Unit 5. Sludge treatment

Based on Dr. Fahid Rabah lecture notes
**Sludge definition:**

Sludge is made of solid materials separated from the water line during wastewater treatment. In addition to solids, sludge contains a high percent of water.

**Sludge sources:**

In wastewater treatment sludge is classified into the following types:

A. **Grit sludge:**
   It is all the solids collected in the grit removal chamber, because grit can be easily drained and is relatively stable in terms of biological activity, it does not need treatment and is generally disposed directly to landfills.
B. **Primary or raw sludge:**
Primary sludge is the sludge taken from the bottom of the primary settling tanks. It contains from 3-8% solids \((1\% \equiv 10,000 \frac{mg}{L})\). This sludge is composed of settleable raw solids. **Almost 7% of the primary sludge is organic.**

C. **Secondary Sludge:**
This sludge consists of microorganisms and inert materials that has been wasted from the secondary treatment processes. Thus 9% of this sludge is organic this sludge contains from 0.8 to 2% solids \((i.e. \ 8,000 – 20,000 \frac{mg}{L})\).
Sludge quantities:

A. **Primary sludge:**
The quantity of primary sludge is calculated using the following equation:

\[ M_p = E \cdot ss \cdot Q_{in} \]  

Where,

\[ M_p = \text{mass of primary sludge}, \quad \frac{kg}{d} \]

\[ ss = \text{suspended solids in the influent}, \quad \frac{kg}{m^3} \]

\[ E = \text{efficiency of primary sedimentation tank} \rightarrow \text{taken from (Figure (1))} \]

\[ Q_{in} = \text{influent flow to primary sedimentation tank}, \quad \frac{m^3}{d} \].
To convert the sludge quantity from $\frac{kg}{d}$ to $\frac{m^3}{d}$:

$$Q_p = \frac{M_p}{X_p} \ \ \ \ \ \ \ \ (2)$$

$Q_p =$ flow rate of primary sludge, $\frac{m^3}{d}$.

$X_p =$ concentration of solids in primary sludge, $\frac{kg}{m^3}$.

$$X_p = \rho_{sludge} \cdot S \ \ \ \ \ \ \ \ (3)$$

where,

$$\rho_{sludge} = sludge \ density, \ \frac{kg}{m^3} \ (usually \ taken \ as \ \rho_{water} = 1000 \ \frac{kg}{m^3} \ unless \ given)$$

$S =$ solids fraction in sludge expressed as decimal fraction (i.e. $0.05 = 5\%$).
Example 1:-

Determine the quantity of primary sludge both in $\frac{kg}{d}$ and $m^3/d$, given the following:-

SS = 700 mg/l

$Q_{in} = 2000 m^3/hr$

S = 5% dry solids in the sludge.

D = 36 m (diameter of primary sedimentation tank)
Solution:-

a) find the overflow rate to the primary sedimentation tank:

\[ O/F = \frac{Q_{in}}{A} \]

\[ A = \frac{\pi D^2}{4} = \frac{\pi \times 36^2}{4} \approx 1018 \, m^2 \]

\[ O/F = \frac{2000 \, m^3 \cdot hr}{1018 \, m^2 \cdot d} \cdot \frac{1}{24 \, hr} = 47 \, \frac{m^3}{m^2 \cdot d} = 47 \, \frac{m}{d} \]

b) Find the sedimentation efficiency (E):

from figure (1), \( E = 54\% \)
c) Calculate sludge quantity:

\[ M_P = E \times SS \times Q_{in} \]

\[ SS = 700 \frac{mg}{L} \times 10^3 \frac{L}{m^3} \times \frac{kg}{10^6 mg} = 0.7 \frac{Kg}{m^3} \]

\[ Q_{in} = 2000 \frac{m^3}{hr} \times \frac{24 hr}{d} = 48000 \frac{m^3}{d} \]

\[ M_P = 0.54 \times 0.7 \frac{Kg}{m^3} \times 48000 \frac{m^3}{d} = 18144 \frac{Kg}{d} \]

\[ Q_P = \frac{M_P}{X_P} \]

\[ X_P = \rho_{SL} \times S = 1000 \frac{Kg}{m^3} \times 0.05 = 50 \frac{Kg}{m^3} \]

\[ Q_P = \frac{18144 Kg}{d} \times \frac{m^3}{50 Kg} \approx 363 \frac{m^3}{d} \]
b) Secondary sludge quantities:-

Secondary sludge quantities were discussed previously in the suspended growth treatment:-

\[ P_x = \text{sludge production } \frac{kg}{d} = \frac{XV}{\theta_c} \]

\[ Q_w = \frac{P_x}{X_r}, \text{sludge production in } \frac{m^3}{d} \]

For more details on these quantities return to chapters 3 and 4.
sludge treatment:-

The main goal of sludge treatment is to convert it to an inert solid product that can be safely disposed in the environment or reused for useful purposes.

