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Biological Wastewater Treatment I - Activated Sludge

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Biological Wastewater Treatment Processes I: Activated Sludge

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1. Introduction

Biological wastewater treatment is very widely used for removal of biodegradable materials from wastewater. This course starts with a discussion of the biochemical oxygen demand that is created by biodegradable materials in water and the reason why such materials must be removed from wastewater. The course is primarily about the activated sludge process, including description and background information, as well as presentation of process design calculations and operational calculations. Numerous illustrative example calculations are included for both, along with discussion of the use of Excel spreadsheets for those calculations.

This course is Part I of a three-part series. The other two courses in this Biological Wastewater Treatment series are about Moving Bed Biofilm Reactor (MBBR) processes and Membrane Biofilm Reactor (MBR) processes.



Activated Sludge Aeration Tank

Image Credit: Bergan County Utilities Authority

http://www.bcua.org/index.asp?SEC=B72FCC01-8879-4FC8-BA9C-9E10B1443AAF&Type=B_LIST

2. Learning Objectives

At the conclusion of this course, the student will

- Know the equation for biological oxidation and how it fits into the organic carbon cycle
- Know the equation for photosynthesis and how it fits into the organic carbon cycle
- Know the major components of an activated sludge wastewater treatment system
- Be able to describe the differences between an extended aeration and conventional activated sludge system
- Be able to describe the differences between a contact stabilization and conventional activated sludge system
- Be able to calculate required aeration tank volume (in U.S. units) for a specified volumetric loading, hydraulic residence time, or aeration tank F:M ratio, if given suitable aeration tank influent and aeration tank parameter information
- Be able to calculate required aeration tank volume (in S.I. units) for a specified volumetric loading, hydraulic residence time, or aeration tank F:M ratio, if given suitable aeration tank influent and aeration tank parameter information
- Be able to calculate the required activated sludge recycle flow rate, waste activated sludge flow rate, and aeration tank F:M ratio, if given suitable wastewater stream and aeration tank information along with the desired value for sludge retention time
- Be able to calculate the required air/oxygen blower requirements and alkalinity requirements for an activated sludge process.

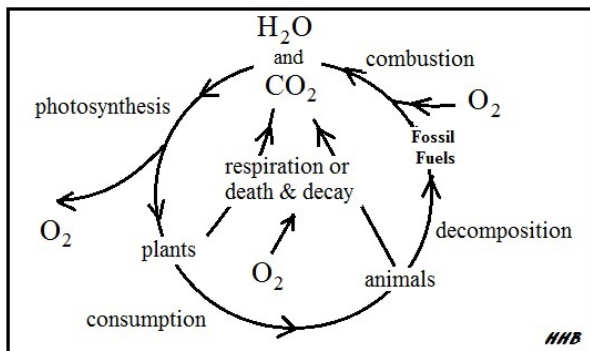
3. Topics Covered in this Course

- I. biochemical Oxygen Demand as a cause of Water Pollution
- II. Description of the Activated Sludge Process
- III. Activated Sludge Process Variations

- IV. Activated Sludge Parameters
- V. Activated Sludge Process Design Calculations
- VI. Activated Sludge Operational Calculations
- VII. Oxygen/Air/Blower Calculations

4. Biochemical Oxygen Demand as a Cause of Water Pollution

Biochemical oxygen demand (BOD) is an indirect measure of the concentration of biodegradable organic matter in water or wastewater. Organic matter (as measured by BOD) is one of the major constituents removed from wastewater in domestic wastewater treatment plants. The reason for being concerned about organic matter in water is its effect on dissolved oxygen in the receiving stream. Dissolved oxygen in water is essential for much of aquatic life, so organic contaminants that affect dissolved oxygen level in water are of concern. The death and decay portion of the organic carbon cycle shown in the above diagram is the portion that takes place in the biological treatment component of a wastewater treatment plant or else takes place in the receiving stream if the organic matter isn't removed in the treatment plant.

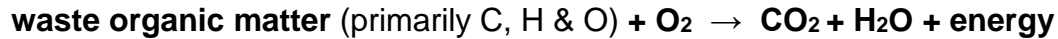


The two major reactions that take place in the organic carbon cycle are biological oxidation of waste organic matter and photosynthesis, which is the process by which green plants produce organic matter from carbon dioxide and water in reactions that are catalyzed by sunlight and the chlorophyll in the green plants. Through the biological oxidation process, aerobic microorganisms utilize oxygen in breaking down organic matter to carbon dioxide and water together with small amounts of other end products. The photosynthesis and biological oxidation processes can be represented by the following two equations:

Photosynthesis:

CO₂ + H₂O + sunlight → **organic plant matter** (primarily C, H, & O) + **oxygen** (this reaction is catalyzed by the chlorophyll in green plants)

Biological Oxidation:

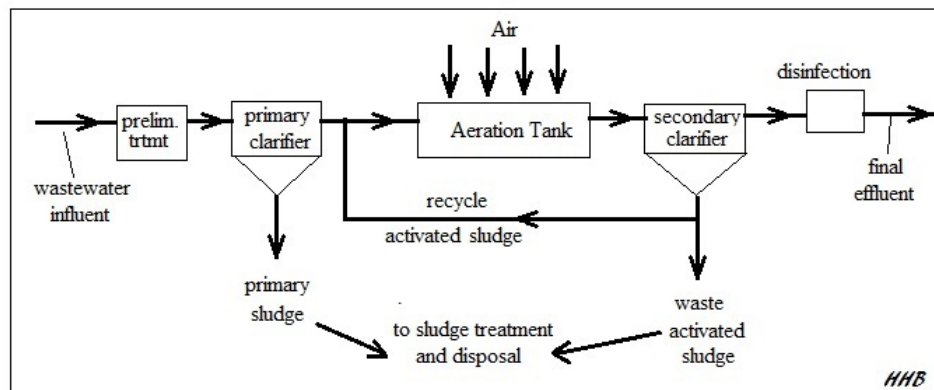


This reaction is the ‘death and decay’ shown in the organic carbon cycle diagram. The process takes place as aerobic microorganisms utilize the waste organic matter as their food (energy) source. The process uses oxygen, so if it is taking place in a water body, dissolved oxygen is consumed. A large quantity of organic matter in the water will result in multiplication of microorganisms and rapid removal of dissolved oxygen, leading to oxygen depletion below the level needed by aquatic life.

