Activated Sludge Refresher Grade IV-V Review

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Why Activated Sludge?

-Activated Sludge treatment is extremely common

-Good efficiency for the cost in achieving BOD removal

-Grade IV/V exams in CA cover Activated Sludge and associated process control modifications

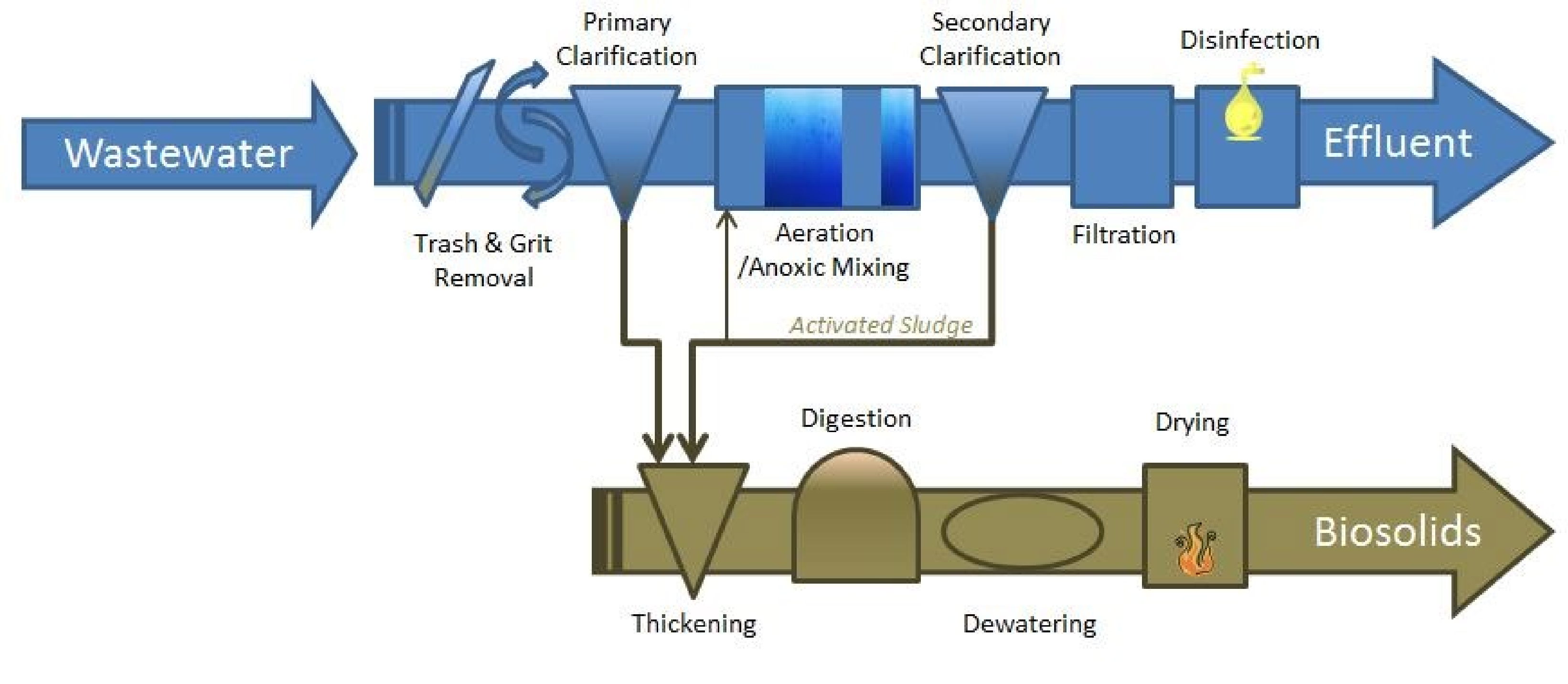
-It is a resilient process that can recover from upsets relatively quickly

-It is a tried and true technique that has been around for ~100 years

-Activated Sludge is a good process for practice math because it is relatively straightforward

And more!

Activated Sludge Overview - plant layout



Activated Sludge - Origin

The activated sludge process was developed between 1913-1914 in Manchester by Ardern and Lockett. They discovered that if they exposed wastewater to air for enough time that floc formed in the water and that the upper layer of water, after the floc had settled, was substantially treated.

In the aeration tank the wastewater is mixed with earlier made activated sludge and with the help of the aeration equipment oxygen is added. Under these conditions the activated sludge can remove both organic as well as other whole or partial contaminants from the wastewater.

