L8. Biological Wastewater Treatment

Based on Dr. Fahid Rabah lecture notes
Biological waste water treatment

1. It is a type of waste water treatment in which microorganisms such as bacteria are used to remove pollutants from waste water through bio-chemical reaction.

**Classification of biological Waste water methods**

- **Suspended and attached treatment**
  - **Suspended growth process** is a biological w.w.t in which microorganisms are maintained in suspension while converting organic matter to gases and cell tissue (Activated sludge).
  - **Attached growth** is a biological w.w.t in which microorganisms responsible for the conversion of organic matter to gases and cell tissue are attached to some inert material such as rocks, sand, or plastic (Trickling filter).

- **Aerobic and anaerobic**
  - **Aerobic**: biological treatment is a process in which the pollutants in the waste water (organic matter) are stabilized by microorganisms in the **presence** of molecular oxygen.
  - **Anaerobic**: biological treatment is a process in which the pollutants in the waste water (organic matter) are stabilized by microorganisms in the **absence** of molecular oxygen.
Activated Sludge System

Process Description:

• It is aerobic suspended growth biological wastewater treatment method in which dissolved organic and inorganic matter can be removed. Some of the suspended and colloidal matter can also be removed indirectly by sticking to the slime bacteria.

• This treatment is achieved in tanks called aeration tanks. Oxygen is supplied to these tanks to allow aerobic biochemical reaction to occur.

• In the aeration tank, the microorganisms feed on dissolved solids mainly organic matter and produce large amounts of bacteria (colonies). This means that microorganisms convert dissolved solids into suspended solids (the bacterial colonies).

• After the aeration tank, a secondary sedimentation tank is installed to separate the bacteria from liquid.

• The separated bacteria is called activated sludge. Part of the sludge is wasted and the remaining part is returned back (Recycle) to the aeration tank. The recycle of the sludge to aeration tank is very important to keep a specific concentration of the bacteria in the system to perform wastewater treatment.

• The mixture of wastewater with bacteria in the aeration tank is called mixed liquor suspended solids (MLSS)
Principal of activated sludge

\[ Q, S_0 \]

\[ \text{Aerated Tank} \]
\[ X, S, V \]

\[ (Q + Q_r) \]

\[ \text{Secondary Sedimentation Tank} \]
\[ (Q - Q_r) \]
\[ S, X_e \]

Recycle \[ Q_r, X, S \]

\[ Q_w, X_r \]

\[ Q = \text{waste water flow rate} \]
\[ X = \text{the mixed liquor suspended solids concentration (MLSS) bacteria concentration} \]
\[ X_r = \text{concentration of recycled activated sludge} \]
\[ X_e = \text{effluent suspended solids concentration} \]
\[ Q_w = \text{waste sludge flow rate} \]
\[ Q_r = \text{return sludge flow rate} \]
\[ V = \text{volume of the aerated tank} \]

\[ S_0 = \text{concentration of dissolved pollutants such as BOD} \]
\[ S = \text{concentration of dissolved pollutants in the aerated tank and the effluent} \]
\[ V = \text{volume of the aerated tank} \]
\[ Y = \text{growth rate of the bacteria} \]
\[ \theta = \text{the hydraulic retention time} \]
\[ \theta_c = \text{Sludge age (sludge retention time)} \]
\[ k_d = \text{decay rate of the bacteria} \]
\[ \frac{F}{M} = \text{food to microorganism ratio} \]
Principal of activated sludge

\[ X = \frac{YQ\theta_c(S_o - S)}{V(1 + kd\theta_c)} \quad \theta = \frac{V}{Q} \quad \theta_c = \frac{XY}{Q_wX_r + (Q - Q_w)X_e} \]

\[ Q_r = Q\left\{ \frac{X}{X_r - X} \right\} \]

- **Q** = waste water flow rate
- **X** = the mixed liquor suspended solids concentration (MLSS) bacteria concentration
- **X_r** = concentration of recycled activated sludge
- **X_e** = effluent suspended solids concentration
- **Q_w** = waste sludge flow rate
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- **S_o** = concentration of dissolved pollutants such as BOD
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- **V** = volume of the aerated tank
- **Y** = growth rate of the bacteria
- **\theta** = the hydraulic retention time
- **\theta_c** = Sludge age (sludge retention time)
- **kd** = decay rate of the bacteria
- **F/M** = food to microorganism ratio
Example 1
Design an activated sludge process to yield an effluent BOD of 20 mg/l and suspended solids of 25 mg/l. The influent BOD following primary clarification is 160 mg/l. Assume Y= 0.65, $K_d = 0.05$ and sludge retention time 10 days. The waste flow is 10 m$^3$/min.