This is also the process that takes place in biological oxidation processes in wastewater treatment plants for removal of organic matter from the incoming wastewater.

5. Description of the Activated Sludge Process

The activated sludge process is very widely used for biological wastewater treatment. The figure below shows a general flow diagram with the typical components present in an activated sludge wastewater treatment plant.



Activated Sludge Wastewater Treatment Flow Diagram

The first component is preliminary treatment, typically consisting of screening, flow measurement, and perhaps grit removal. The second component, the primary clarifier, is used to remove settleable suspended matter. The underflow goes to sludge treatment and disposal and the overflow goes to an aeration tank. The aeration tank is the heart of

an activated sludge treatment process. It is here that biological oxidation of dissolved and fine suspended organic matter takes place. The biological oxidation takes place because aerobic microorganisms, organic matter and dissolved oxygen are all brought together in the aeration tank. The organic matter comes in with the primary effluent. The dissolved oxygen level is maintained by blowing air into the aeration tank through diffusers (or in some cases with a mechanical aerator). This also serves to keep the aeration tank contents mixed. A suitable concentration of microorganisms is maintained in the aeration tank by settling out the 'activated sludge' (microorganisms) in the secondary clarifier and recycling them back into the aeration tank.

The activated sludge process was first developed in England in the early 1900s by E. Ardern and W.T. Lockett. They presented their findings to the Manchester section meeting of the Society of Chemical Industry on April 3, 1914. The essentials of the activated sludge process, as described by Ardern and Lockett, are:

1. Aeration of wastewater in the presence of aerobic microorganisms
2. Removal of biological solids from the wastewater by sedimentation
3. Recycling of the settled biological solids back into the aerated wastewater

These three components, shown in the flow diagram above, are still the essence of the activated sludge process, as it is used today.

6. Activated Sludge Process Variations

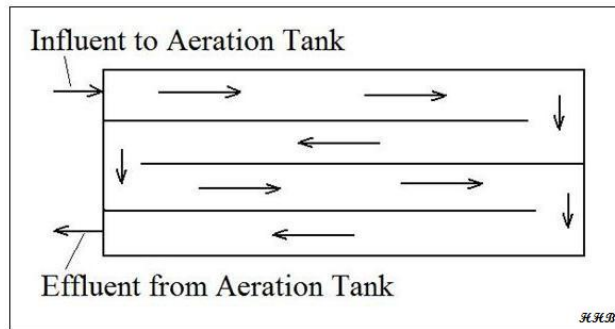
Four common variations of the activated sludge process are:

- Conventional activated sludge
- Extended aeration
- Completely mixed activated sludge
- The contact stabilization process

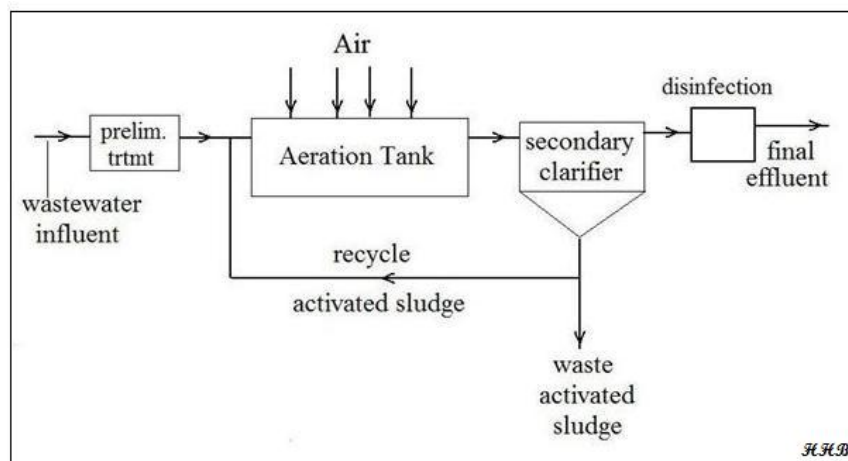
A brief description of each follows.

The Conventional Activated Sludge Process is used over a wide range of wastewater flow rates, from small to very large plants. The flow diagram and general description is that given above in the Activated Sludge Background section. The aeration tank in a conventional activated sludge process is typically designed with a long, narrow configuration, thus giving approximately 'plug flow' through the tank. For large treatment plants, the aeration tank is often built with a serpentine pattern, like that shown in the diagram at the right, in order to obtain the desired plug flow without an excessive length requirement for the tank.

The Extended Aeration Activated Sludge Process is shown in the diagram below. As you can see, this process doesn't use a primary clarifier. Instead, a longer detention time is used for the aeration tank, so that the settleable organic matter will be biologically oxidized along with the dissolved and fine suspended organic matter. This requires a hydraulic detention time of about 24 hours instead of the 6 to 8 hours that is typical for the conventional activated sludge process. This simplifies the operation of the plant by eliminating the primary clarifier and reducing the need for sludge treatment and disposal to a very minimal flow of waste activated sludge that must be drawn off periodically.