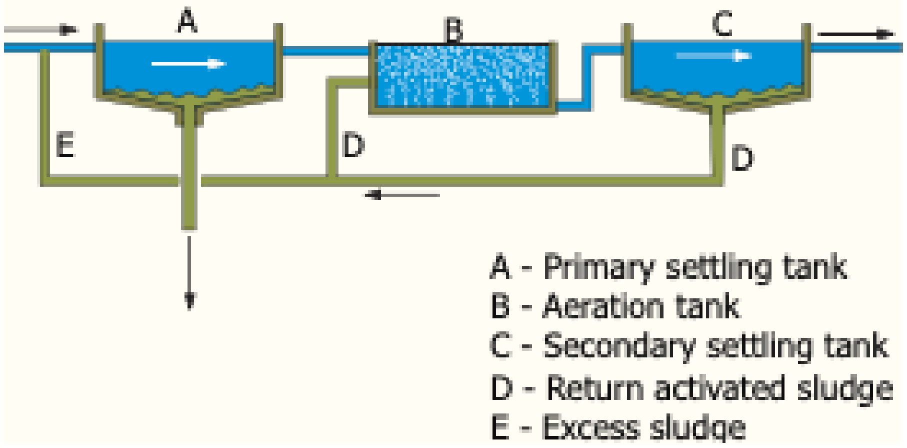


Figure 3.7 – Scheme of an activated sludge installation

Basic Components

- A reactor (an aeration tank) in which microorganisms are kept in suspension by mixing or aerating the wastewater
- A settling tank (a secondary clarifier) in which suspended solids (biological flocs) from the reactor is separated by gravity settling
- A recycle system to return the portion of settled sludge (activated sludge) generally from the clarifier bottom to the reactor.

The design of activated sludge processes requires the consideration of following significant aspects:

- The quality or characteristics of raw wastewater to be treated
- The desired quality or characteristics of effluent or treated wastewater
- The type of reactor that will be used
- Volumetric and organic loading that will be applied to the reactor
- The amount of oxygen required and the aeration system that will be provided to supply oxygen and to support mixing
- The quantity of sludge that will be generated and wasted for its further management

SWRCB Grade V Exam- Math/Essay

In addition, the Grade V examination includes questions on process control, activated sludge process modifications and tertiary treatment, requirements and practices for water reclamation and reuse, supervision/management responsibilities such as energy management, safety program development, operator training and budget development and control. Examinees will be asked to write essay answers to some questions.

-Practicing the math problems without multiple choice options and showing all steps and labeling all units is good practice in case partial credit is warranted

-Being able to explain what you know about Activated Sludge in a clear and concise essay is critical. Practicing writing on actual paper and having a coworker look over it can help in making sure that you convey your ideas clearly

Activated Sludge - Biological Mechanism

The principle role microorganisms have in the activated sludge process is to convert dissolved and particulate organic matter, measured as biochemical oxygen demand (BOD), into cell mass. In a conventional activated sludge process, microorganisms use oxygen to break down waste so it can be used as food for their growth and survival. Over time and as wastewater moves through the aeration basin, food (BOD) decreases as microorganisms utilize it in the presence of oxygen for growth and reproduction with a resultant increase in cell mass (MLSS concentration). This is known as the Growth Phase, where excess food (BOD) is available allowing for optimal bacterial cell growth with the uptake of oxygen. As food (BOD) is used and decreases, growth declines (Declining Growth Phase) and bacteria eventually reach a level production. This is known as the Stationary Phase. As the food (BOD) is used up and decreases over time to very low levels, microorganisms will then use stored food in their cells and slowly begin to die. Cell mass (MLSS) will decrease. This is known as the Endogenous Phase.

Hydraulic and Solids Retention Time

-The ability to separate the solids loading from the hydraulic loading is a powerful feature of Activated Sludge systems

-The sludge age for conventional Activated Sludge is on the order of 3.57 days, and hydraulic retention might only be a few hours.

Detention Time or Hydraulic Retention Time (HRT)

$HRT[hr] = \frac{V}{Q}$ If Q is in $\left[\frac{gal}{d}\right]$ and V is in [ft^3], then detention time is

$$HRT = \frac{V\left[ft^3\right] \times \frac{7.48\,gal}{ft^3}}{Q\left[\frac{gal}{d}\right] \times \frac{d}{24\,hr}} = \frac{V\left[ft^3\right] \times \frac{7.48\,gal}{ft^3} \times \frac{24\,hr}{d}}{Q\left[\frac{gal}{d}\right]}$$

Typical Process Parameters

-It is always important to keep typical process parameters in mind for the exam. Since the essays and math questions don't provide possible answers, it helps to know what is typical

-Knowledge of the normal process values will make it easier to notice abnormal conditions on the exam, and explaining what is wrong can be necessary

