Lesson 11:
Sludge Thickening

Objective

In this section we will answer the following question:

- What are the different methods that can be used to thicken the sludge?
- Sludge thickening calculations.

Reading Assignment

Read the online lecture.

Lecture

Sludge Thickening

Treatment of sewage sludge may include a combination of thickening, digestion, and dewatering processes. Thickening is usually the first step in sludge treatment because it is impractical to handle thin sludge, a slurry of solids suspended in water. Thickening is usually accomplished in a tank called a gravity thickener. A thickener can reduce the total volume of sludge to less than half the original volume. An alternative to gravity thickening is dissolved air flotation.

Thickening is the process by which biosolids are condensed to produce a concentrated solids product and a relatively solids-free supernatant (the relatively clear water layer between the sludge on the bottom and the scum on the surface of a tank or basin, an anaerobic digester, or a septic tank (interceptor)). Thickening wastewater solids reduces the volume of residuals, improves operation, and reduces costs for subsequent storage, processing, transfer, end use or disposal. For example, thickening liquid-solids (slurry) from 3 to 6 percent will reduce the volume by 50 percent. Thickening is typically performed on secondary waste sludge (WAS) but can also be performed on primary sludge.

A thickener operates pretty much like a settling tank. The feed enters from the middle, are distributed radially, the settled sludge is collected from the underflow, and the effluent exits over the weirs.

In a continuously operated thickener, there are different zones of concentration. The topmost zone is free of solids and comprises the liquid that eventually escapes over the weirs. The next zone is called the feed zone, although this zone does not necessarily have the same concentration of feed solids. This zone is characterized by a uniform solids concentration. Below the feed zone is a zone of increasing solids concentration (from feed zone concentration to underflow concentration). This zone is the compaction zone.
The most commonly used thickening processes include gravity thickening, dissolved air flotation, and rotary drum thickening. Centrifuge thickening is also becoming more common. The type of thickening selected is usually determined by the size of a wastewater plant, its physical constraints and the downstream process.

There are several points in a treatment plant where sludge may be thickened, including prior to anaerobic digestion, dewatering and disposal. Sludge pumped to an anaerobic digester should be in the range of 4-6% total solids.

**Thickening Processes**

There are three main thickening processes that can be used in wastewater treatment, including gravity thickening, gravity belt thickening and dissolved air floatation. It is always best to NOT send thin sludge to the anaerobic digester, which we will discuss a little later.

**Gravity Thickener**

A gravity thickener is much like a clarifier in that the sludge/water mixture enters through the center in the influent line. This reduces the hydraulic force of water and sludge that enters the thickener. In the lower portion of the thickener is the sludge rake, which moves sludge to the hopper, where sludge is collected and compacted. Sludge can be thickened to 8-10% total solids. A pump then sends the sludge to the anaerobic digester. At the top of the basin is the scum collector and discharge.
A gravity thickener uses gravitational forces to separate water from sludge and is mainly used on primary sludge at plants still using this technology. As the solids separate, they settle on the bottom and become compacted as more solids settle. Thickened sludge is then sent to the stabilization process for treatment. Secondary sludge is NOT well suited for gravity thickening. Activated sludge is usually not sent to a gravity thickener either.

The sludge rake, or scraper blade, on the bottom of the basin has steel pickets mounted on them to help separate solids from gas bubbles. The supernatant (liquid) flows over the effluent overflow weir while scum removal equipment removes scum from the surface.

There are several factors that will affect the operation of the gravity thickener, including:

- **the type of sludge being treated.** Gravity thickeners can only be used on primary sludge, since secondary sludge doesn't settle well due to the high water content.

- **sludge age.** Older sludge will denitrify (remove nitrogen) and cause settling issues.

- **sludge temperature.** Warmer temperatures result in better settling, but can also increase nitrification and fermentation.

- **sludge blanket depth.** A thick sludge blanket will help compact the sludge at the bottom of the basin. Sludge is removed so gasification doesn't occur from the bottom, causing the sludge to float.

- **solids and hydraulic detention time.** It is best to leave the sludge as long as possible before nitrification occurs, which would cause solids to float.