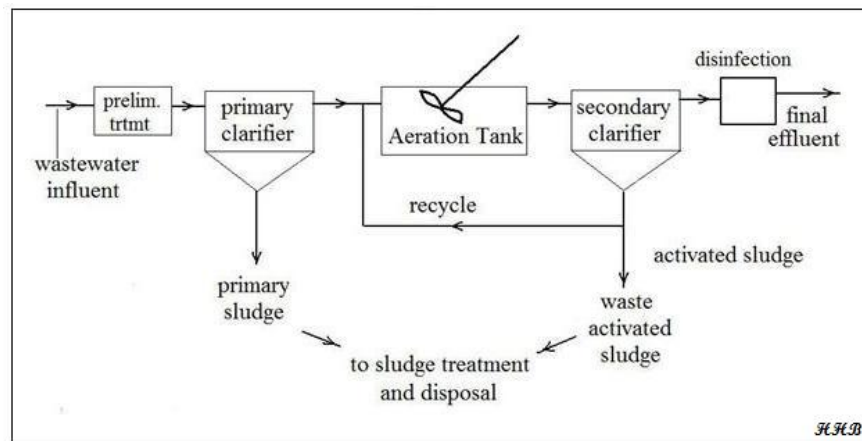
Serpentine Pattern Activated Sludge Aeration Tank



Extended Aeration Activated Sludge Wastewater Treatment Process

The Completely Mixed Activated Sludge Process has the same overall flow pattern as the conventional activated sludge process. The main differences are the method of aeration and the aeration tank configuration. For the completely mixed option, aeration is usually with a mechanical mixer, rather than with diffused air. Also, the tank configuration is usually approximately square, rather than long and narrow. This combination of mixing and tank configurations makes the aeration tank approximate a completely mixed reactor rather than the plug flow reactor approximated by the conventional activated sludge aeration tank. The flow diagram below illustrates this.

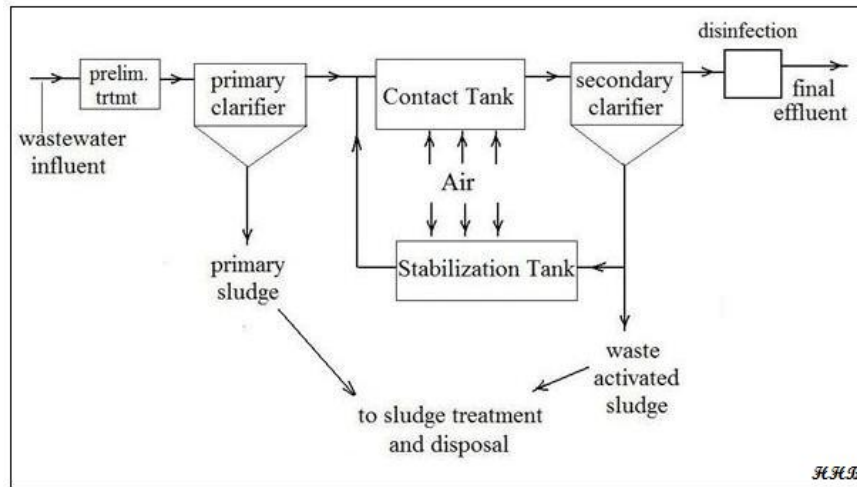
Typical applications of the completely mixed activated sludge process are cases where slug flows of high concentration, hard to oxidize, or toxic wastes enter the treatment plant. The complete mixing dilutes such flows into the entire tank contents more rapidly than a plug flow design, making the slug flow less likely to upset or kill the microorganisms.



Completely Mixed Activated Sludge Flow Diagram

The Contact Stabilization Activated Sludge Process gets by with less total aeration tank volume than that needed for the conventional activated sludge process. This is accomplished because the full wastewater flow is aerated for only 0.5 to 2 hours in an aerated contact tank. This is sufficient time for removal of the organic matter from the wastewater flow by the microorganism. If those microorganisms were recycled directly into the aeration tank after settling out in the secondary clarifier, however, they would not continue to take up organic matter, because they are “still full” from the 0.5 to 2 hour feast they recently had. If the recycle sludge is aerated for 3 to 8 hours to allow the microorganisms to “digest” the organic matter that they’ve taken up, then they go back into the aeration tank ready to go to work. Since the recycle activated sludge flow is less

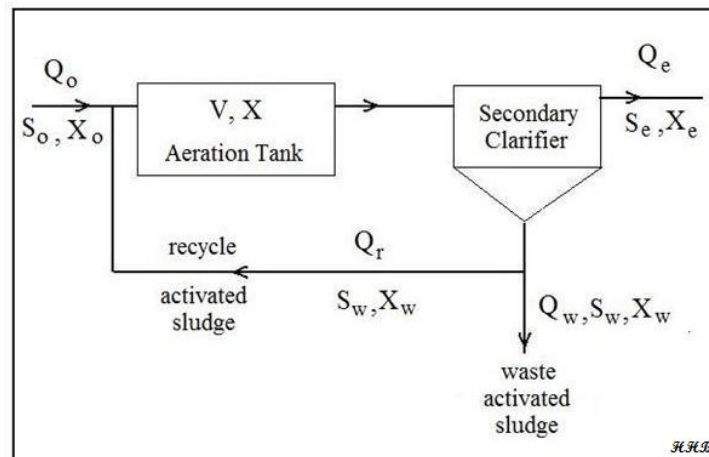
than the full wastewater flow, this results in less overall aeration tank volume for a given wastewater flow rate to be treated. The diagram below shows this process.



Contact Stabilization Activated Sludge Flow Diagram

7. Activated Sludge Parameters

The diagram below shows an activated sludge aeration tank and secondary clarifier with parameters for the primary effluent, secondary effluent, waste activated sludge, and recycle activated sludge streams.



Activated Sludge Flow Diagram & Parameters

The parameters in the diagram and a few others that will be used for the upcoming activated sludge calculations are summarized in the list below.