Table 8.1 Process criteria

Process	*SRT* θ_c (d)	*HRT* θ (h)	*MLSS* X (mg/L)	Q_r/Q *ratio*	*F/M ratio* (d^{-1})	*Volumetric loading* (kg BOD_5/ 1000 m^3d)
Conventional plug flow	5–15	4–8	1000–3000	0.25–0.75	0.2–0.5	300–600
Complete-mix	1–15	3–5	1000–6500	0.25–1.0	0.20–1.00	800–2000
Extended aeration	20–30	18–36	1500–5000	0.50–1.5	0.05–0.15	160–400
Oxidation ditch	10–30	8–36	1500–5000	0.75–1.5	0.05–0.30	80–480

MCRT - Mean Cell Residence Time

How long is the average biological cell retained in the system before it is removed?

This is useful because sludge age influences the organisms that will dominate in the sludge.

Mean Cell Residence Time (MCRT): typical units [d]

$$MCRT[d] = \frac{MLSS_{tank}[lb] + MLSS_{clarifier}[lb]}{SS_{effluent}\left[\frac{lb}{d}\right] + SS_{WAS}\left[\frac{lb}{d}\right]}$$

F:M ratio - keeping the biology well fed

F:M ratio is an important parameter that an operator can use to make sure that the microorganisms have the food that they need, while also avoiding the problems associated with too much or too little food.

Pounds of BOD applied per day, divided by the mass of microorganisms available to consume the BOD. Often in the range of .2-.5; imagine eating half your bodyweight in a day, it is easier for bacteria than for us!

Food to Microorganism Ratio (F/M): typical units $\left[\dfrac{\text{lb BOD}}{\text{lb VSS}\cdot\text{d}}\right]$

$$F/M\left[\frac{lb}{lb\cdot d}\right]=\frac{BOD\ applied\left[\frac{lb}{d}\right]}{MLVSS\,[lb]}$$

F:M Ratio cont.

-Too high a ratio can lead to poor effluent quality because there is too much BOD for the microorganism inventory to handle

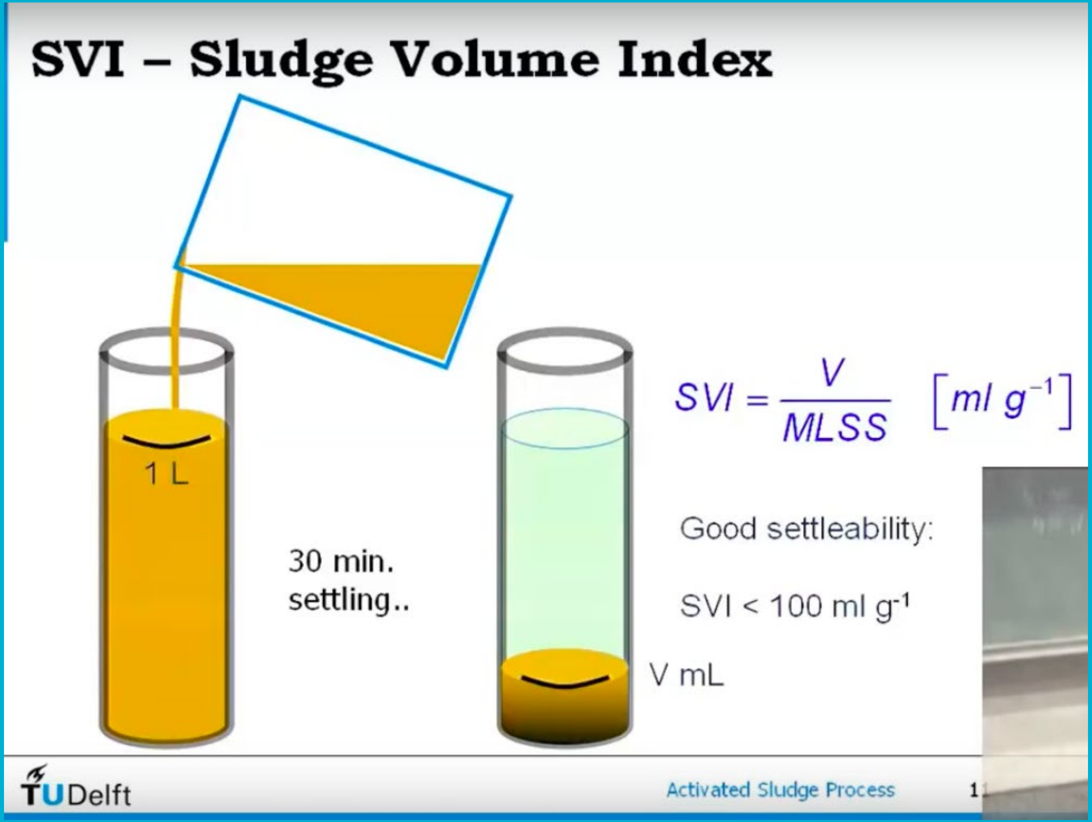
-A high ratio can also lead to viscous bulking, which is a condition that could be imagined as “fat” bugs; they don’t settle as well and may float and overflow the secondary clarifier

