjust speed as appropriate/turn collector on.
12. Dead spots in aeration tank.	12a. Diffusers plugged.	12a. Visually inspect diffusers.	12a. Clean or replace diffusers—check air supply—install air cleaners ahead of blowers to reduce plugging from dirty air.
	12b. Underaeration resulting in low DO.	12b. Check DO.	12b. Increase rate of aeration to bring DO concentration up to 1 to 3 mg/*L*.
	12c. Air supply valves improperly adjusted.	12c. Air supply valve settings.	12c. Adjust valving as appropriate.
	DIFFUSED AERATION		
	12d. Inadequate number of diffusers.	12d. (1) Check aeration rate CFM. (2) Check air back pressures in manifolds and headers.	12d. (1) Increase output CFM. (2) Add diffusers to air header to reduce back pressure on supply and allow more air to aeration tank.
	MECHANICAL AERATION		
	12e. Rotor or turbine speed too low.	12e. Speed of rotors or turbines.	12e. Increase speed of rotors or turbines.
	12f. Aeration basin water level too low.	12f. Water level in basin.	12f. Increase water level in basin.
	12g. Insufficient energy input.	12g. Dye test basin.	12g. Add rotors or turbines.

Exercise

1. You notice that the MLSS concentrations differ significantly from one aeration basin to another. What is the potential cause(s) of this and how would you solve it?

2. The sludge concentration in the return sludge is low. What are the four possible causes of this? For each cause, identify what you should check or monitor.

3. There are thick billows of white, sudsy foam on the aeration tank. It has been determined that the reason for this is because the MLSS is too low. What should you do to resolve this problem?

Surface Aerators

Operational Problems

Table 2.2 Surface Aerator Operational Problems[2]

ABNORMAL SURFACE AERATOR OPERATION

Item	Abnormal Condition	Possible Cause	Operator Response
Motor	High or uneven amperage	Moisture	Have electrician MEG[a] check motor. Have motor rewound.
		Winding breakdown	
		Degree of impeller submergence results in amperage draw in excess of motor amperage design	Adjust aerator.
		Excessive motor bearing or gear reducer friction	Inspect and lubricate bearings and gears. Overhaul if needed.
Gear Reducer	Bearing or gear noise	Lack of proper lubrication	Repair or replace oil pump. Change oil.
			Remove obstruction in oil line.
Shaft Coupling	Unusual noise and vibration	Cracked coupling	Replace coupling. Align impeller shaft.
		Loose coupling bolts/nuts as a result of vibration	Torque bolts.[b] Use "locking" nuts. Align impeller shaft.
Impeller	Unusual noise and vibration	Loose blades	Torque blade bolts.[b] Use lock-washers. Align impeller.
		Cracked blades	Replace. Torque bolts.[b] Align.

[a] Use instrument (megger) to check insulation resistance of motor.
[b] Tighten bolts to manufacturer's torque rating. Ratings are given in foot-pounds or kilogram-meters.

Maintenance

Follow manufacturer's operation and maintenance manuals. General guidelines:

- Motors
  - Grease the motors after about 2,000 hours of operation.
  - After approximately 5 years of operation, check the motor windings for deterioration due to moisture and heat.
- Gear Reducers
  - Allow new gear reducers to "break in" for about 400 hours before changing oil.
  - Change oil about every 1,400 hours of operation.
  - Check drained oil after "break in" period for metal particulates. If excessive, consult with manufacturer.
  - Inspect the operation of the gears and the flow of oil after each oil change.
  - Lubricate grease-lubricated bearings about every 500 hours of operation.
- For the coupling and impeller, stop the aerator every 6 to 12 months and do the following:
  - Retorque the nuts and bolts on the coupling and impeller according to manufacturer's recommendations.
  - Check the impeller for cracks and worn parts.
  - Check the impeller and shaft for proper alignment.

Air Filters

Operational Problems

- The cleanliness of air filters is typically measured by the pressure difference between the inlet and outlet with a manometer. The pressure difference will increase as the filters are loaded with particulate. When the pressure difference exceeds the "clean" filter pressure difference by about 2 to 3 inches of water column, it is time to change the filter. Excessive pressure drops across the air filters will result in reduced blower performance.

Maintenance

- Air filters should be removed, cleaned and reinstalled according to the manufacturer's operation and maintenance manual.

Blowers

Efficient and reliable operation of your plant's blowers is critical to the activated sludge process. Loss of blower air to the aeration tank for an extended period of time (more than four hours) could result in sludge bulking and a major plant upset.

There are two types of blowers typically used in activated sludge treatment plants: centrifugal and positive displacement. Note that troubleshooting and maintenance will vary based on the type of blower.

Operational Problems

Table 2.3 Blower Operational Problems[3]

ABNORMAL BLOWER OPERATION

Item	Abnormal Condition	Possible Cause	Operator Response
Unusual noise or vibration	Coupling misaligned	Incorrect installation	Align coupling with blower at operating temperature according to manufacturer.
	Loose nuts, bolts, or screws	Vibration	Tighten.
Air system pressure	Low pressure	Bypass valve open, leaks or breaks in distribution piping	Close valve, repair leaks or breaks.
		Diffusers came off air header	Replace diffusers.
	High pressure / High motor temperature	Blockage or partially closed valve in distribution piping	Remove blockage or open valve.
		Plugged diffusers	Blow out or remove and clean.
Air flow	Low total flow	High ambient temperatures	Add more air if needed.
		Blower air control malfunction	Repair or replace control.
System oil pressure	Low pressure	Oil level too low	Add oil.
		Oil filter dirty	Replace.
		Check valve sticks open	Replace valve.
		Incorrect oil type	Drain and refill with proper oil type.
	High pressure	Incorrect oil type	Drain and refill with proper oil type.
Oil discharge pressure	Low pressure	Suction lift too high	Reduce lift.
		Air or vapor in oil	Purge air at filter.
		Coupling slipping on pump shaft	Secure coupling.
Oil temperature	Low temperature	Oil cooler water flow too high	Throttle water flow.
	High temperature	Oil cooler water flow too low	Increase water flow.
		Incorrect oil type	Drain and refill with proper oil type.
		Insufficient oil circulation	Replace oil filter, check oil lines for restrictions.
Bearings	Hot bearing(s)	Blower speed too high	Reduce speed to recommended RPM.
		Defective bearing(s)	Check bearing(s) for clearance, hot spots, cracks or other damage. Repair or replace.
		Oil cooler water flow too low	Increase water flow.
Motor	Won't start	Overload relay tripped	Correct and reset.
	Noisy	Noisy bearing	Check and lubricate.
	High temperature	Restricted ventilation	Check openings and duct work for obstructions.
		Electrical	Check for grounded or shorted coils and unbalanced voltages between phases.