- primary effluent flow rate, Q_o , MGD (m^3/day for S.I.)
- primary effluent biochemical oxygen demand (BOD) concentration, S_o , mg/L (g/m^3 for S.I.)
- primary effluent suspended solids conc., X_o , mg/L (g/m^3 for S.I.)
- aeration tank volume, V , ft^3 (m^3 for S.I.)
- aeration tank MLSS (suspended solids conc.), X , mg/L (g/m^3 for S.I.)
- secondary effluent flow rate, Q_e , MGD, (m^3/day for S.I.)
- secondary effluent susp. solids conc., X_e , mg/L (g/m^3 for S.I.)
- secondary effluent biochemical oxygen demand (BOD) concentration, S_e , mg/L (g/m^3 for S.I.)
- waste activated sludge flow rate, Q_w , MGD (m^3/day for S.I.)
- waste activated sludge biochemical oxygen demand (BOD) conc., S_w , mg/L (g/m^3 for S.I.)
- waste activated sludge susp. solids conc., X_w mg/L (g/m^3 for S.I.)
- recycle activated sludge flow rate, Q_r , MGD (m^3/day for S.I.)
- Food to Microorganism ratio, **F:M**, lb BOD/day/lb MLVSS (kg BOD/day/kg MLVSS for S.I.)
- Hydraulic retention time, **HRT**, hours (hours for S.I.)
- Sludge retention time (also called sludge age), **SRT**, days (days for S.I.)
- Volumetric loading, **VL**, lb BOD/day/1000 ft^3 (kg BOD/day/ m^3 for S.I.)
- % volatile solids in the aeration tank mixed liquor suspended solids, **%Vol.**

8. Activated Sludge Process Design Calculations

Table 1 below shows typical values for three design parameters sometimes used for sizing activated sludge aeration basins: volumetric loading, food to microorganism ratio (F:M), and hydraulic residence time (HRT). Note that values for volumetric loading are

given in both U.S. and S.I. units. The other two parameters are the same for either U.S. or S.I. units, since F:M will be the same expressed as either lb BOD/day/lb MLVSS or as kg BOD/day/kg MLVSS, and HRT is simply in hours in either system of units.

Table 1. Activated Sludge Aeration Tank Design Parameters – Typical Values

Activated Sludge Process	Volumetric Loading		F/M	HRT hours
	lb BOD/day 1000 ft ³	kg BOD/day m ³	kg BOD/day kg MLSS	
Conventional Plug Flow	20 - 40	0.3 - 0.7	0.2 - 0.4	4 - 8
Complete Mix	20 - 100	0.3 - 1.6	0.2 - 0.6	3 - 5
Extended Aeration	5 - 15	0.1 - 0.3	0.04 - 0.1	20 - 30

(adapted from Metcalf & Eddy, 4th Ed – Reference #1)

NOTE: F:M values will be the same for units of lb BOD/day/lb MLVSS.

Calculations with these design parameters can be made in U.S. units using the following equations:

- $V = [(8.34 \cdot S_o \cdot Q_o) / VL] (1000)$
- $V_{MG} = V \cdot 7.48 / 1,000,000$
- $HRT = 24 \cdot V_{MG} / Q_o$
- $F:M = (8.34 \cdot S_o \cdot Q_o) / (8.34 \cdot \%Vol \cdot X \cdot V_{MG})$
 $= (S_o \cdot Q_o) / (\%Vol \cdot X \cdot V_{MG})$

V_{MG} is the tank volume in millions of gallons. It is introduced for convenience in calculations, since the primary effluent flow rate is given in MGD. The other parameters in the equations are as defined in the list above. The 8.34 factor in the equations above is used to convert mg/L to lb/MG, and the 7.48 is for conversion of ft³ to gallons. Also,

note that the primary sludge flow rate is typically very small in comparison with the influent wastewater flow rate, so the secondary effluent flow rate, Q_e , is typically taken to be equal to the plant influent flow rate.

Example #1: Calculate the aeration tank volume requirement for a conventional activated sludge plant treating a daily average flow rate of 3.5 MGD, with primary effluent BOD estimated to be 175 mg/L. The design criterion is to be a volumetric loading rate of 30 lb BOD/day/1000 ft³.

Solution: The required volume can be calculated from the first equation in the list above:

$$V = [(8.34 * S_o * Q_o) / VL] (1000) = 8.34 * 175 * 3.5 * 1000 / 30 = \underline{170,275 \text{ ft}^3}$$

Example #2: For an assumed aeration tank MLSS of 2100 mg/L and assumed % volatile MLSS of 75%, what would be the aeration tank F:M ratio and hydraulic residence time for the plant inflow and aeration tank volume from Example #1?

Solution: The HRT and F:M ratio can be calculated using the last three equations in the list above, as follows:

$$V_{MG} = V * 7.48 / 1,000,000 = 170,275 * 7.48 / 1,000,000 = 1.27 \text{ MG}$$

$$\text{HRT} = 24 * V_{MG} / Q_o = 24 * 1.27 / 3.5 = \underline{8.7 \text{ hours}}$$

$$\begin{aligned} \text{F:M} &= (8.34 * S_o * Q_o) / (8.34 * \% \text{Vol} * X * V_{MG}) = (175 * 3.5) / (0.75 * 2100 * 1.27) \\ &= \underline{0.31 \text{ lb BOD/day/lb MLVSS}} \end{aligned}$$

Example #3: Set up and use an Excel spreadsheet to find the solutions to Examples #1 and #2.T

Solution: The screenshot on the next page shows an Excel spreadsheet with the solution to this example.

This spreadsheet is set up for user entry of specified design volumetric loading, VL , and input values for primary effluent flow rate, Q_o , primary effluent biochemical oxygen

demand (BOD), S_o , aeration tank MLSS, X , and % volatile solids in the aeration tank, %Vol.

