Activated Sludge Math -
How we can understand and control our secondary process

Meryl Abramson, Lead Operator,
City of Hayward Water Pollution Control Facility

February 28, 2019
EBMUD Headquarters Building
275 11th Street
Oakland, CA 94607

Activated Sludge Math

- BOD_5
- F/M
- SVI/SDI
- MCRT/SRT/CRY
- RAS, WAS Control
- Nutrients

Factoring Affecting Activated Sludge

Adequate Inventory (RAS, WAS control)

Water Temperature

pH

Nutrients: 100 BOD: 5 N: 1 P: 0.5 Fe

Sufficient Aeration/Oxygen Uptake (OUR)

Toxics

Food (F/M ratio)

Adequate detention time

We can control aeration (DO concentration), WAS rate, and RAS rate.

BioCHEMICAL Oxygen Demand (BOD or BODS)

BioCHEMICAL Oxygen Demand (BOD or BOD_5) - (aerobic) bugs use/need oxygen to feed on waste

- A measure of the organic strength of the wastewater
- A concept and a lab test
- BOD loading, lbs/day
- Total BOD= CBOD + NOD. Carbonaceous and Nitrogenous.
- BOD test: measure oxygen differential after 5 days of incubation at 20 degrees C
- 300 ml bottle, some ml of sample
- May/may not add seed
- May/not add inhibitor (from nitrification)
- Run a blank, DO consumed $\leq$ 0.2 mg/L. Not used in calculation, QA (quality assurance)/QC (quality control)
- DO Final (remaining) $\geq$ 1.0 mg/L
- Depletion/consumption/differential must be $\geq$ 2.0 mg/L.
- BOD mg/L = $\dfrac{[(\text{DO Initial, mg/L}) - (\text{DO Final, mg/L}) - (\text{seed, if any, mg/L})] \times 300 \text{ ml}}{\text{ml of sample}}$

BOD Example 1

BOD Loading, Lbs/day

The BOD content of the wastewater entering an aeration tank is 155 mg/L. If the flow to the aeration tank is 3,120,000 gpd, what is the lbs/day BOD loading?

NOTE: BOD content of 155 mg/L determined by lab test.
This is "Food" in F/M calculation.

Answer: 4,033 lbs/day

BOD Example 2

BOD tests are run on the final clarifier effluent of an activated sludge plant. These tests are run with and without a nitrification inhibitor such as N-serve. What percentage of the average total BOD is the average nitrogenous BOD?

Tests with Inhibitor

Sample Size, ml	25	50	75	Blank
Initial DO, mg/L	11.0	10.8	9.7	8.1
Final DO, mg/L	9.0	6.5	9.5	8.0

Tests without Inhibitor

Sample Size, ml	25	50	75	Blank
Initial DO, mg/L	11.0	10.8	8.9	8.1
Final DO, mg/L	7.5	4.3	0.8	8.0

Answer: 38.5%

F/M Ratio

Food: Defined as *what is coming into* the Activated Sludge Basin, in pounds of BOD

Microorganisms: Defined as what is already in the tank, in pounds of MLVSS

Know your pounds formula!!!

MLSS vs. MLVSS

$$F/M = \frac{\text{BOD lb/day}}{\text{MLVSS, lb}} \qquad \text{no units}$$

Variations:
Given MLSS, not MLVSS;
Given the ratio, solve for other unknown;
Given other parameters such as TSS, or WAS, or BODs for other flows –
USE only Primary Effluent Flow and BOD.

F/M Example 1

Solids Inventory in the Aeration Tank

The volume of an aeration basin is 180,000 gallons. If the MLVSS concentration is 2160 mg/L, how many pounds of volatile solids are under aeration?

This is "M" in F/M calculations

Answer: 3,243 lbs/day

F/M Example 2

Calculate the F/M ratio when the primary effluent flow is 16 MG (D), with a BOD concentration of 110 mg/L.

The aerator volume is 1.0 MG with a MLVSS content of 3,000 mg/L.

Answer: 0.6

F/M Example 3

Same problem, except: MLSS is 3000 mg/L and volatile solids are 80% of MLSS.

Answer: 0.7

F/M Example 4

An Activated Sludge plant has a F/M ratio of 0.14. The influent flow is 5.8 MGD. The aeration basin has a capacity of 1.86 MG with a MLSS concentration of 3,298 mg/L that is 84% volatile solids.

What is the primary effluent BOD?