- Too low a ratio can select for the wrong type of microorganisms, namely filamentous type, which exhibit poor settling characteristics and can negatively impact the sludge and water separation process in the secondary clarifier

-Since the operator cannot control the BOD coming into the plant, they need to work to maintain their inventory of bugs accordingly via WAS and RAS flows

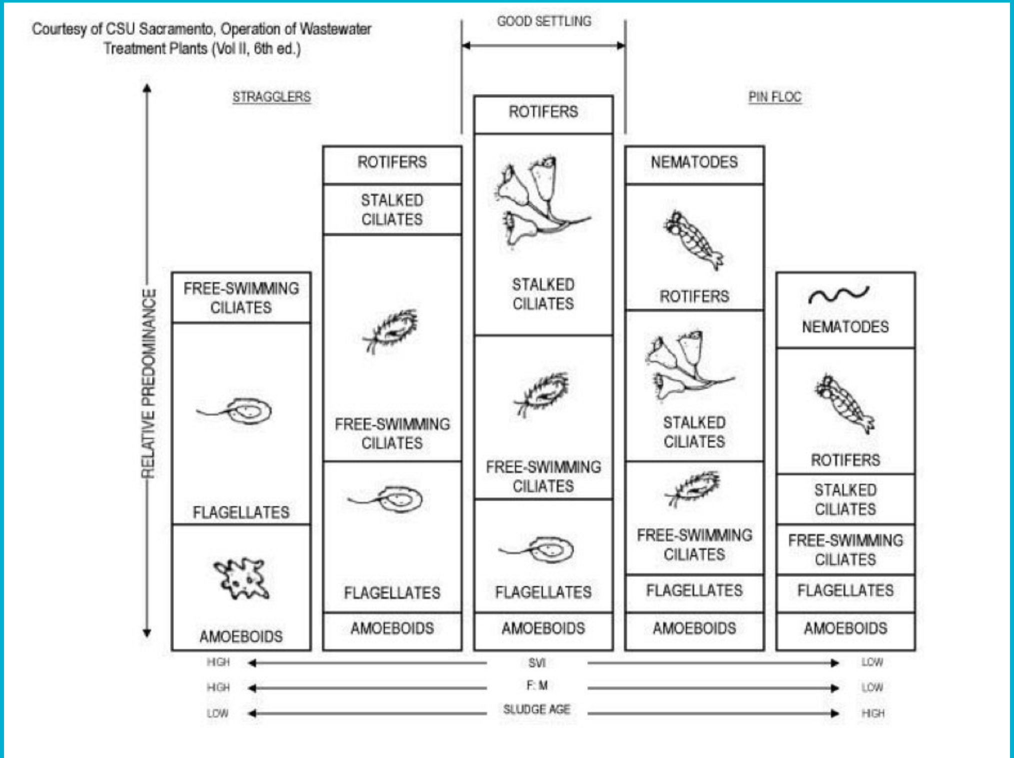
SVI - Sludge Volume Index

Settleability of the sludge in the secondary clarifier is an important quality to quantify and monitor. Avoid washout of sludge in the secondary clarifier! The concentration of the sludge in the return line also depends on the settling of the sludge in the clarifier (if settling is poor, RAS solid concentrations will become low)



Microorganisms VS operating parameters

When looking at these individual parameters as a whole system, it is important to keep the different values in check to keep the system operating smoothly. It is good to know in which direction each of the parameters select for a population of microorganisms.