The spreadsheet then uses the equations presented above to calculate the design aeration tank volume and the resulting values for the other two design parameters, **F:M** and **HRT**.

To solve this Example problem, the given values ($Q_o = 3.5$ MGD, $S_o = 175$ mg/L, $VL = 30$ lb BOD/day/1000 ft³, $X = 2100$ mg/L, % Vol = 75%) were entered into the blue cells in the left portion of the spreadsheet. The spreadsheet then calculated the parameters in the yellow cells in the right portion of the spreadsheet. As shown in the screenshot on the next page, the same values for **V**, **HRT**, and **F:M** are obtained as those shown above for Example #1 and Example #2:

$$V = \underline{170,275 \text{ ft}^3}$$

$$\text{HRT} = \underline{8.7 \text{ hours}} \quad \text{F:M} = \underline{0.31 \text{ lb BOD/day/lb MLVSS}}$$

Calculations in S.I. units can be made using the following equations:

- $V = (S_o * Q_o / 1000) / VL$
- $\text{HRT} = 24 * V / Q_o$
- $\text{F:M} = (S_o * Q_o) / (\% \text{Vol} * X * V)$

The equations are slightly simpler, because the S.I. system doesn't have a strange volume unit like the gallon. The S.I. units for all of the parameters are given in the long list above. Note that the S.I. concentration unit g/m³ is numerically equal to mg/L.

Example #4: Calculate the aeration tank volume requirement for a conventional activated sludge plant treating a daily average flow rate of 20,000 m³/day, with primary effluent BOD estimated to be 140 g/m³. The design criterion is to be a volumetric loading rate of 0.5 kg BOD/day/m³.

Solution: The required volume can be calculated from the first equation in the list above:

$$V = (S_o * Q_o / 1000) / VL = (140 * 20,000 / 1000) / 0.5 = \underline{5,600 \text{ m}^3}$$

Activated Sludge Waste Water Treatment Calculations - U.S. units					
1. Aeration Tank Design					
Instructions: Enter values in blue boxes. Spreadsheet calculates values in yellow boxes					
Inputs			Calculations		
Prim. Effl. Flow Rate, Q_o =	3.5	MGD	(Design Based on Volumetric Loading.)		
Prim. Effl. BOD, S_o =	175	mg/L	Aeration tank volume, V =	170,275	ft ³
Aeration tank MLSS, X =	2100	mg/L	Aeration tank vol. V_{MG} =	1.27	MG
Design Vol. Loading, VL =	30	(lb BOD/day/1000 ft ³)	Check on other design parameters:		
			Aeration tank HRT =	8.7	hr
% volatile MLSS, %Vol =	75%		Aeration tank F:M =	0.31	
			(lb BOD/day/lb MLVSS)		

Screenshot of Spreadsheet Solution to Example #3

Example #5: For an assumed aeration tank MLSS of 2100 mg/L and assumed % volatile MLSS of 75%, what would be the aeration tank F:M ratio and hydraulic residence time for the plant inflow and aeration tank volume from Example #3?

Solution: The HRT and F:M ratio can be calculated using the last two equations in the list above, as follows:

$$\text{HRT} = 24 * V / Q_o = 24 * 5,600 / 20,000 = \underline{\underline{6.7 \text{ hr}}}$$

$$\begin{aligned} \text{F:M} &= (S_o * Q_o) / (\%Vol * X * V) = (140 * 20,000) / (0.75 * 2100 * 5600) \\ &= \underline{\underline{0.32 \text{ kg BOD/day/kg MLVSS}}} \end{aligned}$$

9. Activated Sludge Operational Calculations

Table 2 below shows typical ranges for several operational activated sludge wastewater treatment process parameters. Note that these values remain the same for U.S. or S.I. units. **SRT** will still have units of days for the U.S. or S.I. system. **MLSS** concentration will have the S.I. unit of g/m³, which is numerically equal to mg/L. **F:M** will have the S.I. unit of kg BOD/day/kg MLVSS, which is numerically equal to lb BOD/day/lb MLVSS. The % unit for **Q_r/Q_o** remains the same for U.S. or S.I. units.

Table 2. Activated Sludge Operational Parameters – Typical Values

Activated Sludge Process	SRT days	MLSS mg/L	F/M	Q _r /Q _o %
			kg BOD/day kg MLSS	
Conventional Plug Flow	3 - 15	1000 - 3000	0.2 - 0.4	25 - 75
Complete Mix	3 - 15	1500 - 4000	0.2 - 0.6	25 - 100
Extended Aeration	20 - 40	2000 - 5000	0.04 - 0.1	50 - 150

(adapted from Metcalf & Eddy, 4th Ed – Reference #1)

Calculations with these parameters can be made in U.S. units using the following equations:

- $$Q_r = [Q_o(X - X_o) - Q_w X_w] / (X_w - X)$$
 [sometimes approximated by:

$$= Q_o(X - X_o) / (X_w - X)$$
 (See discussion in next section of course)
- $$V_{MG} = V * 7.48 / 1,000,000$$
- $$Q_w = (1/X_w) [(V_{MG} * X / SRT) - X_e Q_e]$$
- $$F:M = (8.34 * S_o * Q_o) / (8.34 \% Vol * X * V_{MG})$$

$$= (S_o * Q_o) / (\% Vol * X * V_{MG})$$

The aeration tank volume in millions of gallons, V_{MG} , is used primarily in calculating Q_w and the **F:M** ratio.

Example #6: For the 3.5 MGD activated sludge plant in Example #1, with an aeration tank volume of 170,275 ft³, calculate a) the required recycle activated sludge flow rate (using the simplified equation), b) the waste activated sludge flow rate, and c) the aeration tank F:M ratio, based on the following: primary effluent BOD = 175 mg/L, primary effluent TSS = 200 mg/L, waste/recycle activated sludge SS concentration = 7,000 mg/L, aeration tank MLSS = 2000 mg/L, % volatile solids in the aeration tank = 75%, intended sludge retention time = 12 days.