Answer: 127 mg/L BOD

F/M Example 5

An Activated Sludge plant is to be operated at a F/M ratio of 0.21. Determine the MLSS concentration required to achieve this, given the following:

Parameter	TSS	BOD
Primary Influent	300 mg/L	260 mg/L
Primary Eff	110 mg/L	180 mg/L
Secondary Eff	15 mg/L	25 mg/L

More info

Aerator volume: 0.75 MG

Plant Flow: 2.0 MGD

Volatile % MLSS: 75%

Answer: 3,048 mg/L MLSS

F/M Practice at Home

1. Plant influent flow is 9.2 MGD and primary effluent BOD is 117 mg/L. Basin volume is 2.2 MG with a MLSS concentration of 2,065 mg/L. Calculate the percent volatile solids of the MLSS to hold a F/M ratio of 0.3.

   Answer: 79%

2. Influent flow 9.2 MGD, secondary influent BOD is 142 mg/L. Basin capacity is 2.1 MG, MLSS concentration is 3,156 mg/L and is 81% volatile solids. F/M ratio?

   Answer: 0.24

3. Plant flow is 20 MGD, BOD of primary eff is 98 mg/L, MLVSS is 2,500 mg/L in a 3.125 MG aeration tank. F/M?

   Answer: 0.25

4. Primary eff flow: 14.7 MGD with BOD of 93 mg/L. MLSS is 2,600 mg/L and is 73% volatile. F/M ratio is 0.4, what is capacity of the aeration basin?

   Answer: 1.8 MG

Sludge Volume Index (SVI)

Sludge Volume Index (SVI): the volume that 1 gram of MLSS occupies

30-minute settleability test

$$\text{SVI ml/gram} = \frac{\text{settled sludge volume (ml/L)} \times 1000 \text{ mg/g}}{\text{MLSS (mg/L)}}$$

Note equivalents: 1 L=1000 ml
1 g=1000 mg

By convention, often not given units

SVI Example 1

Compute the Sludge Volume index for an activated sludge plant that has an aeration basin MLSS concentration of 2,500 mg/L and a 30-minute settleability of 213 ml/L.

Answer: 85

SVI Example 2

To hold a SVI of 90 in an activated sludge plant that has an aeration basin MLSS concentration of 3,180 mg/L, what is the settleability test value in ml/1000 ml?

Answer: 286 ml/1000 ml or 286 ml/L

SVI Practice at Home

1. Find the 30-minute settleability test result, in ml/L, that will give a SVI of 85, for an aeration basin MLSS concentration of 2,800 mg/L.

   Answer: 238 ml/L

2. Same question as #1, but the information on basin concentration is in MLVSS which is 80% of MLSS. The MLVSS is 2,240 mg/L.

   Answer: 238 ml/L

3. Aeration tank MLSS concentration is 3,280 mg/L, with a 30 minute settleability test of 410 ml/1000 ml. SVI?

   Answer: 125

4. 30-minute settleability: 450 ml/L, MLSS concentration of 5,294 mg/L. SVI?

   Answer: 85

Mean Cell Residence Time (MCRT)

A detention time formula, in pounds: what we have in the system, divided by what we are losing from the system. Turnover rate, the time an average biological cell will be in the secondary system.

Can use MLSS from Aeration Basin for concentration in FC, or can grab several core samples (sludge judge)

Unit is days

$$\text{MCRT} = \frac{\text{Pounds in Aerator and Pounds in Secondary Clarifier}}{\text{Pounds out in Wasting and in Secondary Effluent}}$$

Mean Cell Residence Time (MCRT)

Looks intimidating, just a collection of pound formulas!

MCRT=(Volume in Aerator x 8.34 lbs/gal x MLSS, mg/L) +(Vol Secondary Clarifier x 8.34 lbs/gal x MLSS, mg/L)

(Q, WAS, MGD x 8.34 x WAS concentration, mg/L) + (Q, Secondary EFF, MGD x 8.34 x SS, mg/L)

Simplify:

MCRT= (Volume of Aerator + Secondary Clarifier) x (8.34 lbs/gal) x (MLSS, mg/L)

[(Q, WAS, MGD x WAS Concentration, mg/L) + (Q, Secondary EFF, MGD x SS, mg/L)] (8.34 lbs/gal)

If you are more comfortable, keep the 8.34 lbs/gal—sometimes the data is given to you in a way that you will need to use it. For example, lbs of one of the variables is given to you.