Maintenance

- Generally, all new oil-lubricated equipment requires a “break in” period of about 400 hours before changing the oil.
- Change the oil after every 1,400 hours of operation, which requires the monitoring of elapsed run times.
- Check the drained oil after “break in” period for metal particulates. If excessive, consult with manufacturer.
- Lubricate the grease-lubricated bearings after every 500 hours of operation.
- See the aerator section for blower motor maintenance.
- Routinely (e.g., once a month) check the operation of the discharge pressure relief valve. Manually actuate the valve to ensure that it is not seized and check pressure relief setting by SLOWLY closing discharge valve until the relief valve opens. Never completely close the discharge valve while the blower is running.
- Check the suction and discharge valves once a month by opening and closing them manually to ensure that they are not seized.
- Check the discharge check valve to ensure that it is not seized and that it seats properly.
- Clean and change the air intake filters.

Air Distribution System

The air distribution system consists of the network of pipes, valves, and flow meters used to convey air from the blowers to the air headers and diffusers in the aeration tank. Although there are not many moving parts in the air distribution system, failures can still occur.

Operational Problems

Table 2.4 Air Distribution System Operational Problems[4]

ABNORMAL AIR DISTRIBUTION SYSTEM OPERATION

Item	Abnormal Condition	Possible Cause	Operator Response
Meter(s)	High, low, or no indication	Loose movement	Tighten or replace.
		Out of calibration	Calibrate.
		Dirt in mechanism	Clean.
		Pointer dragging on scale plate	Adjust pointer.
		Bypass valve open or leaking	Close or repair.
		Meter piping leaks	Tighten or replace.
		Meter piping plugged	Clean piping.
Seals, gaskets, and flex connections	Leaking	Loose bolts or fittings	Tighten.
		Blown out	Replace.
	Worn	Usual deterioration	Replace.
Pipe	Corrosion	Condensate	Drain traps daily, install additional traps, flush pipe, paint pipe, and/or remove standing water from around pipe.
	Sludge inside pipe	Vacuum action by blower operating in reverse	Flush pipe, install check valve on blower, and/or repair check valve.
	Dirt	No or inefficient air filtration	Install filters. Clean filters more frequently.
Valves	Difficult to operate or frozen	Hardened grease	Remove old grease and apply seizing[a] inhibitor. Operate valves monthly.
		Corrosion	Drain condensate traps daily. Apply seizing inhibitor.

[a] Seizing. Seizing occurs when an engine overheats and a component expands to the point where the engine will not run. Also called freezing.

Maintenance

Inspect for the following at least every six months:

- Loose pipe support clamps.
- Shifting of pipes out of original alignment.
- Loose nuts and bolts on flanges and fittings.
- Seized valves.
- Corrosion damage.
- Prevent metal surfaces from corroding by maintaining paint coatings. Exercise valves with the blower off at least once a month to prevent seizing.

Air Header/Diffusers

Air headers and diffusers are used to convey air from the blower air distribution system to the water in the aeration tank.

Operational Problems

The primary operational problem associated with air headers is general deterioration due to corrosive environments and mechanical wear and tear. Air diffuser operational problems are typically caused by the clogging of porous surfaces by dirt and biological growths. Typical operational problems and potential solutions are shown in the following tables.

Table 2.5 Air Header Operational Problems[5]

ABNORMAL AIR HEADER OPERATION

Item	Abnormal Condition	Possible Cause	Operator Response
Valve	Valve leaks at stem	Loose stem packing nut	Tighten nut.
		Defective packing	Secure distribution system and replace packing.
	Valve will not seat closed	Corrosion	Secure distribution system and clean or replace valve.
		Butterfly rubber seat defective	Secure distribution system and replace rubber seat.
		Butterfly or gate has come off valve system	Secure distribution system and replace.
Swing header pivot joints	Air leaks from joint	Defective "O" ring	Close header valve, pull header from tank with crane, and replace "O" ring.
		Loose joint	Tighten.
		Insufficient grease in joint	Apply 3 to 5 shots of grease.
		Cracked joint	Replace.
Fixed header couplings or unions	Air leaks from couplings, unions, or end caps	PVC has defective glue bond	Remove, clean with PVC solvent, bond, and allow bond to cure.
		Pipe has leak through thread	Remove, apply teflon tape, tighten.
Horizontal header	Uneven water motion (roll) in tank	Header not perfectly level, thus allowing more air to one side	Level header with surveyor's level (tank empty) or use Mason's level.
		"O" rings or gaskets defective or connections loose	Replace "O" rings or gaskets. Tighten connections.
Header pipe	Interior corrosion	Moisture	Use PVC or galvanized pipe.
	Exterior corrosion	Moisture	Use PVC, galvanized pipe, or paint pipe with an epoxy coating.
		Electrolysis	Use a sacrificial (magnesium) anode or coat surface.

Table 2.6 Air Diffuser Operational Problems[6]

ABNORMAL AIR DIFFUSER OPERATION

Item	Abnormal Condition	Possible Cause	Operator Response
Fine-bubble diffuser	Exterior clogged	Biological growth	Raise air header, remove diffuser, scrub and wash diffuser.
	Interior clogged	Dirt from distribution system	Raise air header, remove diffuser, scrub and wash diffuser. Install filters, clean filters more frequently.
Coarse-bubble diffuser	Exterior clogged	Biological growth	Raise air header, scrub and wash diffuser. Once a month increase air flow 2 to 3 times normal for 15 minutes to "blow out" diffuser orifices.
	Cracked	Overtightened when installed, structural failure	Replace.
Fine- and coarse-bubble diffusers	Accumulation of rags, hair, string	Inefficient pretreatment, normal conditions	Yearly, raise headers and clean diffusers.
	Insufficient diffusion pattern or oxygen transfer	Clogged diffusers	Clean the diffusers.
		Inadequate diffuser arrangement	Modify diffuser arrangement.
		Too few diffusers	Add diffusers or install a different type.

Maintenance

On a monthly basis:

- Exercise all regulating/isolation valves to prevent seizing for coarse bubble diffusers but not for porous media diffusers.
- Apply grease to the upper pivot swing joint O-ring cavity (swing header).
- Check for loose fittings, nuts and bolts. Tighten if necessary.
- Increase air flow to the diffusers to 2-3 times the normal flow to blow out biological growths.

On a yearly basis:

- Raise the headers, clean and check for loose fittings, nuts and bolts.
- Apply grease to the pivot joint O-ring cavity (swing header).
- Check for corrosion and paint, as necessary, with epoxy coating.
- Raise the header and inspect diffusers for damage. Clean and replace diffusers as needed.

Motors

Operational Problems

- See the surface aerator section for information on motor operational problems.

Gear Reducers

Operational Problems

- See the surface aerator section for information on gear reducer operational problems.