Solution: a) The sludge recycle rate needed can be calculated from the simplified form of first equation in the list above:

$$Q_r = Q_o(X - X_o)/(X_w - X) = 3.5(2000 - 200)/(7000 - 2000) = \underline{\underline{1.26 \text{ MGD}}}$$

b) The waste activated sludge flow rate needed to give SRT = 12 days can be calculated from the second and third equations in the list above:

$$V_{MG} = V \cdot 7.48 / 1,000,000 = 170,275 \cdot 7.48 / 1,000,000 = 1.27 \text{ million gallons}$$

- $Q_w = (1/X_w)[(V_{MG} \cdot X / \text{SRT}) - X_e Q_e] = (1/7000)[(1.27 \cdot 2000 / 12) - (20 \cdot 3.5)]$
 $= \underline{\underline{0.0203 \text{ MGD}}} \quad \text{or} \quad \underline{\underline{20,300 \text{ gal/day}}}$

c) The aeration tank F:M ratio can be calculated using the last equation in the list above together with the equation for V_{MG} :

$$V_{MG} = V \cdot 7.48 / 1,000,000 = 170,275 \cdot 7.48 / 1,000,000 = 1.27 \text{ million gallons}$$

$$\text{F:M} = (S_o \cdot Q_o) / (\% \text{Vol} \cdot X \cdot V_{MG}) = (175 \cdot 3.5) / (0.75 \cdot 2000 \cdot 1.27)$$

$$= \underline{\underline{0.321 \text{ lb BOD/day/lb MLVSS}}}$$

Example #7: Use an Excel spreadsheet to find the solution to Example #6.

Solution: The screenshot on the next page shows an Excel spreadsheet with the solution to this example.

This spreadsheet is set up for user entry of primary effluent flow rate, Q_o , primary effluent biochemical oxygen demand (BOD), S_o , primary effluent TSS, X_o , recycle/waste activated

sludge concentration, X_w , aeration tank volume, V , aeration tank MLSS, X , % volatile solids in the aeration tank, %Vol, and the target value for sludge retention time, **SRT**. The spreadsheet then uses the equations presented above to calculate the recycle activated sludge flow rate, Q_r , the waste activated sludge flow rate, Q_w , and the aeration tank **F:M** ratio.

To solve this Example problem, the given values ($Q_o = 3.5$ MGD, $S_o = 175$ mg/L, $X_o = 200$ mg/L, $X_w = 7000$ mg/L, $V = 170,275$ ft³, $X = 2000$ mg/L, % Vol = 75%, **SRT** = 12 days) were entered into the blue cells in the left portion of the spreadsheet. The spreadsheet then calculated the parameters in the yellow cells in the right portion of the spreadsheet.

Activated Sludge Waste Water Treatment Calculations - U.S. units			
2. Activated Sludge Operational Calculations			
Instructions: Enter values in blue boxes. Spreadsheet calculates values in yellow boxes			
Inputs		Calculations	
Prim. Effl. Flow Rate, $Q_o =$	3.5	MGD	
			Recycle Activated
Prim. Effl. BOD, $S_o =$	175	mg/L	Sludge Flow Rate, $Q_r =$ 1.26 MGD
Prim. Effl. TSS, $X_o =$	200	mg/L	Aeration tank vol. $V_{MG} =$ 1.27 MG
Sec. Effl. TSS, $X_e =$	20	mg/L	
Waste/recycle activated			Waste Activated Sludge
sludge SS conc., $X_w =$	7,000	mg/L	Flow Rate, $Q_w =$ 0.0203 MGD
Aeration tank vol., $V =$	170,275	ft ³	Aeration tank F:M = 0.321
			(lb BOD/day/lb MLVSS)
Aeration tank MLSS, $X =$	2000	mg/L	
% volatile MLSS, %Vol =	75%		
Sludge ret. time, SRT =	12	days	

Screenshot of Spreadsheet Solution to Example #7

As shown in the screenshot above, the same values for Q_r , Q_w , and **F:M** are obtained as those shown above for **Example #6**:

$$Q_r = \underline{1.26 \text{ MGD}}$$

$$Q_w = \underline{0.0203 \text{ MGD}}$$

$$\mathbf{F:M} = \underline{0.321 \text{ lb BOD/day/lb MLVSS}}$$

Calculations in S.I. units can be made using the following equations:

- $Q_r = [Q_o(X - X_o) - Q_w X_w] / (X_w - X)$ [sometimes approximated by:
 $= Q_o(X - X_o) / (X_w - X)$] (see discussion in next section of course)
- $Q_w = (1/X_w)[(XV/SRT) - Q_e X_e]$
- $\mathbf{F:M} = (S_o * Q_o) / (\%Vol * X * V)$

Note that these equations are the same as those used for U.S. units except that there is no need to calculate V_{MG} , because volume in m^3 can be used for all of the calculations.

More Detail on the Equations for Q_r and Q_w : Most of the equations presented and used above are rather straightforward application of a loading factor, calculation of detention time as volume divided by flow rate, or the equation follows directly from the units. The sources of the equations for Q_w and Q_r aren't quite as obvious, however, so they are discussed briefly here.

Waste Activated Sludge Flow Rate: The equation for waste activated sludge flow rate, Q_w , is based on the principle that the average length of time activated sludge solids stay in the aeration tank [the sludge retention time (SRT) or sludge age] is equal to the mass of solids in the aeration tank divided by the rate at which solids are being wasted from the system. In equation form:

$$\mathbf{SRT} = \text{lb act. sludge in aeration tank} / (\text{lb act. sludge leaving system/day})$$

$$\mathbf{SRT} = (8.34 * X * V_{MG}) / [(8.34 * X_w * Q_w) + (8.34 * X_e * Q_e)]$$

(Note that the factor 8.34 converts mg/L to lb/MG.)