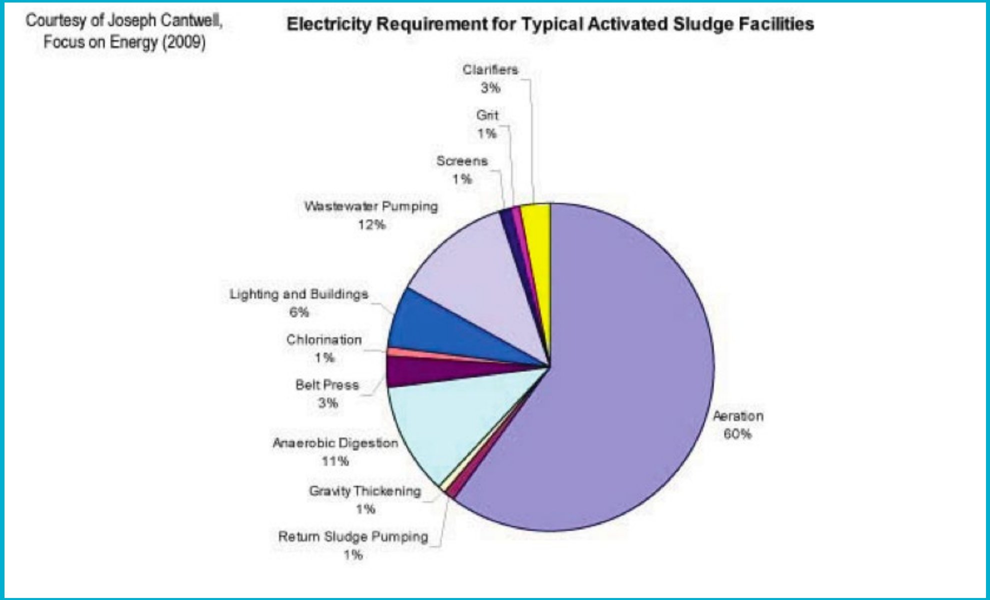
Aeration of Activated Sludge

- Accomplished by compressed air forced the the bottom of the aeration tank or by pure oxygen injection. Can also be accomplished by mechanical surface aeration using atmospheric oxygen

- Oxygen transfer efficiency (OTE) depends on several factors which include water depth, layout, and diffuser air rate.

- Aeration is a very expensive component of a treatment plant

- Air added to excess to maximize BOD removal



Return Activated Sludge

-Very useful control parameter, it is how the MCRT can be made long enough to achieve the level of treatment desired

-Since it is only a return flow, it represents the solids that or returned/recycled into the aeration basin and resume biodegradation in the presence of food and oxygen

-RAS flow is coordinated with WAS in order to maintain a proper sludge age based on the treatment plant's goals

-RAS flow can be set as a percentage of influent flow or set independently

Return Activated Sludge (RAS) Flow Rate ($Q_{RAS\text{-}SS}$): typical units [Mgal/d or MGD]

$$Q_{RAS\text{-}SS}\left[\frac{Mgal}{d}\text{ or } MGD\right] = \frac{Q\left[\frac{Mgal}{d}\right]\times MLSS_{tank}\left[\frac{mg}{L}\right] - Q_{WAS}\left[\frac{Mgal}{d}\right]\times SS_{RAS}\left[\frac{mg}{L}\right]}{SS_{RAS}\left[\frac{mg}{L}\right] - MLSS_{tank}\left[\frac{mg}{L}\right]}$$

Note: $SS_{RAS} = SS_{WAS}$

Waste Activated Sludge

-This is how the biomass that has been created during the removal of BOD is disposed of, sending the excess sludge to sludge handling facilities in order to maintain the desired MCRT

Low F:M ratio? Increase wasting to ensure there is enough food to go around for your inventory.

High F:M? Slow or stop wasting to build up the bug population to handle the incoming BOD.

Waste Sludge Rate (SS_{WAS}): typical units [lb/d]

$$SS_{WAS}\left[\frac{lb}{d}\right]=\frac{MLSS_{tank}[lb]+MLSS_{clarifier}[lb]}{MCRT[d]}-SS_{effluent}\left[\frac{lb}{d}\right]$$

Nutrient Removal

Nitrogen
-Organic Nitrogen, i.e. urea
-Ammonia, NH_4^+
-Nitrate, NO_3^-

Phosphorous
-Organic Phosphorus
-Polyphosphate/Orthophosphate

These are both nutrients for plants (including algae), which can lead to eutrophication of receiving water if left unchecked.

Nitrogen

Removal of nitrogen during wastewater treatment is typically the result of natural biological processes including uptake, biological nitrification and denitrification (generically termed “biological nitrogen removal”), and anaerobic ammonia oxidation.

-A longer SRT is normally needed in order to accomplish BNR

Nitrification is the biological oxidation of ammonia to nitrate. Influent ammonia is first oxidized to nitrite (NO2) by ammonia-oxidizing bacteria (AOB), then nitrite is oxidized further to nitrate (NO3) by nitrite - oxidizing bacteria (NOB). Nitrification requires both oxygen and alkalinity to buffer against a pH drop that can inhibit nitrifying bacteria. A portion of this lost alkalinity is recovered in the subsequent denitrification process.