Solution
The BOD of the effluent solids can be estimated to be 0.63 (SS). The soluble effluent BOD must thus be reduced to $20 - 0.63(25) = 4$ mg/l.

The total biological mass is

$$VX = \frac{YQ\theta_c(S_o - S)}{(1 + k_d\theta_c)} = \frac{0.65(10^4 \times 1440)(10)(160 - 4)}{(1 + (0.05 \times 10))} = 9.73 \times 10^9 \text{ mg}$$

Assuming the mixed liquor volatile suspended solids concentration (X) = 2500 mg/l

$$V = \frac{9.73 \times 10^9}{2500} = 3.894 \times 10^6 \text{ L} = 3894 \text{ m}^3$$

The rate of sludge production is obtained from

$$\frac{dx}{dt} = \frac{VX}{\theta_c} \frac{9.73 \times 10^9}{10} = \text{mg / day} = 973.5 \text{ kg / day}$$
Assuming the solids are 80% volatile, total production would be \( \frac{973.5}{0.8} = 1217 \text{ kg/day} \)

The underflow solids concentration is unlikely to exceed 15,000 mg/l and could be less.

Assume \( X_r = 15,000 \text{ mg/l} \)

\[ Q_w = \text{total sludge production rate} / \text{Solid concentration} = \frac{1217 \times 10^6 \text{ mg/day}}{15 \times 10^3 \text{ mg/l}} = 81.1 m^3 / \text{day} \]

\[ Q_r = \frac{QX}{X_r - X} = \frac{10(2500)}{12500} = 2 m^3 / \text{min} \]

The hydraulic retention time in the reactor is

\[ t = \frac{V}{Q} = \frac{3.894 \times 10^3}{14400} = 0.27 \text{ days} = 6.5 \text{ hours} \]
The required amount of oxygen which must be provided in suspended growth process is equal to the difference between the ultimate BOD of the waste which is removed and the ultimate BOD of the solids which are wasted. For ordinary domestic sewage this may be taken as equal to: 

$$O_2 \text{ demand} = 1.47 \ (S_0 - S)Q - 1.14X_r \ (Q_w)$$

$$O_2 \text{ demand} = 1.47(160 - 4)(14.4 \times 10^6) - 1.14(15,000)(81,100)$$

$$= 1.915 \times 10^9 \text{ mg/day} = 1915 \text{ kg/day}$$

Calculate the volume of air to be supplied:-

- At standard conditions i.e \( T = 20 \degree \text{C} \), pressure = 1 atm, air density = 1.185 kg/m\(^3\)
- % oxygen by mass in air = 23.2%.
- Assuming 100% oxygen transfer efficiency:

$$Q_{\text{air}} = \frac{R_0}{\rho_{\text{air}} \times [O_2 \%]} = \frac{1915 \text{ kg}O_2 / d}{1.185 \text{ kg/m}^3 \times 0.232} = 6965.7 \text{ m}^3 \text{ air / d}$$

- Assume 7% oxygen transfer efficiency:-

$$Q_{\text{air}} = \frac{6965.7}{0.07} \approx 99510 \text{ m}^3 \text{ air / d}$$
Principal of Trickling Filter

1. Trickling filter is an aerobic attached growth biological system

2. The major components of the trickling filter are:
   - The tank
   - Rotary distributor
   - Filter media (crushed stones, gravel, plastic)
   - Under drain system
   - Ventilation

3. Biological process
   - The bacteria is attached to the filter media forming a biological layer called also bio-film
   - Sprinkled wastewater over the filter media forms liquid film including food and dissolved oxygen.
   - The bacteria (bio-film) absorbs the organic matter and oxidized it producing CO₂, H₂O, NH₃ and new cell
   - The biological layer consists of aerobic and anaerobic partitions.
   - When the mass of the bio-film increase the lower layer will be anaerobic with lower food supply which will lead to the decrease of the attaching force between the bio-film and the filter media. In this case the bio-film is sloughed out (disconnected) and flows out with the wastewater to the final sedimentation tank where it settles.
Types of trickling filters

- Low rate T.F
- High rate T.F
  - One Stage
  - Two Stage
    - With intermediate clarifier
    - Without intermediate clarifier
Low Rate Trickling Filter

• No recycle (the only return flow occurs from the final clarifier to the wet well to be pumped to the primary clarifier to be settled there.
• Typical BOD loading rate is 250 g/m$^3$.day only which is very low.
• It is not feasible for new construction and most plants with existing low rate T.F are converting them to high rate T.F.