The main sludge treatment steps are-
   a. Sludge thickening.
   b. Sludge stabilization.
   c. Sludge dewatering.

In the following section, a detailed discussion of these treatment steps is given.
**Sludge thickening:-**

The main goal of sludge thickening is to reduce the sludge volume by removing as much as possible of the water content of sludge, leading to the increase of the solids content of sludge. Thickening is achieved by the following three methods:-

a) **Gravity thickening:-**

Gravity thickening is achieved in circular tanks similar to sedimentation tanks. Sludge is allowed to settle and compact. The thickened sludge is withdrawn from the bottom of the thickener. To improve thickening some chemicals are added, this process is called sludge conditioning. Sludge conditioning is discussed below.
b) Flotation thickeners:-

For sludges with low weights, gravity thickeners are not efficient. In this case, the sludge floats on the surface and than removed by scum removal arms.

c) Mechanical thickening:-

Mechanical thickeners include centrifuges, rotary drums and filter belts. The centrifuges and rotary drums use the centrifugal force to separate solids from liquids.

Filter belts are squeezing machines in which the sludge is inserted between two moving belts resulting in the separation of solids from liquids.
Sludge conditioning:-

Sludge conditioning is a pretreatment step to increase the efficiency of sludge thickening and dewatering of sludge. The two most common methods of sludge conditioning are:-

a) **Chemical conditioning:-**

- Addition of lime Ca (OH)$_2$.
- Addition of ferric chloride Fe cl$_3$
- Addition of alum AL$_2$ (SO$_4$)$_3$.
- Addition of organic polymers.

These chemicals are coagulants as they neutralize and destabilize the electrically charged particles in the water and allow them to settle efficiently.
• Organic polymers replace Fe\text{cl}_3 and AL_2 (SO_4)_3 salts in order to overcome the major problems involved with these inorganic chemicals.

Advantages of organic polymers over inorganic chemicals are:-

• Dosage is around 10 times lower than that of inorganic chemicals (typical dosage is 5-10 kg/ ton_{sludge})

• Cost saving obtained in capital cost and running cost.

• Treated sludge does not contain inorganic chemical such as Fe^{3+} and AL^{3+}. 
**b) Heat treatment:-**

Heat treatment is a conditioning process that involves heating of sludge for short periods of time under pressure. By heat treatment, the structure of sludge flocks is altered to liberate more water from particles. The high capital cost of equipment limit the use of this method to small treatment plants only.
Design of gravity thickeners:-
Primary and secondary sludge are either treated in separate thickeners or in one common thickener. The following table gives the design criteria for gravity thickeners according to the sludge source:-

<table>
<thead>
<tr>
<th>Sludge source</th>
<th>Influent S (%)</th>
<th>Expected under flow S (%)</th>
<th>Mass loading kg/d.m²</th>
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<tbody>
<tr>
<td>- Separate sludges</td>
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<tr>
<td>PS ...............</td>
<td>2-7</td>
<td>5-10</td>
<td>100-150</td>
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<tr>
<td>TF ...............</td>
<td>1-4</td>
<td>3-6</td>
<td>40-50</td>
</tr>
<tr>
<td>RBC .............</td>
<td>1-3.5</td>
<td>2-5</td>
<td>35-50</td>
</tr>
<tr>
<td>WAS...............</td>
<td>0.5-1.5</td>
<td>2-3</td>
<td>20-40</td>
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<tr>
<td>- Combined Sludges</td>
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<tr>
<td>PS + WAS .......</td>
<td>0.5-4</td>
<td>4-7</td>
<td>25-70</td>
</tr>
<tr>
<td>PS + TF .........</td>
<td>2-6</td>
<td>5-9</td>
<td>60-100</td>
</tr>
<tr>
<td>PS + RBC ........</td>
<td>2-6</td>
<td>5-8</td>
<td>50-90</td>
</tr>
</tbody>
</table>