Phosphorous

Removal of phosphorus during wastewater treatment is typically the result of natural biological processes, including uptake and enhanced biological phosphorus removal (EPBR), although many WWTPs will use metal salts to precipitate phosphorus to the solids (sludge) fraction. In either case (biological or chemical treatment), phosphorus is removed by converting it to a solid, so it partitions to the sludge.

Specialized bacteria in activated sludge mixed liquors called “polyphosphate accumulating organisms” (PAOs) can be used to biologically remove phosphorus from wastewater to levels that might meet water quality objectives. PAOs require two stages for phosphorus removal, anaerobic and then aerobic.

Abnormal Operating Conditions

Hydraulic overloading, often caused by wet weather bringing in additional inflow/infiltration is common. What are some possible mitigations?

-Maximize solids separation as much as possible to compensate for the decreased hydraulic retention time, one way to encourage separation is with good sized floc that has good settling characteristics

-Optimize clarifier performance by making sure that flows are evenly distributed (if there is more than one secondary clarifier)

- Set RAS flow rate to keep the sludge blanket low during the high flow period

- Reduce solids loading by bringing in an out of service clarifier if possible

- Remove an aeration basin from service if possible to store solids for faster plant recovery if the hydraulic loading is very high

Poor Settling in Clarifier

When there are too many solids in the system, the solids settling in the final clarifier may "hinder" the settling of solids above them. There are just too many solids in the water column to settle well. This can be observed in 30 minute settling tests and the tests will usually be high (>800 mL/L). To differeniate a settling problem caused by hindered settling versus excessive filaments, an operator can do a diluted settleability test by diluting the mixed liquor sample in half (50%) with clear final effluent. If the 30 minute settleability test and settling curve improves, this indicates with less solids, settling is better. Additional wasting would be warranted. If settling does not improve after diluting the sample, filaments may be present and the operator should use their microscope for filamentous organism identification.

Increased fats, oil, grease (FOG) loading

Although FOG can be very problematic on equipment once it reaches a plant, it is difficult for bacteria to break down. Bacteria are only capable of using soluble organics for food. In order to utilize FOG, the bacteria have to expend extra energy to produce enzymes to solubilize the greases and fats before they can be used for food. On the other hand, foam-causing filamentous bacteria such as Nocardia, Microthrix and type 1863 can utilize FOG very easily and will dominate when there is an excess amount available. Nocardia will favor greases and oils in warmer temperatures, Microthrix has the ability to break down greases and oils in colder temperatures and type 1863 has the ability to break down greases and oils when there is a decline in the aeration basin pH.

Activated Sludge Math - F/M

Given the treatment plant data, calculate the F/M ratio and its significance.

GIVEN:

Influent BOD5 = 40 pounds

Aeration basin MLSS = 4,000 pounds

FORMULA & SOLUTION:

F/M Ratio = pounds of incoming BOD5 ÷ pounds of MLSS under aeration

F/M Ratio = 40 lbs BOD5 ÷ 4,000 lbs MLSS

F/M Ratio = 0.01 (this is a very low F/M ratio for extended aeration and indicates that there are too many solids (MLSS) under aeration for the amount of food (BOD5) coming in

Activated Sludge Math - SVI

Calculate the sludge volume index (SVI) and discuss possible causes.
GIVEN:

30 minute settling test = 800 mL/L
MLSS = 4000 mg/L

FORMULA & SOLUTION:

SVI = [settled volume in 30 minutes (mL/L) ÷ MLSS (mg/L)] × 1,000 SVI = [800mL/L÷ 4,000mg/L] × 1,000

SVI = 200

Possible causes for high SVI: Filamentous organisms, young sludge, too high a MLSS

Activated Sludge Math - Sludge Age

Calculate the sludge age in days -

GIVEN: Mixed liquor suspended solids (MLSS) = 2,400 mg/L,

Aeration basin volume = 35,000 gallons

Waste activated sludge (WAS) concentration = 3,500 mg/L

Waste activated sludge (WAS) flowrate = 0.001 MGD

FORMULA & SOLUTION:

Sludge Age (days) = [(MLSS in mg/L) × (aeration basin volume in MG) × 8.34 lbs/gal] ÷ [(WAS concentration in mg/L) × (WAS flowrate in MGD) × 8.34 lbs/gal]

Sludge Age = [(2,400 mg/L) × (0.0350 MG) × 8.34 lbs/gal] ÷ [(3,500 mg/L) × (0.001 MGD) × 8.34 lbs/gal]

Sludge Age = 700 lbs ÷ 29 lb per day = 24 days

Activated Sludge Math - WAS rate

Calculate how many gallons of sludge to waste to achieve a desired sludge age.