High Rate Trickling Filter

• Recycle is used to increase the efficiency of treatment. Different ways of recycle are used.
• Typical BOD loading is 500-1500 g/m$^3$.day for one stage T.F and 700-1100 g/m$^3$.day for two stages
• It is feasible for new construction
BOD Removal Efficiency

The BOD removal Efficiency in T.F is calculated using different imperial formulas.

A) For first stage T.F:

\[ E = \frac{100}{1 + 0.443 \left( \frac{BOD\text{Load}}{F} \right)^{0.5}} \]

\[ F = \frac{1 + R}{(1 + 0.1R)^2} \]

E = BOD removal efficiency
R = Recycle Ratio

Figure 1: Efficiency curve for single stage rock filled trickling filter treating wastewater at 20°C based on NRC data
Diagram for correcting BOD removal efficiency from NRC at 20°C to efficiency to another temperatures between 12oC and 28oC

Trickling filter efficiency at T°C percent

Trickling filter efficiency at 20°C percent

Diagram for correcting BOD removal efficiency from NRC at 20°C to efficiency to another temperatures between 12oC and 28oC
B) For Second stage T.F:

Second Stage (SS) BOD load adjusted

\[ \text{Adjusted SS BOD load} = \frac{\text{Actual SS BOD load}}{\left\{100 - \%\text{ of first stage efficiency} \right\}/100} \]

Note: Actual SS BOD load = \( Q \times \text{BOD of settled WW} / \text{volume of filter media} \)

- BOD settled = BOD coming out from the first stage T.F or from the intermediate clarifier.
- After calculating the SS BOD load adjusted for treatability.

- Overall treatment efficiency

\[ E = 100 - 100 \left\{ \left(1 - \frac{35}{100}\right) \left(1 - \frac{E_1}{100}\right) \left(1 - \frac{E_2}{100}\right) \right\} \]
Efficiency curve for second stage trickling filter based on NRC

BOD load (g/m³/day)

Efficiency percent BOD removal
Example 2

Design a one stage high rate trickling filter to produce a BOD effluent of 50 mg/L. given the following data:

\[ Q = 10,000 \text{ m}^3/\text{d} \]

Influent BOD = 400 mg/L

Temperature (T) = 20 °C

Primary sedimentation tanks will be used before the trickling filter

Solution

To design trickling filter the following things should be found:

• The volume of the filter media
• The depth of the filter media
• The surface area of the trickling filter
• The recycle value (R)
BOD entering T.F = 0.67 x 400 = 268 mg/L

BOD load to the trickling filter = 10,000 x 268 x 10^{-6} x 10^3 = 2680 kg BOD/d

The required efficiency of the T.F is:

\[ E = \frac{268 - 50}{268} = 0.813 \quad = 81.3\% \]

Go to figure (), the 81.3\% efficiency can be achieved by following combinations:

R = 1.0 \quad \text{BOD load} = 500 \text{ g BOD/m}^3\text{.d}

R = 2.0 \quad \text{BOD load} = 620 \text{ g BOD/m}^3\text{.d}

R = 3.0 \quad \text{BOD load} = 700 \text{ g BOD/m}^3\text{.d}

Note: any recycle (R) less than 1.0 is not accepted to achieve 81.3\% efficiency because it will give a BOD load less than 500 gBOD/m^3.d while the accepted range for one stage high rate trickling filter is 500 – 1500 g BOD/m^3.d

So use R = 2.0 \quad \text{BOD load} = 620 \text{ g BOD/m}^3\text{.d}

Volume of the filter media = Daily BOD load / volumetric BOD load

\[ = 2680 \times 10^3 / 620 \quad = 4323 \text{ m}^3 \]

The surface loading rate \ (Typical range 10-30 m^3/m^2.d). Take it as 20 m^3/m^2.d
QTS = Q + RQ = 3Q
RQ = Q'R + QR = 2Q

So the surface area = \(3 \times 10,000 / 20 = 1500\) m²

Assume that we want to use on T.F only, so the diameter of T.F is \(\pi D^2 / 4 = 1500\), \(D = 43.7\) m

The max diameter should not exceed 35 m

So we use 2 Trickling filters each has

\[ D = \{(1500/2)\times4/T\}^{0.5} = 31\] m

The volume of each = \(4323/2 = 2161.5\) m³

The area of each T.F = \(\pi (31)^2 / 4 = 755\) m²

The depth of each = \(2161.5/ 755 = 2.86\) m

Standard depth range 1.5 to 3.5 m

The layout of the treatment plant is two parallel lines

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