**Note:** PS = primary sludge., TF = Trickling filter sludge, RBC = Rotating biological contactor sludge, WAS = Waste activated sludge.
- The area of the thickener is determined using the mass loading criteria according to the sludge source as shown in the above table.
- The depth of the thickener is determined as follows.
  As shown in Figure (4), the thickener depth is divided to the following regions:

\[ h_1 = \text{free board depth above sludge surface, typically taken as 0.6m.} \]
\[ h_2 = \text{clear liquid zone, typically taken as 1.0m.} \]
\[ h_3 = \text{settling zone, typically taken as 1.5m.} \]
\[ h_4 = \text{Thickening zone, it is a sludge storage region and have to be calculated as shown later.} \]
So, the thickener side wall depth (H) is calculated as:
\[ H = h_1 + h_2 + h_3 + h_4 \]
The depth at the center of the thickener is calculated by adding (H) to \( h_5 \):
\[ h_5 = \frac{d}{16}, \quad d = \text{thickener diameter}. \]
To calculate (\( h_4 \)), the thickening zone height, we assume that this zone has a volume enough to store one day thickened sludge. So the total solids interring the thickener will accumulate in this zone but the concentration of solids in the thickened zone will be much more than that in the sludge interring the thickener so, to calculate (\( h_4 \)):
\[ V_{TZ} = A_T \cdot h_4 \]
\( V_{TZ} = \text{Volume of sludge in the thickening zone, m}^3 \)
\( A_T = \text{Surface area of the thickener, m}^2 \)
\[ V_{TZ} = \frac{(m_T)_{in}}{(X_T)_{out}} \quad \text{............6} \]
\( (m_T)_{in} = (M_T)_{in} \cdot t \quad \text{............7} \)
\( (X_T)_{out} = (\rho_{SL})_T \cdot (S_T)_{out} \quad \text{............8} \)
\((m_T)_{in} = \text{mass of sludge dry solids accumulated in the thickening zone, (kg)}\)

\((M_T)_{in} = \text{mass of sludge dry solids interring the thickener per day,}\ \frac{Kg}{d}\)

t = \text{time, days.}\)

\((X_T)_{out} = \text{concentration of solids in sludge in the thickening zone and in the thickening zone and in the thickened sludge coming out of the thickener, (kg/m}^3\))

\((\rho_{SL})_T = \text{density of thickened sludge, (kg/m}^3\))

\((S_T)_{out} = \text{concentration of solids in the thickened sludge expressed as decimal fraction.}\)

Combine equations (4) and (6) and solve for \(h_4:\)

\[
h_4 = \frac{(m_T)_{in}}{A_T (X_T)_{out}} \quad .............(9)\]
**Example (2):**

Design a gravity thickener to treat a combined primary and activated sludge. The following data is given:

**Primary sludge:**

\[ Q_p = 500 \, m^3/d, \rho_{SL} = 1100 \, \frac{kg}{m^3}, S = 5\% \]

**Secondary sludge (activated sludge):**

\[ Q_s = 150 \, m^3/d, \rho_{SL} = 1040 \, \frac{kg}{m^3}, S = 1\% \]

**Thickener design criteria:**
- \( L_S = \) solids loading rate = 50 kg/m\(^2\).d (assumed)
- Thickened sludge concentration (\( S_{Tout} \)) = 7\%
  \( (\rho_{SL})_T \) = density of thickened sludge = 1120 kg/m\(^3\)
Solution:-

1) calculate \((M_T)_\text{in}\), \((m_T)_\text{in}\):-

\[ (M_T)_\text{in} = M_p + M_S \]

\[ M_p = Q_p \cdot X_p = Q_p \cdot \rho_{sl} \cdot S = 500 \frac{m^3}{d} \cdot 1100 \frac{kg}{m^3} \cdot 0.05 = 27500 \frac{kg}{d} \]

\[ M_S = Q_s \cdot X_s = Q_s \cdot \rho_{sl} \cdot S = 150 \frac{m^3}{d} \cdot 1040 \frac{kg}{m^3} \cdot 0.01 = 1560 \frac{kg}{d} \]

\[ (M_T)_\text{in} = 27500 \frac{kg}{d} + 1560 \frac{kg}{d} = 29060 \frac{kg}{d} \]