Key Points for Unit 2 – Typical Operational Problems

- Activated sludge plants require more volatile suspended solids and less air flow in the winter.
- In order to maintain a consistent, meaningful process database, it is critical to be consistent with regard to sampling locations and methods.
- The presence of filamentous organisms is the predominant cause of sludge bulking.
- Sludge becomes septic when it is allowed to sit stagnant in a vessel or pipe long enough to deplete residual DO.
- Rising sludge is caused by the process of denitrification in the secondary clarifiers.
- Foaming/frothing is the condition describing a buildup of foam or froth on the surface of the aeration tank.
- The EPA has developed a list of approximately 150 toxic substances, or "priority pollutants," based on their known or suspected carcinogenicity (cancer forming potential), mutagenicity (DNA altering potential), teratogenicity (potential for causing structural developmental defects during formation of individual organs), or high acute toxicity.
- VOCs are a concern to wastewater treatment plant operators because they can be easily released to the atmosphere, especially at the headworks and in the aeration basin, presenting a health risk hazard.
- Inorganic compounds, such as copper, lead, silver, chromium, arsenic, and boron cations (positively charged ions) can be toxic to microorganisms.
- In the event of an upset due to a toxic discharge and in the absence of design controls, reduce or cease sludge wasting and return all available sludge to the aeration tank.
- There are two types of blowers typically used in activated sludge treatment plants: centrifugal and positive displacement. Note that troubleshooting and maintenance will vary based on the type of blower.
- Generally, all new oil-lubricated equipment requires a "break in" period of about 400 hours before changing the oil.
- Air diffuser operational problems are typically caused by the clogging of porous surfaces by dirt and biological growths.

Exercise for Unit 2 – Typical Operational Problems

1. If the shaft coupling on the surface aerator makes an unusual noise and vibration, what are the possible causes and how would you fix the problem?

2. Explain the monthly maintenance requirements for air headers/diffusers.

3. Describe the typical operational problems associated with air filters.

4. If sludge is present in the pipe of the air distribution system, what is the possible cause and how would you resolve the issue?

[1]John Brady, "Activated Sludge", in *Operation of Wastewater Treatment Plants: A Field Study Training Program*, Vol II, (Sacramento California: California State University, Sacramento Foundation, 1999), p. 74-76.

[2]Brady, p. 79.

[3]Brady, p. 80.

[4]Brady, p. 81.

[5]Brady, p.82-83.

[6]Brady, p. 82-83.

Unit 3 – Microbiology of the Activated Sludge Process

Learning Objectives

- Explain why microbiology is important in the activated sludge process.
- Name four typical microorganisms found in activated sludge.
- List the equipment required during sample collection.
- Identify four sampling locations for various treatment plant processes.
- Explain two methods of sample preparation.
- Identify the components of a microscope typically used at Wastewater Treatment Plants.
- Explain three common observations that are recorded.
- List and explain three means of interpreting results of microscopic observations.
- Explain how to decide when to make a process change.
- List possible process changes that can be made and explain what the purpose of each process change is.
- Explain how frequently processes should be monitored during good operations, poor operations and following a process change.

Activated Sludge is a Biological Process

The activated sludge process relies on many different types of microorganisms to treat the wastewater. Therefore, the activated sludge process is a living process that requires knowledge of the microorganisms involved. You should know which microorganisms are desirable and undesirable and how these microorganisms respond to the environment in the aeration tanks.

Tools for Process Control

Since it is a biological process, the activated sludge process is complex and constantly changing. Microbiology is a tool you can use to control the process. It can be difficult to control the process based on lab data, calculated process parameters, and visual observations alone, especially when you are confronted with conflicting data. At times like this, a visual observation of the numbers and types of microorganisms in a sample of activated sludge using a microscope can be very helpful in figuring out what is happening and deciding which process change to make.

Another benefit of the "microbiology tool" is that it can be used to forecast potential plant upsets. Plant operators who react to plant upsets instead of preventing them often find that their effluent quality degrades before their process change takes effect. Incorporating microscopic observations of the activated sludge into your routine process control strategy will enable you to "see" the beginning stages of deteriorating conditions before any significant impact to the final effluent quality.

Bacteria

- Bacteria are single-celled organisms and constitute the majority of organisms in activated sludge.
- Bacteria have the following designations based on their shape:
  - Coccus – round or spherical shape
  - Bacillus – cylindrical or rod shape
  - Spirillum – spiral shape
- Bacteria reproduce by binary fission, which means each single cell splits into two cells. The time it takes bacteria to divide is called the generation time. *E. Coli*, bacteria found in the intestines of warm-blooded animals and human, take about 17 minutes to divide in a broth medium. The average human excretes about 200 billion E. *Coli* per day.
- The following figure shows the typical growth cycle for bacteria:

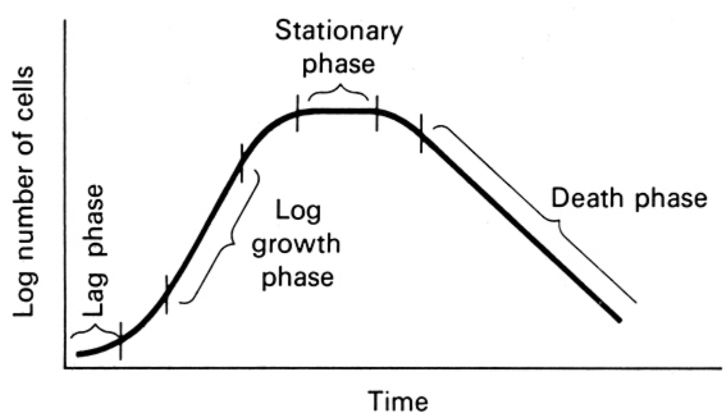


Figure 3.1 Typical Growth Cycle for Bacteria[1]