- **solids and hydraulic loading.** A higher hydraulic loading rate means there will be a lower solids concentration in the waste stream.

<table>
<thead>
<tr>
<th>Sludge Type</th>
<th>Solids Loading, lb/day/ft²</th>
<th>% TS of Thickened Sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>20-30</td>
<td>8-10</td>
</tr>
<tr>
<td></td>
<td>5-8</td>
<td>2-4</td>
</tr>
</tbody>
</table>
Gravity Belt Thickening

Sludge must be pre-conditioned with polymer before it is sent to a gravity belt thickener. This conditioned sludge is applied to the belt traveling 2-10 ft/min. This belt speed can vary, depending on the device. Once the sludge is loaded onto the belt, water drains through the belt pores, leaving the dried sludge on the belt surface. This thickened sludge is then removed from the belt and sent to the stabilization process, which is usually done in an anaerobic digester.
Let's watch a short video showing how a gravity belt thickener operates.

The incoming secondary sludge ranges from 0.3 - 0.6% total solids while the thickened sludge leaving the belt ranges from 4 - 6% total solids. This indicates that the sludge leaves the gravity belt thickener about 10 times thicker than when it entered. The belt pores need to stay unclogged, so built in spray nozzles are used to spray water through the belt, removing any built up sludge preventing the filtrate from flowing through.

There are several factors that will affect the operation of the gravity belt thickener, including:

- **amount of conditioning chemicals used on the sludge.** Too much polymer can bind the belt, clogging the belt pores and causing a washout.

- **belt speed.** The ideal belt speed is the slowest speed that can be maintained without washing out the belt.

- **belt size and type.**

- **hydraulic and solids loading.** Allow enough time for water to drain from the sludge, but not long enough to clog the belt pores.

**Dissolved Air Flotation**

The dissolved air flotation (DAF) unit utilizes compressed air (45 - 70 psi) to saturate the water and is used on secondary sludge (WAS), and usually yields 3 - 5% total solids. When the atmospheric pressure drops in the unit due to the injection of air, it causes air bubbles to come out of solution. The lighter weight organic matter attaches to the air bubbles, floating them to the surface of the unit for removal while the heavier sludge settles to the bottom. Polymer may be used to enhance the process. The concentrated solids are removed from the DAF unit and sent to the stabilization process.
There are several factors that will affect the operation of the dissolved air flotation (DAF) unit, including:

- **type of sludge.** DAF units are used on **secondary** sludge which is lighter in weight and will float easier.

- **solids and hydraulic loading.**

- **air to solids ratio (A/S).** This is an important parameter, ensuring enough air is supplied to float a good ratio of floatable solids.

- **recycle rate.** The recycle rate needs to be high enough to supply enough air into solution to float solids, but low enough to prevent a hydraulic overload.

- **sludge blanket depth.** The sludge blanket on top of the surface needs to be deep enough so the skimmer does not dip into the supernatant (liquid) below the blanket. The blanket should not become deep enough to allow for solids carry over.

We know polymer can be added to enhance sludge thickening in a DAF unit. Let's take a look at how polymer addition can impact the operational parameters of the process.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>With Polymer</th>
<th>Without Polymer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids Loading, lb/day/ft²</td>
<td>24 - 48</td>
<td>10 - 24</td>
</tr>
<tr>
<td>Hydraulic Loading, gpm/ft²</td>
<td>0.5 - 2.0</td>
<td>0.5 - 1.5</td>
</tr>
<tr>
<td>Recycle, %</td>
<td>100 - 200</td>
<td>100 - 200</td>
</tr>
<tr>
<td>Air/Solids Ratio, lb/lb</td>
<td>0.01 - 0.1</td>
<td>0.01 - 0.1</td>
</tr>
<tr>
<td>Minimum Feed TS (WAS), mg/L</td>
<td>5,000</td>
<td>5,000</td>
</tr>
<tr>
<td>Floating Sludge TS, %</td>
<td>3 - 5</td>
<td>2 - 4</td>
</tr>
<tr>
<td>Solids Recovery, %</td>
<td>90 - 98</td>
<td>50 - 90</td>
</tr>
</tbody>
</table>

This table illustrates that you can increase the amount of sludge effectively treated from 10 - 24 lb/day/ft² to 24 - 48 lb/day/ft² through the use of polymer. It is also very effective for solids recovery, helping separate the solids from the
liquids at a faster rate.