GIVEN:

Aeration basin volume = 90,000 gallons, MLSS = 1800 mg/L,

WAS concentration = 5,000 mg/L, Desired sludge age = 9 days

lbs MLSS under aeration = (aeration basin volume in MG) × (MLSS in mg/L) × 8.34 lbs/gal
= 0.09 MG × 1,800 mg/L × 8.34 lbs/gal = 1351 lbs

How many pounds is that per day? 1351 lbs ÷ 9 days = 150 lbs/day

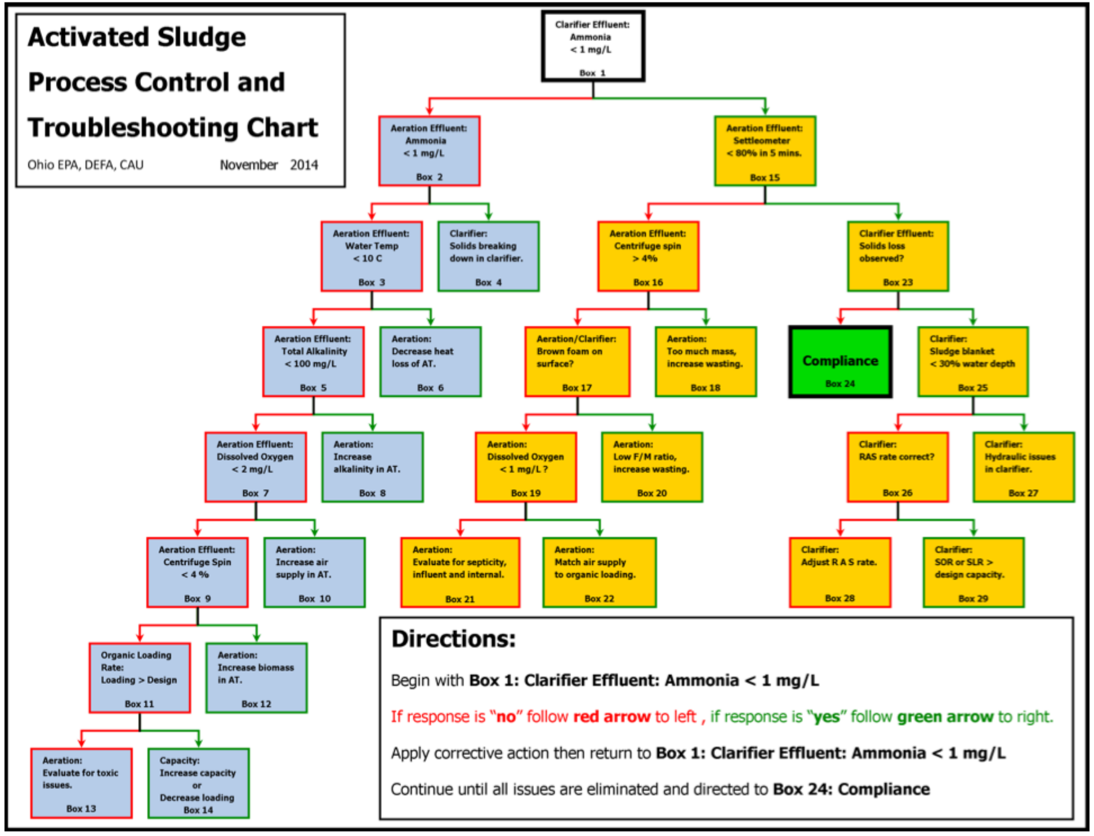
Now convert [150 lbs ÷ (5,000 mg/L × 8.34 lbs/gal)] × 1,000,000 = 3,600 gallons/day

Activated Sludge Math - MLSS Adjustment

Calculate how many gallons of sludge to waste to achieve a desired MLSS level.
GIVEN:
Aeration Basin Volume = 250,000 gallons
Current MLSS = 2,200 mg/L
Desired MLSS = 2,000 mg/L
WAS concentration = 4,000 mg/L

Current MLSS (lbs) = (0.250 MG) × (2200 mg/L) × 8.34 lbs/gal = 4587 lbs
Desired MLSS (lbs) = (0.250 MG) × (2000 mg/L) × 8.34 lbs/gal = 4170 lbs
WAS (lbs) to be wasted = 4,587 lbs - 4,170 lbs = 417 lbs
Gallons to be wasted = [WAS (lbs) to waste ÷ (WAS concentration in mg/L × 8.34 lbs/gal)] × 1,000,000
= [417 lbs ÷ (4,000 mg/L × 8.34 lbs/gal)] × 1,000,000 = 12,500 gallons

Math Break for Troubleshooting Flowchart



Thinking of Activated Sludge in a dropdown flowchart can help you to keep the different operating parameters straight, especially when trying to answer essay questions

Activated Sludge Math - Sludge Age #2

The flow through an oxidation ditch is 750,000 gpd.
MLSS = 3,170 mg/L
SS(Eff) = 142 mg/L
Oxidation ditch capacity = 1.888 acre-ft

What is the sludge age in days?