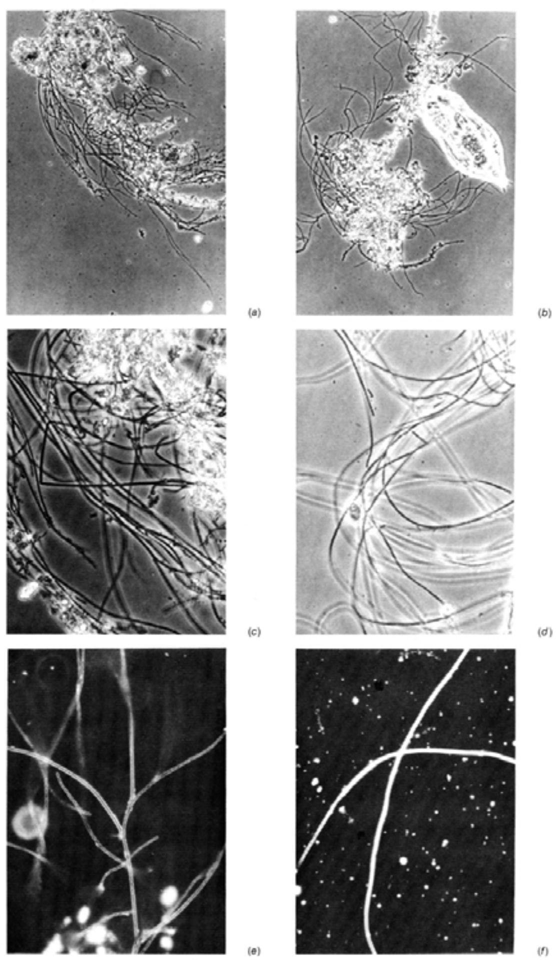
- Bacterial growth occurs in four stages:
  - The lag phase - cells become acclimated to the waste and begin to divide.
  - The log-growth phase - cells divide at their generation rate, which is only limited by their ability to degrade the waste because there is plenty of food available.
  - The stationary phase - the growth rate decreases due to the depletion of the food supply.
  - The death phase (also called the "endogenous" phase) - cells begin to feed on themselves in the absence of another food supply.

Filaments

- A special kind of bacterial growth important in activated sludge systems is called the filament. Filaments are formed by filamentous bacteria, which attach themselves to each other, forming multi-cellular chains.

- Filaments can be classified as "long" and "short."

  - **Long Filaments**
    A certain amount of long filaments is essential in activated sludge because they are the "backbone" that holds bacterial flocs together, giving them good settling characteristics. However, sludge bulking results when filaments begin to predominate and grow out of control. Long filaments can transform a non-bulking sludge to bulking within 2 to 3 days, so routine observation of the activated sludge will give you advance warning of this type of process upset. Pictures of filamentous bacteria found in bulking sludge are shown in the following figure.



Typical filamentous organisms found in bulking sludge: (*a* and *b*) phase contrast, 100X, (*c*) phase contrast, 400X, (*d* and *e*) filaments of *Sphaerotilus*, phase contrast and dark field, 400X, and (*f*) filaments of *Thiothrix*, dark field, 400X.

Figure 3.2 Filamentous Bacteria Found in Bulking Sludge[2]

- **Short Filaments**

  The most common short filament in activated sludge plants is called *Nocardia*. Nocardia form short, web-like branches and can cause foaming and/or frothing in the aeration tanks and excessive brown floating scum in secondary clarifiers. Routine microscopic observations of the activated sludge will enable you to identify short filament formation before it becomes a major problem. Special staining techniques are used to make Nocardia visible under the microscope. Nocardia will start to grow in and around bacterial flocs and eventually in the open spaces between flocs.

Protozoan

Protozoa are single celled organisms ranging in size from 10 microns to over 300 microns.

- They are easily visible under the microscope at 100X magnification.
- The presence or absence of protozoa is an indicator of the amount of bacteria in the sludge and the degree of treatment.
- There are five types of protozoa: amoeba, mastigophora, free-swimming ciliate, stalked ciliate, and suctoria.

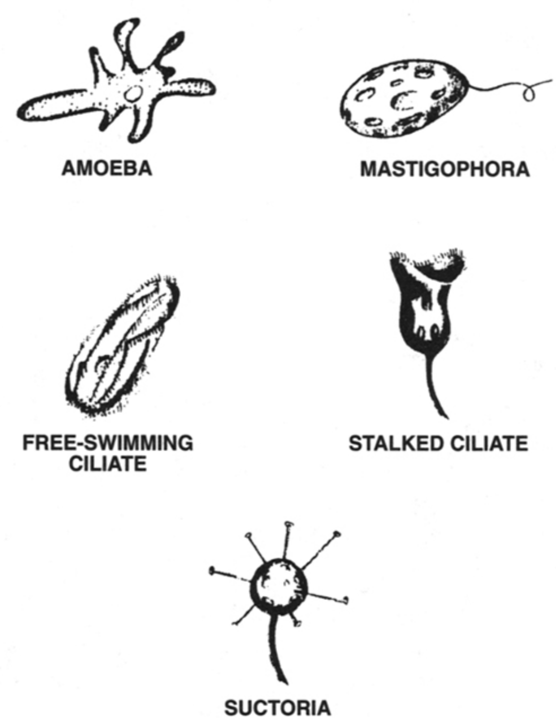


Figure 3.4 Protozoa[3]

Rotifers

Rotifers are multicellular animals with rotating cilia on the head and a forked tail.

- They are an indication of an old activated sludge with a high MCRT and are usually associated with a turbid effluent.

Worms

- Worms are strict aerobes and can metabolize solid organic matter that is not easily metabolized by other microorganisms.
- They are usually found in sludge from extended aeration plants.

Equipment

Sample Collector

The equipment required to collect a sample of activated sludge from the aeration tank is simple. You'll need a dipper pole with a bottle holder, such as that shown in the figure below.

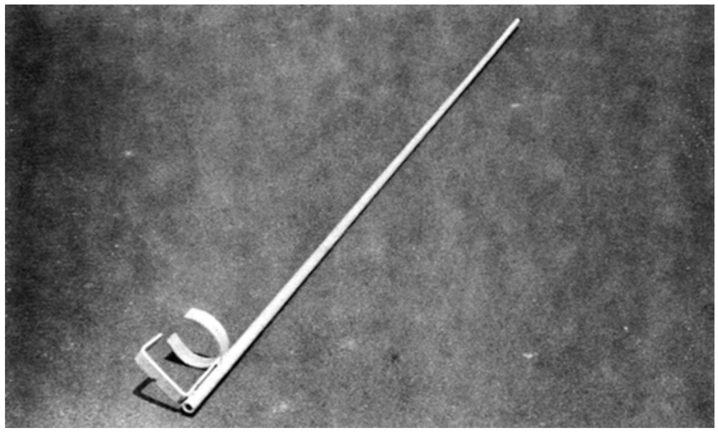


Figure 3.5 Dipper Pole and Bottle Holder[4]

Use a 100 to 300 mL plastic bottle to collect the sample. If you use a larger sample bottle to collect the sample out of the aeration tank and then transfer some of the sludge to a smaller bottle, completely mix its contents before the transfer to ensure you are getting a representative sample.

Sampling Locations for Various Treatment Processes

In general, you want to observe the bugs after they have fed and are hungry. You will be able to tell if they are healthy based on your observation of them in this state. The location in the aeration tank where this condition occurs depends on the type of plant you have.