**Centrifugal Thickening**

Centrifugal thickening is a high speed process that uses the force from rapid rotation of a cylindrical bowl to separate the solids from the liquid in the waste stream. Centrifuges operate as continuous feed units which remove solids by a scroll conveyor and discharge liquid over the weir. The shape of the bowl helps lift solids out of the liquid, allowing them to dry on an inclined surface before being discharged.

Centrifuges are commonly used for thickening waste activated sludge (WAS). Primary sludge is normally not fed to a centrifuge since it may contain abrasive material. In addition to being effective in thickening, centrifuges have the advantage of less space requirement, less odor potential and housekeeping requirement.

Sometimes polymer is added to the influent of the centrifuge to help thicken the solids. The two most important factors that affect the centrifuge are the volume of the biosolids put into the unit (gpm) and the pounds of solids put in. The water that is removed from the unit is called the centrate. Normally, hydraulic loading is measured as flow rate per unit of area; however, because of the variety of sizes and designs, hydraulic loading to centrifuges does not include area considerations. It is expressed only as gallons per hour.

The difference between the rotational speeds of the bowl and the conveyor becomes important. This is referred to as the differential speed. If the differential speed is at the minimum, this means the conveyor is moving only slightly faster than the bowl. When this happens, the solids are inside the centrifuge for the maximum amount of time. At this minimum differential speed the solids produced are the driest possible. Minimum differential speed also means minimum output. If the differential speed is large, then the conveyor is moving much faster than the bowl is. A large differential speed pushes a lot of sludge through but does not concentrate it very much. The best operation involves a compromise between thickened sludge concentration and the gallons of sludge put into the unit.

![Diagram of centrifuge](image)

**Part 2: Thickening Calculations**
Lesson 11:

Sludge Thickening Calculations

Objective

In this section we will learn how to calculate:

- Sludge Detention Time (hours)
- Hydraulic loading rate (gpd/ft²)
- Solids loading rate (lb/day/ft²)
- Solids recovery (%)

Reading Assignment

Read the online lecture.

Lecture

Sludge Detention Time

As an operator, you must ensure your solid waste is disposed of properly and that treatment is complete. You need to determine the amount of time the flow needs to stay in the process. You must ensure the units entered are compatible. Let's take a look at how to determine the detention time.

\[
\text{Detention time} = \frac{\text{Volume}}{\text{Flow}}
\]

Example:

Your utility uses a gravity thickener that is 28 ft in diameter and has a sludge blanket depth of 4.5 ft. If the sludge is pumped from the bottom of the unit at a rate of 20 gpm, what is the sludge detention time, in hours, in the thickener?

The first step is to determine the volume of the gravity thickener:

\[
\text{Volume, ft}^3 = 0.785 \times \text{Diameter}^2 \times \text{Depth}
\]
Volume, ft³ = 0.785 \times 28 \text{ ft} \times 28 \text{ ft} \times 4.5 \text{ ft}

Volume, ft³ = 2,769 ft³

Since the flow is in gallons per minute, that means we need to convert the volume of the gravity thickener from cubic feet to gallons:

Volume, gal = 2,769 ft³ \times (7.48 \text{ gal/ft}³) = 20,716 \text{ gal}

Now determine the sludge detention time using the units you currently have:

\[
\text{Detention time} = \frac{\text{Volume}}{\text{Flow}}
\]

\[
\text{Detention time} = \frac{20,716 \text{ gal}}{20 \text{ gpm}}
\]

\[
\text{Detention time} = 1,036 \text{ min}
\]

This gives us the detention time in minutes, but the question asked for hours. That means we have one more conversion to do:

\[
1,036 \text{ min} \times \frac{1 \text{ hour}}{60 \text{ min}} = 17.3 \text{ hours}
\]

**Hydraulic Loading Rate**

Wastewater hydraulic loading is defined as the volume of wastewater applied to the surface of the process per time period, usually gpd/ft². This is also the surface loading rate.

\[
\text{Hydraulic loading rate, gpd/ft}^2 = \frac{\text{Total flow applied, gpd}}{\text{Area, ft}^2}
\]
Example:

A 6 ft wide, 10 ft long gravity thickening belt receives a flow of 140 gpm of primary sludge. What is the hydraulic loading rate, in gpd/ft²?