2) calculate the area of the thickener "\(A_T\)":-

\[ A_T = \frac{(M_T)_\text{in}}{L_S} \cdot \frac{29060 kg/d}{50 kg/m^2 \cdot d} = 581 m^2 \]

\[ (m_T)_\text{in} = (M_T)_\text{in} \cdot t = 29060 \frac{kg}{d} \cdot 1d = 29060 kg \]

Note: \(t\) is always one day for the design of thickener
- Find the diameter:

\[ d = \sqrt{\frac{4}{\pi} A_T} = \sqrt{\frac{4}{\pi} \cdot 581} = 27.2 \text{ m} > 20 \text{ m} \ (not \ o.k) \]

(note:- the maximum diameter for thickeners is 20m)

Use two thickeners:

Area of each thickener = \[ \frac{581}{2} = 291 \text{ m}^2 \]

\[ d = \sqrt{\frac{4}{\pi} \cdot 291} = 19 \text{ m} < 20 \text{ m} \quad o.k \]

3) calculate the depth of each thickener:-
\[ h_4 = \frac{(m_t)_{in}}{A_T (X_T)_{out}} \]

\[ (X_T)_{out} = (\rho_{sl})_T (S_T)_{out} = 1120 \frac{kg}{m^3} \times 0.07 = 78.4 \frac{kg}{m^3} \]

\[ (m_T)_{in} = \frac{29060}{2} = 14530 \text{ kg} \]

\[ h_4 = \frac{14530 \text{ kg}}{291 m^2 \times 78.4 \frac{kg}{m^3}} = 0.64 m, \text{ say } 0.65 m \]

\[ h_5 = \frac{d}{16} = \frac{19}{16} = 1.19 m, \text{ say } 1.2 m \]

Side wall depth:
\[ H = h_1 + h_2 + h_3 + h_4 = 0.6 + 1.0 + 1.5 + 0.65 = 3.75 m \]
Depth at the center = 3.75 + 1.2 = 4.95 m = \( H_C \)
4) Calculate the reduction of sludge volume:

\[ Q_T = \frac{(M_T)_{out}}{(X_T)_{out}} = \frac{29060/2}{78.4} = 185 \text{ m}^3 / \text{d} \]

\[ (Q_w)_{\text{Removed}} = Q_p + Q_s - Q_T = \{(500+150)/2 - 185\} \text{ m}^3 / \text{d} = 140 \text{ m}^3 / \text{d} \]

\[ \% \text{ reduction} = \frac{(Q_w)_{\text{Removed}}}{(Q_p + Q_s)} \cdot 100 = \frac{140}{(500+150)/2} \cdot 100 = 43\% \]
**sludge stabilization:-**

Sludge stabilization is the process in which the biodegradable organic matter is converted to non-biodegradable (or inert) matter.

The main purpose of this process is to produce a sludge that will not undergo any further decomposition when disposed to the environment (i.e stable sludge).

If sludge is disposed without stabilization it will create bad odor and health hazards.

The most common method used for sludge stabilization is the anaerobic digestion.

This process is achieved in a closed anaerobic tank called digester.

The digester shown is a cylindrical tank with a conical shaped bottom. It is an anaerobic completely mixed reactor.
The cover of the digester is a floating cover to give flexibility for gas accumulation and to prevent explosion.

The sludge in the digester is heated to 35°C to give the best digestion efficiency.

The digested organic matter is converted into gases such as methane (CH₄), carbon dioxide (CO₂) and (H₂O).

The produced methane is collected and used for energy production.
Sludge transformed to $H_2$ and $CH_3COOH$ by fermentation

\[ *CO_2 + 4 H_2 \rightarrow CH_4 + 2 H_2O \]
\[ *CH_3COOH \rightarrow CH_4 + CO_2 \]
Cross section through a typical standard rate digester

**Solids reduction in digesters:**
The solids in the sludge interring to the digester is classified as follows:

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From this classification, we understand that the solids reduction will be performed only on the biodegradable portion of the organic matter, while the inorganic and the non-biodegradable portions will leave the digester without reduction.
**Anaerobic digester design:**

The volume of the digester is determined based on the sludge detention time ($\theta_c$) using the following relation:

$$V = Q_{in} \theta_c \quad \ldots \ldots (10)$$

and ($\theta_c$) is selected in the range of 15-20 days based on the percent of organic matter destruction. The following equation is used to calculate the percent reduction as a function of ($\theta_c$):

$$R_s = 13.7 \ln (\theta_c) + 18.9 \quad \ldots \ldots (11)$$

Where:

$$R_s = \text{percent Reduction of organic matter,}\%$$

$$\theta_c = \text{sludge detention time, days.}$$
The diameter of the digester is typically in the range 5-20m.