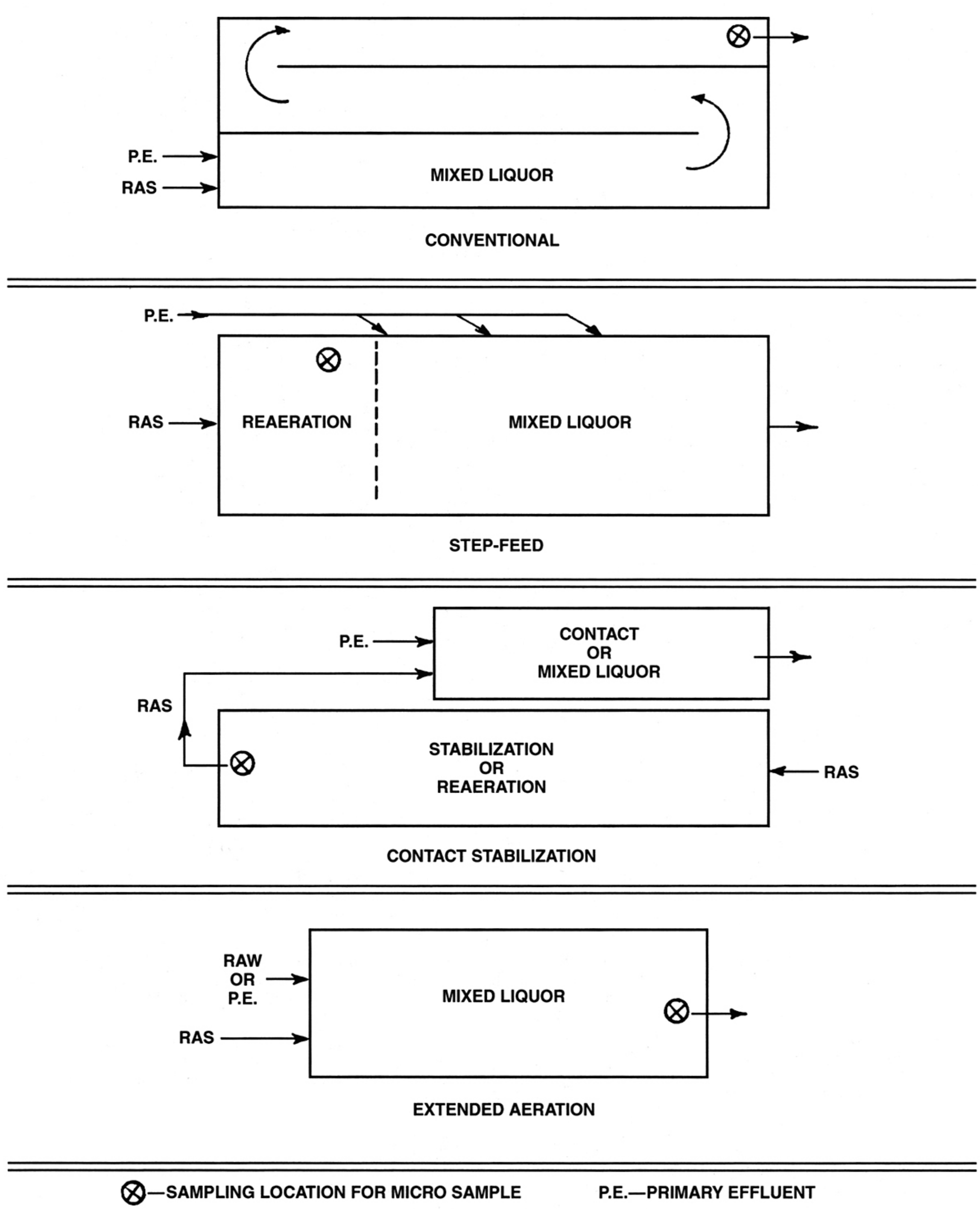


Figure 3.6 Sampling Locations for Various Treatment Processes[5]

Conventional Activated Sludge Plant

- Collect the sample from the end of the aeration tank. For circular, completely mixed aeration tanks, it doesn't matter where you collect the sample as long as you are consistent.

Step Feed

- The bugs will be hungriest at the end of the reaeration zone in step feed plant.

Contact Stabilization

- The bugs will be hungriest at the end of the stabilization (or reaeration) tank.

Extended Aeration

- The bugs will be hungriest at the end of the aeration tank in extended aeration systems.

Sample Preparation

Once you have collected the sample, you should conduct the microscopic observation within 15 minutes. Otherwise, the DO will drop too low and the microorganisms will appear dead.

- You will need the following supplies to prepare your sample:
  - Flat glass slides (3 inches x inch x 1 mm thick)
  - Cover glasses (1 inch square)
  - Eye dropper or pipette
  - Lens cleaning paper
  - Methylene blue solution
- There are two methods of sample preparation: a wet mount and a stained dry slide. The wet mount slide is used to observe live organisms and the stained dry slide is used to observe stained filamentous bacteria.

The Microscope

There are two broad categories of microscopes, light microscopes and electron microscopes.

- Light microscopes are typically used in activated sludge plants and are divided into five categories:
  - Bright field
  - Dark field
  - Ultraviolet
  - Fluorescence
  - Phase contrast

Component Parts

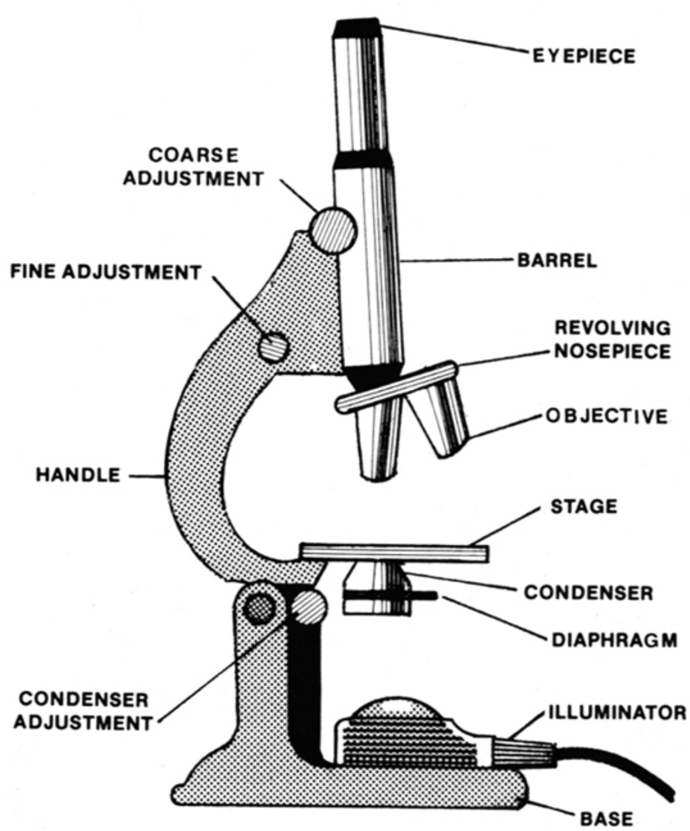


Figure 3.7 A Basic Compound Microscope[6]

Recording Observations

It is important to record your observations during periods of good and bad effluent quality so that you gain an understanding of what the microscopic environment should look like.