MCRT Example 1

Given the following, calculate the MCRT:

<u>Tank Volumes:</u>	
Aerator	1.30 MG
Secondary Clarifier	1.0 MG
<u>Wastewater Flows:</u>	
Daily Plant Flow	5.0 MGD
Waste Sludge Flow	0.125 MGD
<u>SS Concentrations:</u>	
Secondary Effluent SS	14 mg/L
Waste (or Return) Sludge SS	7,100 mg/L
MLSS	3,200 mg/L

Answer: 7.7 days

MCRT Example 2

Given the following, calculate the MCRT:

Tank Volumes:	
Aerator	2.0 MG
Secondary Clarifier	1.5 MG
Wastewater Flows:	
Daily Plant Flow	7.10 MGD
Waste Sludge Flow	0.277 MGD
SS Concentrations:	
Secondary Effluent SS	16 mg/L
Waste (or Return) Sludge SS	6,247 mg/L
MLSS	3,480 mg/L

Answer: 6.6 days

MCRT Example 3

Some plants take “core samples” from their secondaries. You will use the core concentration as the secondary concentration (not MLSS). Given the following, calculate the MCRT:

	Flow or Tank Volumes:	SS Concentrations, mg/L:
Aerator	1.86 MG	2,200
Secondary Clarifier (cores)	1.52 MG	640
Secondary Eff.	6.5 MGD	19
WAS	0.26 MGD	4,350

Answer: 4.04 days

MCRT Practice at Home

1. Find the MCRT:

	Flow or Tank Volumes:		SS Concentrations, mg/L:
Aeration Basin	1.50	MG	3,000
Secondary Clarifier (cores)	1.25	MG	480
Secondary Eff.	3.8	MGD	27
WAS	0.426	MGD	3,750

Answer: 3 days

MCRT Practice at Home

2. The Aeration tank volume is 2.05 MG, and the Secondary clarifier is 2.0 MG. The waste activated sludge flow rate is 0.06 MGD. The Aeration basin MLSS concentration is 4,400 mg/L. The final (secondary) clarifier has a SS concentration of 890 mg/L. The plant flow rate is 10 MGD and the secondary clarifier concentration is 14 mg/L. The waste activated sludge concentration is 8,900 mg/L. Find the MCRT.

Answer: 16 days

3. You may be given the MCRT and asked to solve for another variable. Take your time, remember the concept, check your formula.

   Find the secondary clarifier cores suspended solids concentration, in mg/L, while maintain a 6.6 day MCRT, using the following data:

Answer: 863 mg/L

Wasting Rates

Wasting Rates are an important control—inventory must be maintained. Too many bugs lead to too little food and 'endogenous respiration'. Wasting rate is a derivation of MCRT formula, units are MGD.

Given that you have determined the best MCRT to run your plant, you can determine the wasting.

$$MCRT = \frac{\text{Pounds in Aerator and Pounds in Secondary Clarifier}}{\text{Pounds out in Wasting and in Secondary Effluent}}$$

So:

Lbs. of wasting =lbs. in aerator and lbs. in Secondary Clarifier--lbs. lost in sec. eff MCRT

Depending on what parameters you are given, divide out the 8.34 lbs/gal on each side, or not.

Return Rates

Return Rates are another important control - inventory must be maintained.

Typical RAS rates for activated sludge: 25-50% (of flow into secondary clarifier, or influent flow). Higher for extended aeration.

Three ways to calculate:

1. Solids balance approach. Assumes NO net growth or change in lbs. of solids in basin. Assumes that lbs. into the secondary clarifier equal the lbs. returned to the aeration basin. Also, lbs. wasted = lbs. new bug growth.

   $$Q_R = Q \times \frac{MLSS}{(RAS-MLSS)}$$

2. Use the SVI:

   $$Q_R = Q \times \frac{SVI_{30}}{1000-SVI_{30}}$$

3. Can frequently adjust Q_R to maintain a constant blanket in the secondary clarifier.

Return Rate Example

Given the following data, calculate the RAS Return Rate Q_R, fusing the aeration balance solids balance equation.

MLSS=2100 mg/L

RAS=7490 mg/L

Q=6.3 MGD

Answer: Q_R=2.45 MGD

Additional References

"The Math Text for Water and Wastewater Technology," by Glover Wright (Contact BACWWE or Solano Community College Water/Wastewater Tech program)

"Operation of Wastewater Treatment Plants Volume I & II," by Kenneth D. Kerri; California State University, Sacramento

"Applied Math for Wastewater Plant Operators and Workbook," by Joanne Kirkpatrick Price; CRC Press

Online:

"Introduction to Activated Sludge Study Guide and Advanced Activated Sludge Study Guide," Wisconsin Department of Natural Resources Wastewater Operator Certification; http://dnr.wi.gov

"Activated Sludge Process Control Training Manual for Wastewater Treatment Plant Operators," State of Michigan Department of Environmental Quality; www.michigan.gov/deq