The sidewall depth should not be less than 8m because of mixing difficulties in shallow tank, and maximum sidewall depth is 15m.

The floor of the digester is usually conical with a bottom slope of 1:6.

The rate of gas production in digesters is typically taken as 0.5 m$^3$ gas for each "kg" organic matter destroyed.

The percent of methane is approximately 65% of the total gas production.

The produced gas is collected from the top of the digester and passed through a water tank in which CO$_2$ and H$_2$S and other gases are dissolved while CH$_4$ (methane) is collected again and stored in a cylindrical tank called gas holder.

Then, methane is used for power generation that can be used in the wastewater treatment to operate the electrical equipments.
Example (3):-

Anaerobic digester is to be designed to treat a thickened sludge having the following data:-

\[ Q_T = 370 \text{ m}^3/\text{d}, \ S = 7\%, \ M_T = 29060 \text{ kg/d}, \ S.G = 1.12 \]

\[ \theta_c = 20 \text{ days}, \ 70\% \text{ of } M_T \text{ is organic}, \ S.G = 1.05 \text{ after digestion.} \]

1) **Calculate the required digester volume:-**

\[ V = Q_T \cdot \theta_c = (370 \text{ m}^3/\text{d}) \cdot 20 \text{ day} = 7400 \text{ m}^3 \]

This volume dose not include the volume of the conical volume at the bottom. Assume the sidewall height
H = 8m, So the surface area \( A_s = \frac{V}{H} \)

\[
A_s = \frac{7400}{8} = 925 \, m^2
\]

\[
d = \sqrt{\frac{925 \times 4}{\pi}} = 34 \, m > 20 \, m \text{ not ok}
\]
So we can either increase the depth "H" to a value in the range of 8-15m, or we can use two digesters.

Let us first try to increase H to 15m:

$$So \Rightarrow A_s = \frac{7400}{15} = 493 \text{ m}^2$$

$$d = \sqrt{\frac{493 \times 4}{\pi}} = 25 \text{ m} > 20 \text{ m \ not. ok},$$

so let us use 2 digesters.
So ⇒ \[ Q_T = \frac{370}{2} = 185 \, m^3/d \] (for each digester)

\[ V = Q_T \cdot \theta_c = (185 \, m^3/d) \cdot 20 = 3700 \, m^3 \]

assum \( H = 15 \, m \)

\[ A_s = \frac{3700}{15} \approx 247 \, m^2 \]

\[ d = \sqrt{\frac{247 \cdot 4}{T}} = 17.7 \, m, \text{ say} 18 \, m \]
Slope = 1:6

0.5 m free beard
if the digesters needed to be lower than 15m we can use 3 or 4 digesters to get smaller digesters.

Correct "H" for d = 18m :-

\[ A_s = \frac{Td^2}{4} = 254.47 \, m^2 \]

\[ H = \frac{V}{A} = \frac{3700}{254.47} \approx 14.5 \, m \]

add a (0.5m) as freeboard between the maximum sludge level and the floating cover

- Calculate the conical part depth:-

\[ h = \frac{d}{12} = \frac{18}{12} = 1.5 \, m \]
2. Calculate the efficiency of solids reduction:

\[ R_s = 13.7 \ln \theta_c + 18.9 \]
\[ = 13.7 \ln 20 + 18.9 \approx 60\% \]

Calculate the organic matter weight:

\[ M_T = \frac{29060}{2} = 14530 \text{ kg/d (for each digester)} \]
\[ M_o = \text{organic matter} = 70\% \times 14530 = 10171 \text{ kg/d} \]
\[ (M_{iaert})_{Raw} = \text{inert matter} = 30\% \times 14530 = 4359 \text{ kg/d} \]
4) Calculate the gas production: -

\[ \text{Gas} = 0.5 \, \text{m}^3/\text{kg} \times M_{\text{dest}} \]

\[ = 0.5 \, \frac{m^3}{kg} \times 6103 \, \frac{kg}{d} \approx 3052 \, \frac{m^3}{d} \]

\[ 10171 \, \text{kg/d} \times 0.6 = 6103 \, \text{kg/d} \]

\[ \text{Methane} = 60\% \times 3052 \, \frac{m^3}{d} \approx 1831 \, \frac{m^3}{d} \text{ from each digester} \]
Note: this volume is at standard conditions i.e. $T = 0^0 C$, $P = 1$ atmospheric. It is usually stored in gas holders (or gas storage tanks) at a pressure larger than the atmospheric pressure to reduce the volume of gas holders for example, if the gas is stored at $P = 2$ atm the volume

$$V_2 = \frac{V_1 P_1}{P_2} = \frac{1831*1}{2} \approx 916 m^3$$ so we can size the gas holder.