Size and Nature of Floc Particles

- Characterize the size and nature of the floc particles. Are they big or small, dark or light, clumped or dispersed?

- Some microscopes are outfitted with cameras, and taking and cataloging pictures is a great way to record observations. Floc with good settling properties will be large, clumped masses with minimal filaments visible.

Microorganism Counts

- The presence of certain types and numbers of protozoa and rotifers is an indication of the health of the activated sludge biological community. Therefore, it is important to get a rough count of these organisms, or at least to qualitatively describe their numbers as "light," "moderate," or "heavy". The definition of these qualitative terms can only be determined by field experience with your particular sludge.

- It would be too time consuming and virtually impossible to count every microorganism on the slide. Instead, using 100 X total magnification, divide a one-inch square cover glass into 28 equal fields, 14 up and down and 14 across, and count and record the number of organisms in each field by observing the consecutive fields across and up or down the entire length of the cover glass.

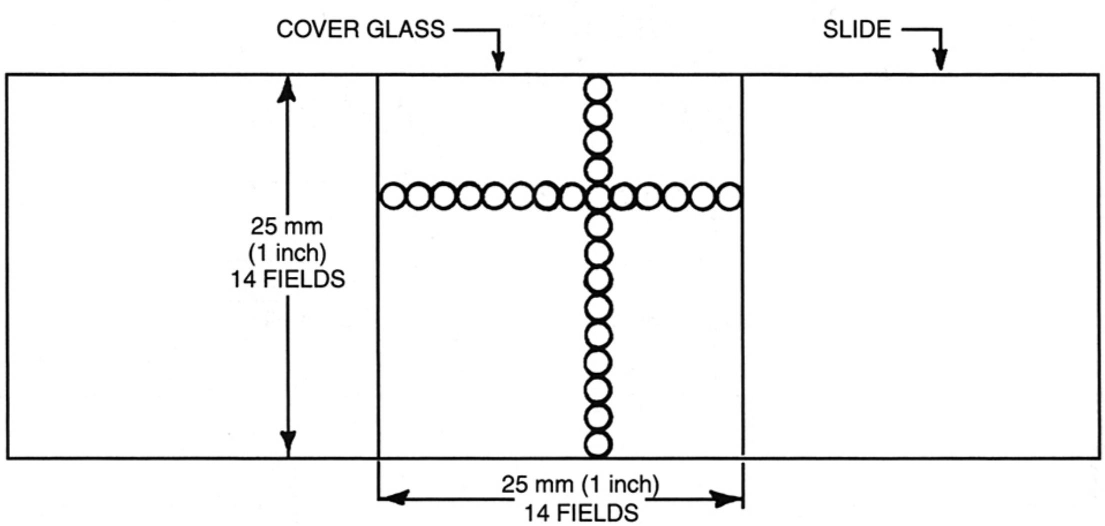


Figure 3.8 Microorganism Counts on a Slide[7]

- Use a worksheet for recording your observations, such as this:

DATE ____________________

TIME ____________________

WORKSHEET
FOR
MICROORGANISM COUNTING

ENTER SUM OF ALL 28 FIELDS FOR TOTAL OF EACH TYPE OF BUG

FIELD		AMOEBA		LARGE FLAGELLATES		CILIATES						ROTIFERS		LONG FILAMENTS	
						FREE SWIMMING		STALKED							
								SINGLES		COLONIES					
1	15														
2	16														
3	17														
4	18														
5	19														
6	20														
7	21														
8	22														
9	23														
10	24														
11	25														
12	26														
13	27														
14	28														
TOTAL															

HIGH ←	SVI	→ LOW
HIGH ←	F:M	→ LOW
LOW ←	MCRT	→ HIGH

TINY FLAGELLATES ____________________ NOCARDIA ____________________

WORMS ____________________ FLOC CONDITION ____________________

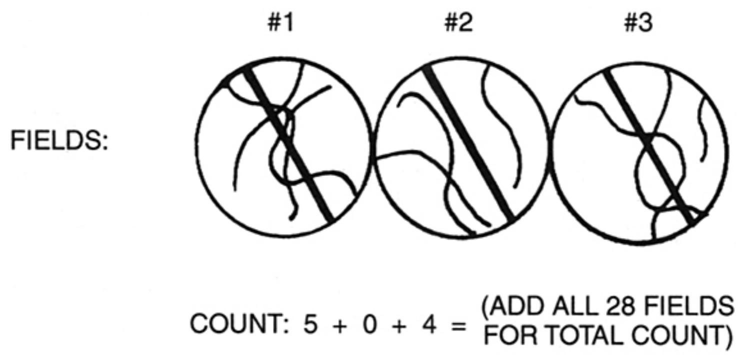
Figure 3.9 Sample Worksheet for Microorganism Counting[8]

- Do not try to count the tiny flagellates, as they move fast and there may be thousands of them on the slide. Qualitatively describe the number of them as “light,” “moderate,” or “heavy.”

- Divide the stalked ciliates into two groups. “Singles” have one or two bells on a stalk and “Colonies” have three or more bells on a stalk.

Filament Index

The filament index is a number used to characterize the amount of filamentous bacteria present in an activated sludge sample. It is applicable to long filaments only. The index is determined by counting the number of times a line etched in the eyepiece is crossed by filaments.



TECHNIQUE FOR COUNTING FILAMENTS*

**NOTE:* Techniques shown are modifications of original work by R. D. Beebe, City of San Jose, California, and D. Jenkins, University of California, Berkeley (1981). Paper presented at California Water Pollution Control Association meeting.

Figure 3.10 Technique for Counting Filaments[9]

- You do not need to count filaments unless you observe a steadily increasing SVI or sludge bulking problems. However, you should determine the acceptable background level of filaments by counting filaments occasionally when the plant is running properly.

Indicators of Stable and Unstable Treatment Process

A well operating system with good settling floc will have a predominance of free-swimming ciliates and stalked ciliates and few rotifers.