Units in above equation are: $[(\text{lb/MG}) * \text{MG}] / [(\text{lb/MG}) * \text{MG/day}] = \text{lb}/(\text{lb/day}) = \text{days}$

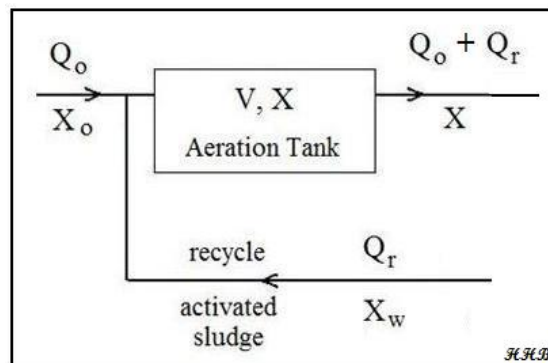
solving for Q_w gives the equation in the list above:

$$Q_w = (1/X_w)[(XV/SRT) - Q_e X_e]$$

Recycle Activated Sludge Flow Rate: An equation for the recycle activated flow rate can be determined by a material balance around the aeration tank. The aeration tank portion of the 'activated sludge parameters' diagram from above is reproduced on the next page. It shows that the inflows to the aeration tank are Q_o with suspended solids concentration of X_o and Q_r with suspended solids concentration of X_w . The outflow from the aeration tank is $Q_o + Q_r$ with suspended solids concentration of X (equal to that in the aeration tank.)

A material balance over the aeration tank must take into account the fact that there is a net growth of activated sludge solids in the aeration tank. The material balance is thus:

Rate of solids outflow – Rate of solids inflow = Growth rate of solids



Aeration Tank Material Balance Diagram

The growth of activated sludge is typically hydraulically controlled with the activated sludge wasting rate and is equal to $Q_w X_w$. The material balance equation thus becomes:

$$(Q_o + Q_r)X - (Q_o X_o + Q_r X_w) = Q_w X_w$$

For S.I. units, the flow rates in the above equation will be in m^3/day and the suspended solids concentrations will be in kg/m^3 , thus giving units of kg/day for each term in the equation.

For U.S. units, the flow rates in the equation will be in MGD and the suspended solids concentrations will be in mg/L. A factor of 8.34 will be needed with each term to convert mg/L to lb/MG, resulting in lb/day for each term. Solving the equation for Q_r , the 8.34 in each term will 'cancel out.'

Through a bit of algebraic manipulation, the equation can be solved for Q_r to give:

$$Q_r = [Q_o(X - X_o) - Q_w X_w] / (X_w - X)$$

The activated sludge wasting rate, Q_w , is typically much less than the influent flow rate, Q_o , so the term $Q_w X_w$ is sometimes dropped out to simplify the equation to:

$$Q_r = Q_o(X - X_o) / (X_w - X)$$

10. Oxygen/Air/Blower Calculations

Oxygen/Air Requirement and Blower Calculations will be made using the "Rule of Thumb" guidelines shown below. These guidelines are made available by Sanitaire, a manufacturer of aeration diffusers. The guidelines shown below can be found at the following website:

www.xylemwatersolutions.com/scs/sweden/sv-se/productter/cirkulationpumps/documents/san3.pdf

Rules of Thumb for Estimating Oxygen/Air Requirements - Coarse or fine Bubble Diffusers:

1. The typical AOR/SOR (or AOTE/SOTE) is 0.50 for a coarse bubble aeration system or 0.33 for a fine bubble aeration system.
2. The typical SOTE is 0.75% per foot (2.46% per m) of diffuser submergence for a coarse bubble system or 2.0% per foot (6.56% per m) of diffuser submergence for a fine bubble system.
3. 1 SCF of air has a density of 0.075 lbf/ft³ (1.20 kg/m³) and contains 23% oxygen by weight, thus: 1 SCF of air contains 0.0173 lbf of oxygen (1SCM contains 0.2770 kg of oxygen).

4. For biological treatment with SRT from 5 to 10 days, mass of oxygen required /mass BOD removed is typically in the range from 0.92 - 1.1 lb O₂/lb BOD (or kg O₂/kg BOD). Higher SRT results in a higher value of mass O₂ required/mass BOD removed.
5. The oxidation of ammonia nitrogen typically requires 4.1 to 4.6 lb of oxygen/lb ammonia Nitrogen oxidized (or kg oxygen/kg ammonia nitrogen oxidized).

Example #8: Calculate the oxygen requirement in lb/hr, the air requirement in SCFM, and the required blower outlet pressure for the wastewater flow used in the previous examples (3.5 MGD wastewater flow with primary effluent BOD of 175 mg/L, primary effluent TKN of 35 mg/L, target effluent BOD of 20 mg/L, and target effluent NH₃-N of 7 mg/L).

Solution: The screenshots shown below and on the next page show an Excel spreadsheet with the solution to this example. The first screenshot shows the wastewater characteristics user inputs needed for the calculation and the second screenshot shows the diffuser parameters/characteristics inputs needed and the calculation of the oxygen requirement, air requirement, and blower outlet pressure needed for BOD removal and for BOD removal and nitrification.