Calculat the weight of the destroyed organic matters.

$$M_{\text{dest}} = 60\% \times \text{organic matter}$$
$$= 0.60 \times 10171 \text{ kg/d (for one digester)}$$
$$= 6103 \text{ kg/d}$$

$$(M_{\text{dest}}) = 10171 - 6103 = 4068 \text{ kg/d (inert matter)}$$

Calculate the total inert materials leaving the digester:-

$$M_d = (M_{\text{inert\_Raw}} + (M_{\text{inert\_d}}) = 4359 + 4068 = 8427 \frac{kg}{d}$$
* Calculate the percent reduction of total solids by the digester:

\[
\% R = \frac{M_T - M_{\text{dest}} \cdot 100}{M_T} = \frac{14530 - 8427}{14530} \cdot 100 \approx 42\%
\]

5) Calculate the concentrations of solids after digestion:

\[
(X_{\text{out}})_d = \frac{(Md)}{Qd} = \frac{8427 \text{ kg} / \text{d}}{185 \text{ m}^3 / \text{d}} = 45.6 \text{ kg/m}^3
\]

\[
S_d = \frac{(X_{\text{oud}})_d}{\rho_{se}} = 45.6 \text{ kg/m}^3 \cdot \frac{1}{1000 \text{ kg/m}^3 \cdot 1.05} \approx 0.043 = 4.3\%
\]
* Mass and flow balance:*

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<table>
<thead>
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<tbody>
<tr>
<td>$M_d$</td>
<td>8427 kg/d</td>
</tr>
<tr>
<td>$Q_d$</td>
<td>185 m$^3$/d</td>
</tr>
<tr>
<td>$(X_{out})_d$</td>
<td>45.6 kg/m$^3$</td>
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<tr>
<td>$S_d$</td>
<td>4.3%</td>
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<td>$\rho_{se}$</td>
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<tr>
<td>$M_r$</td>
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<td>$Q_r$</td>
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<tr>
<td>$X_T$</td>
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<td>$S_T$</td>
<td>7%</td>
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<tr>
<td>$\rho_{se}$</td>
<td>1120 kg/m$^3$</td>
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</table>
**Sludge de-watering:**
Dewatering is a physical process used to reduce the water content of sludge after stabilization. Several methods are used for dewatering as follows:

A) **Natural dewatering:**
Natural dewatering depends on evaporation and percolation. Sludge drying beds are the most common example of natural dewatering.

![Diagram of sludge drying beds](image)
• **Sludge Drying Beds**
  – Most popular method
  – Simple
  – Low maintenance
  – Effected by climate
B) Mechanical dewatering:-
Mechanical dewatering methods are divided to three main categories:-

a) Vacuum filtration:-
Water is removed under applied vacuum through a porous media that retains solids and allow water to pass.

- Cylindrical drum covered by mesh or fabric - rotates into partially submerged vat containing conditioned sludge
- Apply vacuum to pull out water
- Achieves 15-30 % solid content
b) Pressure filtration:–
Water is removed by applying presume (squeezing). Belt filter process is the most common example on this method.

- **Belt Filter Press**
  - Forces out water by essentially squeezing water between two moving filter belts
  - Apply pressure to pull out water
  - Achieves ~19 % solid content
  - Lower energy consumption than vacuum filters
  - Does not have problems with sludge pickup like vacuum filters
3) Centrifugation:-
Solids are separated from liquid by centrifugal forces.

**Mass and flow balance is performed on dewatering units as follows:-**

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<thead>
<tr>
<th>M</th>
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<tbody>
<tr>
<td>S</td>
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<td>Q</td>
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Dewatering unit

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<td>Q</td>
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Note:- "S" after dewatering in the range of 25 – 50%.
Volume Reduction

• Incineration
  – Complete evaporation of water from sludge
  – Requires fuel
  – Solid material is inert
  – Exhaust air must be treated prior to discharge