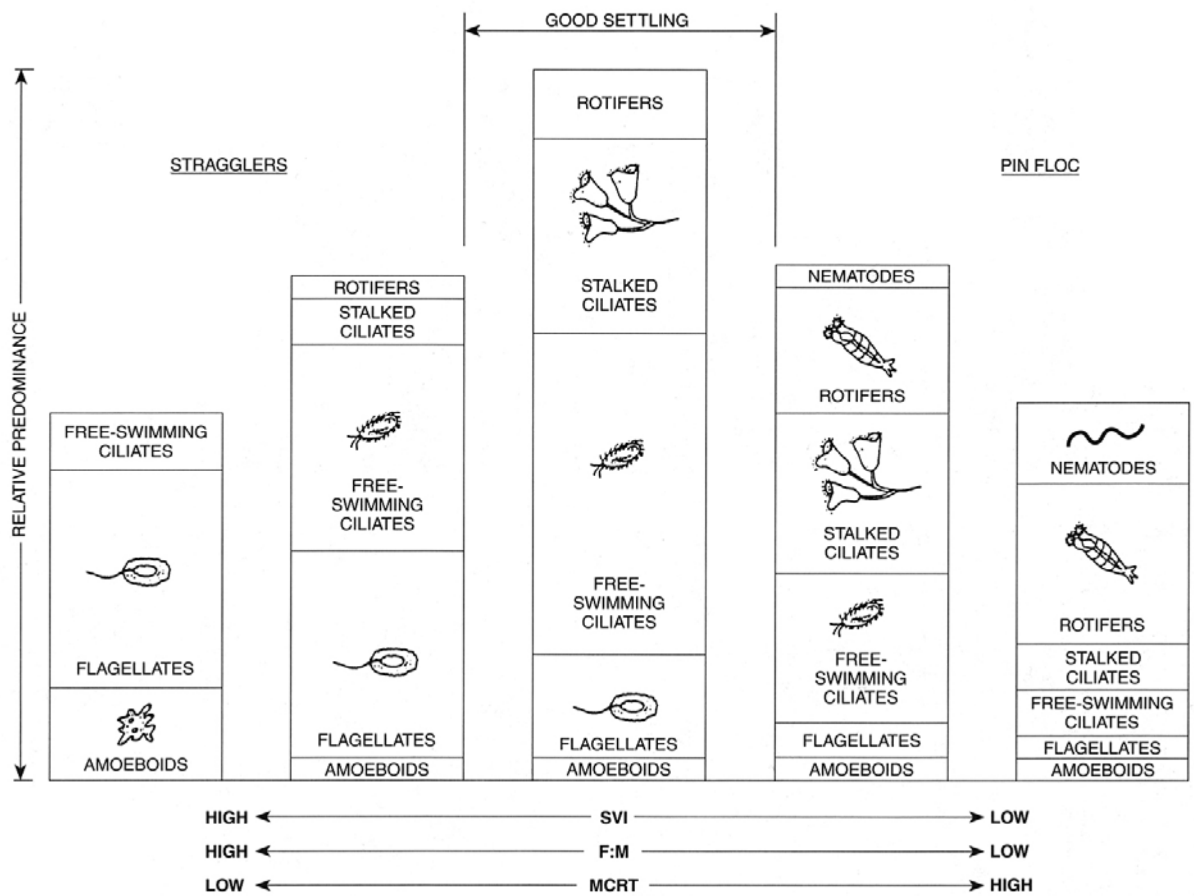


Figure 3.11 Indicators of Stable and Unstable Treatment Process[10]

- Flagellates and amoeboids are often present in activated sludge, but their numbers should be very low. An ideal sludge would have no tiny flagellates or *Nocardia* (short filaments).
- The long filament count should be no greater than 15 to 20.

Microscopy vs. Process Data

You should occasionally compare the results of your microscopic observations with your process control parameters (e.g., SVI, F/M ratio, MCRT) to see if there is a correlation between the two. When you need to make a process adjustment, use both the results of your microscopic observations and your process control data to support your decision to make the adjustment.

Changes in Microorganism Populations

A shift in the predominance of one type of organism to another in response to a process change will not occur overnight. It generally takes about 2 to 3 MCRTs for a shift like this to occur.

This means that if you have a MCRT of 5 days, a major shift in the predominance of organisms will take about 10 to 15 days. So, if you you've been tracking the numbers of free-swimming and stalked ciliates and you notice a steady, gradual decreasing trend with a corresponding increase in the numbers of rotifers over several days, you have an opportunity to reverse the trend before any significant impact to the plant's effluent quality. It may be that you need to lower the MCRT by increasing the wasting rate.

Deciding When to Make a Process Change

Ask yourself the following questions and if you answer yes to any of them, it is probably time to make a process change.

- Is effluent quality poor or deteriorating?
- Is the SVI out of its normal range? (The "normal range" for your plant is determined by your historical process data.)
- Have you observed Nocardia (short filaments) in your sludge samples?
- Are the numbers of flagellates or amoeboids increasing?
- Are the numbers of stalked ciliates decreasing?

Sometimes, process parameters and/or observed microbiology will deteriorate due to a temporary upset. If effluent quality is still well within limits, you have identified the cause for the temporary upset and you are confident that whatever caused the upset will not be a recurring or prolonged problem, then it may be wise to be patient and not make a change.

Another situation requiring patience is when you are confronted with conflicting process data and/or microscopic observations.

Which Process Changes to Make

Process Air Flow

Decreasing MLSS

- It is important to monitor not only the DO concentration in the aeration tanks, but the air flow rate as well.

  Example

  You experience decreasing MLSS concentrations even though you are maintaining a DO concentration of 2.0 mg/L at the end of the aeration tank and your MCRT is in its normal range. You haven't bothered to check the blower air flow rates because you have assumed that the system will operate fine as long as the DO concentration in the aeration tanks is maintained at 2.0 mg/L. Assume that the reason for the decreasing MLSS is because the characteristics in the plant influent have changed, requiring a higher DO concentration in the aeration tanks.

  - Since the current DO concentration maintained by the blowers is inadequate to support the microorganisms, fewer microorganisms are able to survive and the MLSS drops.
  - If you had been monitoring the air flow rates, you would have noticed a decrease in the air flow due to a decrease in the number of microorganisms. The presence of fewer microorganisms will result in the consumption of less oxygen.
  - Microscopic observations would have revealed declining numbers of stalked and free-swimming ciliates.

  To remedy the situation:

  - Preferably try reducing the WAS rate to remedy a decreasing MLSS problem rather than increasing the air flow because the air supply compressors or blowers are major energy consumers.
  - Increase your aeration tank DO setting if you have an automatic DO control system.
  - Increase the blower flow rate to increase the DO concentration in the aeration tanks.

Rising Sludge

- Process air flow adjustments may also be required to remedy rising sludge problems.
- The decision to increase or decrease air flow to remedy rising sludge depends on whether or not you want denitrification to occur. In order for denitrification to occur, nitrifying bacteria must convert ammonia (NH_3) to nitrite (NO_2^-) and nitrite to nitrate (NO_3^-). Denitrification is used in activated sludge plants to reduce the amount of nitrogen discharged to receiving waters.
- Rising sludge is caused by denitrification occurring in the secondary clarifier. If denitrification is desirable, you want it to occur at the end of the aeration tank rather than in the secondary clarifier.