Activated Sludge Waste Water Treatment Calculations - U.S. units			
4. Oxygen Requirement/Blower Sizing Calculations			
Instructions: Enter values in blue boxes. Spreadsheet calculates values in yellow boxes			
Values Transferred from Previous Worksheets:			
Design ww Flow Rate, Q_o =	3.5	MGD	Prim. Effl. BOD, S_o = 175 mg/L
Additional User Inputs:			
Influent TKN, TKN_o =	35	mg/L	Target Effl NH ₄ -N conc, N_e = 0.50 mg/L
	(needed only if nitrification is to be achieved)		(needed only if nitrification is to be achieved)
Target Effluent BOD, S_e =	20	mg/L	

Screenshot of Spreadsheet Solution to **Example #8** – Part 1

The user inputs shown in the first screenshot are those specified in the problem, wastewater flow rate, Q_o = 3.5 MGD; primary effluent BOD, S_o = 175 mg/L; primary

effluent TKN, $TKN_o = 35$ mg/L; target effluent BOD, $S_e = 20$ mg/L and target effluent NH_3-N , $N_e = 7$ mg/L.

In the second screenshot, oxygen and air requirements are calculated for BOD removal only and for BOD removal and nitrification. Operating conditions will determine whether nitrification takes place or doesn't take place. Both BOD removal and nitrification are carried out by aerobic microorganisms, but it is a different set of microorganisms for each. The nitrifying microorganisms are favored by higher temperatures and higher oxygen concentration in the aeration tank. Thus, at low temperatures and/or relatively low oxygen concentrations, BOD removal will still take place but little nitrification will occur. The optimum D.O. level for nitrification is 3.0 mg/L, significant nitrification still occurs for D.O. levels between 2.0 and 3.0 mg/L, and nitrification ceases for D.O. below 0.5 mg/L. The optimum temperature range for nitrification is between 28°C and 32°C, at 16°C, the nitrification rate is about half of that at 30°C. Below 10°C, the nitrification rate is decreased significantly.

A. Simplified Estimates Using "Rules of Thumb" - See Notes at Right					
1. Inputs: (Values of "Rule of Thumb" Constants to be used in Calculations - See notes at right)					
O ₂ needed per lb BOD =	1.20	lb O ₂ /lb BOD	Depth of Diffusers =	12.0	ft
O ₂ needed per lb NH ₃ -N =	4.57	lb O ₂ /lb NH ₃ -N	Standard Temperature =	68	°F
SOTE as Function of Depth =	2.00%	% per ft depth	Standard Pressure =	14.7	psi
AOTE/SOTE =	0.33		Atmospheric Pressure =	14.7	psi
Press. Drop across Diffuser = (from mfr/vendor)	12.0	in W.C.	Air Density at STP =	0.075	lbm/SCF
			O ₂ Content in Air =	0.017	lbm/SCF
2. Calculations for BOD Removal Only:					
BOD Daily Loading =	188.5	lb/hr	AOTE =	7.9%	
Oxygen Requirement =	226.2	lb/hr	Air Requirement =	2751.8	SCFM
SOTE =	24.0%		Blower Outlet Pressure =	20.3	psia
3. Calculations for BOD Removal and Nitrification:					
NH ₃ -N Daily Loading =	42.0	lb/hr	AOTE =	7.9%	
Oxygen Requirement =	418.0	lb/hr	Air Requirement =	5084.4	SCFM
SOTE =	24.0%		Blower Outlet Pressure =	20.3	psia

Screenshot of Spreadsheet Solution to **Example #8** – Part 2

The equations for making the oxygen/air/blower calculations shown in the above screenshot are as follows:

$$\text{BOD Removal Rate} = Q_0 \cdot (S_0 - S_e)$$

$$\text{NH}_3\text{-N Removal Rate} = Q_0 \cdot (\text{TKNo} - N_e)$$

$$\text{O}_2 \text{ Requirement} = (\text{BOD Rem. Rate})(\text{lb O}_2/\text{lb BOD}) + (\text{NH}_3\text{-N Rem. Rate})(\text{lb O}_2/\text{lb NH}_3\text{-N})$$

$$\text{SOTE} = (\text{SOTE \%}/\text{ft depth})(\text{Diffuser Depth})$$

$$\text{AOTE} = \text{SOTE}(\text{AOTE}/\text{SOTE})$$

$$\text{Air Requirement} = (\text{O}_2 \text{ requirement}/\text{AOTE})/(\text{O}_2 \text{ Content in Air})$$

$$\text{Blower Outlet Pressure} = P_{\text{atm}} + \text{Press. Drop across Diffuser} + \square_{\text{air}}(\text{Diffuser Depth})$$

The calculated results for **Example #8**, as shown in **Figure 13** are as follows:

For operating conditions in which only BOD removal will take place:

$$\text{Oxygen Requirement} = \mathbf{226.2 \text{ lb/hr}}$$

$$\text{Air Requirement} = \mathbf{2751.8 \text{ SCFM}}$$

$$\text{Blower Outlet Pressure} = \mathbf{20.3 \text{ psi}}$$

For operating conditions in which BOD removal and nitrification will take place:

$$\text{Oxygen Requirement} = \mathbf{418.0 \text{ lb/hr}}$$

$$\text{Air Requirement} = \mathbf{5084.4 \text{ SCFM}}$$

$$\text{Blower Outlet Pressure} = \mathbf{20.3 \text{ psi}}$$

11. Summary

Extended aeration, contact stabilization, completely mixed activated sludge, and conventional activated sludge are variations of the widely used activated sludge process for biological wastewater treatment. Flow diagrams for these processes were presented along with discussion of the general characteristics of each of them. The parameters and equations used for activated sludge aeration tank design and operational calculations were presented, discussed and illustrated with example calculations for both U.S. and

S.I. units. Example solutions using an Excel spreadsheet were also presented and discussed.

12. References

1. Metcalf & Eddy, Inc, (revised by Tchobanoglous, G, Burton, F.L., Stensel, H.D., *Wastewater Engineering Treatment and Reuse*, 4th Edition, New York, NY, 2003.
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