Mean Cell Residence Time (MCRT): typical units [d]

$$MCRT[d] = \frac{MLSS_{tank}[lb] + MLSS_{clarifier}[lb]}{SS_{effluent}\left[\frac{lb}{d}\right] + SS_{WAS}\left[\frac{lb}{d}\right]}$$

Convert 1.888 acre-ft to MG
=[(1.888 acre-ft)(325,829gal/acre -ft)]/1,000,000/million = .6152MG

Sludge age = [(3,170 mg/L)(.6152MG)(8.34lb/gal)] / [(142 mg/L)(.75mgd)(8.34 lb/gal)] = 18.3 days

Activated Sludge Math - WAS rate #2

Desired MCRT is 6.75 days
Flow = 1645 gpm
Aeration tank volume = 0.502 MG
Clarifier volume = 0.285 MG
MLSS = 2725 mg/L
Effluent TSS = 17.1 mg/L
What is the waste rate in lb/day?

Waste Sludge Rate (SS_{WAS}): typical units [lb/d]

$$SS_{WAS}\left[\frac{lb}{d}\right] = \frac{MLSS_{tank}[lb] + MLSS_{clarifier}[lb]}{MCRT[d]} - SS_{effluent}\left[\frac{lb}{d}\right]$$

Flow of 1645 gpm/694(gpm/MGD) = 2.37 MGD

SS(WAS)lb/day = [(2,725mg/L)(0.502+0.285)(8.34lb/gal]/6.75 MCRT- (17.1mg/L)(2.37 MGD)(8.34 lb/gal)
SS(WAS)lb/day = 2,650 lb/day- 338 lb/day = 2,312 lb/day

Activated Sludge Math - Solids under Aeration

Calculate the number of pounds of suspended solids (SS) contained in an aeration tank, if the tank is 255 ft by 39.5 ft, with an average depth of 14.9 ft, the concentration of SS is 2,270 mg/L, and the specific gravity is 1.03.

Find aeration tank volume in MG = [(255 ft)(39.5 ft)(14.9ft)(7.48 gal/ft^3)] / 1,000,000/miliion = 1.123 MG

lb/gal for SS = (8.34lb/gal)(1.03 specific gravity) = 8.59 lb/gal

Number of pounds under aeration = (2,270 mg/L)(1.123 MG)(8.59 lb/gal) = 21,898 lbs

Activated Sludge Math - Solids Loading Rate

What is the solids loading rate on a secondary clarifier with a diameter of 59.8 ft, if the flow rate is 946,00 gpd, and a MLSS of 3,178 mg/L?

Solids Loading Rate (SLR): typical units [lb/d/ft^2]

$$SLR\left[\frac{lb}{d \cdot ft^2}\right] = \frac{Solids\ applied\left[\frac{lb}{d}\right]}{A\left[ft^2\right]}$$

Find Area of clarifier = (0.785)(59.8ft)^2 = 2,807 ft^2
946,000 gpd = .946 MGD

Solids loading rate = [(MLSS, mg/L)(MGD)(8.34 lb/gal)] / (Area, ft^2)
Solids loading rate = [(3,178)(.946MGD)(8.34 lb/gal)] / 2,807 ft ^2 = 8.93 lb / [(day)(ft^2)]

Resources for Reference

https://www.waterboards.ca.gov/water_issues/programs/operator_certification/exams.html

https://online-learning.tudelft.nl/courses/introduction-to-treatment-of-urban-sewage/

https://dnr.wi.gov/regulations/opcert/documents/wwsgactsludgeadv.pdf

https://www.cedengineering.com/userfiles/02%20-%20Biological%20WWTP%20I%20-%20Activated%20Sludge.pdf

https://youtu.be/sb_heMM5vzs **Youtube video link**

https://www.lenntech.com/wwtp/wwtp-activated-sludge-process.htm

https://epa.ohio.gov/Portals/29/documents/CAU/Activated%20Sludge%20Process%20Control%20and%20Troubleshooting%20Manual.pdf

https://www.epa.gov/sites/production/files/2015-08/documents/case_studies_on_implementing_low-cost_modification_to_improve_potw_nutrient_reduction-combined_508_-_august.pdf