- To promote conditions favorable for denitrification, reduce the air flow rate until the DO at the end of the aeration tank is in the range of 0.2 to 0.5 mg/L. The rising sludge in the secondary clarifier should cease within a few hours. The air flow can then be increased, but not as high as it was before you made the change.

- If you are experiencing rising sludge and you don't need to denitrify the wastewater, increase the air flow rate. The purpose is to increase the DO concentration in the secondary clarifier to inhibit denitrification.

Waste Activated Sludge (WAS) Flow Rate

- The waste activated sludge (WAS) flow rate is used to control the mass of microorganisms in the aeration tank. Plant operators typically use MCRT and the F/M ratio as process control parameters, which are maintained by adjusting the WAS rate.

- The microorganism counting worksheet or the population predominance diagram can be used to adjust the WAS rate based on microscopic observations. For example, you would increase the WAS rate (or decrease the MCRT) if you observed an increasing trend in rotifers.

Return Activated Sludge (RAS) Flow Rate

- The return activated sludge (RAS) flow rate is not typically used to control the activated sludge process. There are times, however, when the RAS rate must be changed. For example, the RAS rate should be temporarily increased to control a rising sludge blanket in the secondary clarifier. Note that increasing the RAS rate can result in an increase in SVI.

Number of Tanks in Service or Plant Changes (Drastic Changes)

- Sometimes a rapidly deteriorating process requires a drastic process change. Taking process tanks out of service or changing the operating mode (i.e., from conventional to step feed aeration) are relatively drastic process changes.

  - Take a primary clarifier out of service to increase F/M ratio

    Removing one or more primary clarifiers from service has the effect of increasing the F/M ratio. The F/M ratio would increase because the BOD/COD that would normally be removed by the clarifier would be discharged to the aeration tank.

- Take an aeration basin out of service to decrease aeration detention time

  If the influent flow rate significantly decreases, the detention time in the aeration tank may become too long, resulting in extended aeration. Extended aeration can result in a high degree of nitrification, pin floc with poor settling characteristics, and a turbid effluent. This can be resolved by taking one or more aeration tanks out of service to effectively decrease the aeration detention time.

- Change to step feed or contact stabilization to reduce SVI and sludge blanket level (due to filaments)

  If you observe a rapidly increasing trend in long filaments causing an increase in the SVI and a rising sludge blanket while operating in the conventional mode, and process changes have not alleviated the problem, try switching the mode of operation to either step feed or contact stabilization.

  Closely observe the SVI, sludge blanket level, and filament index after making the change. The sludge blanket depth should decrease within three to six hours of the change and the SVI should drop within 24 to 48 hours. Remember to collect the samples for microscopic observation from the reaeration zone, not the mixed liquor zone, while operating in the step feed or contact stabilization modes. You can switch back to the conventional mode after the long filaments have disappeared.

- Change to conventional activated sludge to reduce *Nocardia*

  Foaming/frothing in the aeration tanks caused by *Nocardia* while operating in the step feed or contact stabilization modes can be remedied by switching to the conventional mode. *Nocardia* bacteria are short filaments that cause a buildup of thick, dark foam on the surface of the aeration tanks and floating scum in the secondary clarifiers. You should see a decrease in the thickness of foam in the aeration tanks within a few hours of initiating the change. It may take weeks to rid the system entirely of *Nocardia*.

How Much Change to Make

Ideally, you want to monitor the activated sludge process closely enough so that you will be able to detect the beginning stages of an upset condition and make slight process modifications (i.e., minor adjustments to the air flow, WAS, and RAS rates) to reverse deteriorating trends. It is better to make continuous small adjustments than to make occasional drastic changes. You will have to learn by experience how fast your system reacts to process changes.

Frequency of Monitoring

Good Operation

- Reduce the frequency of observations during good plant operation to two to three times per week, or to suit your comfort level.

Poor Operation

- Return to daily or twice-daily microscopic observations during poor plant operation. You will need all the tools available to you when the plant is in an upset condition to get things turned around.

Following Process Change

- Return to daily or twice-daily microscopic observations after a process change is made. Observing changes in the numbers and types of microorganisms will help you determine if the selected process change was the right one.

Key Points for Unit 3 – Microbiology of the Activated Sludge Process

- The activated sludge process is a living process that requires knowledge of the microorganisms involved.
- Bacteria are single-celled organisms and constitute the majority of organisms in activated sludge.
- Filaments are formed by filamentous bacteria, which attach themselves to each other, forming multi-cellular chains.
- A certain amount of long filaments is essential in activated sludge because they are the “backbone” that holds bacterial flocs together, giving them good settling characteristics.
- The most common short filament in activated sludge plants is called *Nocardia*. Nocardia form short, web-like branches and can cause foaming and/or frothing in the aeration tanks and excessive brown floating scum in secondary clarifiers.
- Protozoa are single celled organisms ranging in size from 10 microns to over 300 microns. The presence or absence of protozoa is an indicator of the amount of bacteria in the sludge and the degree of treatment.
- Rotifers are multicellular animals with rotating cilia on the head and a forked tail. They are an indication of an old activated sludge with a high MCRT and are usually associated with a turbid effluent.
- Worms are strict aerobes and can metabolize solid organic matter that is not easily metabolized by other microorganisms. They are usually found in sludge from extended aeration plants.
- There are two broad categories of microscopes, light microscopes and electron microscopes.
- A well operating system with good settling floc will have a predominance of free-swimming ciliates and stalked ciliates and few rotifers.
- Microbiological activity can give good insight to what is going on with plant processes.
- Changes to plant processes should be made slowly so as not to cause an upset condition.

Exercise for Unit 3 – Microbiology of the Activated Sludge Process

1. Name four typical microorganisms found in activated sludge.

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

2. List three observations that are recorded in your activated sludge process.

   a. ______________________________

   b. ______________________________

   c. ______________________________

3. List three possible process changes in an activated sludge process. Briefly explain the purpose of each change.

   a. ______________________________

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   ____

   b. ______________________________

   ____

   ____

   c. ______________________________

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[1]George Tchobanoglous and Frank Burton, *Wastewater Engineering: Treatment, Disposal, Reuse*, 3rd Edition, (New York, NY: Irwin/McGraw-Hill, 1991), p.368.

[2]Tchobanoglous, p. 397.

[3]John Brady, "Activated Sludge", in *Operation of Wastewater Treatment Plants: A Field Study Training Program*, Vol II, (Sacramento California: California State University, Sacramento Foundation, 1999), p. 119.

[4]Brady, p. 112.

[5]Brady, p. 113.

[6]Brady, p. 115.

[7]Brady, p. 122.

[8]Brady, p. 121.

[9]Brady, p.122.

[10]Brady, p. 123.