We concentrate on the unit conversion needed to get to gpd/ft. Our flow is current in gpm, so we need to convert that to gpd.

\[
\frac{140 \text{ gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} = 201,600 \text{ gpd}
\]

Now we need to determine the surface area of the belt:

\[
\text{Area} = \text{Length} \times \text{Width}
\]

\[
\text{Area} = 10 \text{ ft} \times 6 \text{ ft}
\]

\[
\text{Area} = 60 \text{ ft}^2
\]

Now we have the units that the question asked for, which is gpd and ft², so just plug the numbers in the equation to determine the hydraulic loading rate on the gravity belt thickener:

\[
\text{Hydraulic loading rate, gpd/ft}^2 = \frac{\text{Total flow applied, gpd}}{\text{Area, ft}^2}
\]

\[
\text{Hydraulic loading rate, gpd/ft}^2 = \frac{201,600 \text{ gpd}}{60 \text{ ft}^2}
\]

\[
\text{Hydraulic loading rate, gpd/ft}^2 = 3,360 \text{ gpd/ft}^2
\]

**Solids Loading Rate**

The solids loading rate measures the amount of solids being applied to 1 ft² of the gravity thickener's surface area. This calculation utilizes the surface area of the tank bottom, assuming it is flat and has the same dimensions as the surface. The solids loading rate on a gravity thickener can be calculated using the following formula:
Example:

A gravity thickener that is 40 ft in diameter and 8 ft deep receives an influent flow of 42,500 gpd containing 6,800 lb of solids. What is the solids loading rate, in lb/day/ft²?

First, determine the surface area of the gravity thickener:

\[
\text{Area, ft}^2 = 0.785 \times \text{Diameter}^2
\]

\[
\text{Area, ft}^2 = 0.785 \times 40 \ \text{ft} \times 40 \ \text{ft}
\]

\[
\text{Area, ft}^2 = 1256 \ \text{ft}^2
\]

Now determine the solids loading rate for the gravity thickener:

\[
\text{Solids loading, lb/day/ft}^2 = \frac{\text{Solids applied, lb/day}}{\text{Surface area, ft}^2}
\]

\[
\text{Solids loading, lb/day/ft}^2 = \frac{6,800 \ \text{lb/day}}{1256 \ \text{ft}^2}
\]

\[
\text{Solids loading, lb/day/ft}^2 = 5.41 \ \text{lb/day/ft}^2
\]

**Solids Removal Efficiency**

The solids removal efficiency represents the amount of solids that were removed during the process and can be calculated using the following formula:

\[
\text{Removal, } \% = \left( \frac{\text{In} - \text{Out}}{\text{In}} \right) \times 100\%
\]

*Example:*
A 75 ft diameter dissolved air flotation (DAF) thickener receives a sludge flow with a solids concentration of 7010 mg/L. If the effluent solids concentration is 230 mg/L, what is the solids removal efficiency?

\[
\text{Removal, } \% = \left( \frac{\text{In} - \text{Out}}{\text{In}} \right) \times 100\%
\]

\[
\text{Removal, } \% = \left( \frac{7010 \text{ mg/L} - 230 \text{ mg/L}}{7010 \text{ mg/L}} \right) \times 100\%
\]

Removal, \% = 97\%

Example:

What is the efficiency of the gravity thickener if the influent flow to the thickener has a sludge solids concentration of 4% and the effluent flow has a sludge solids concentration of 0.9%?

\[
\text{Removal, } \% = \left( \frac{\text{In} - \text{Out}}{\text{In}} \right) \times 100\%
\]

\[
\text{Removal, } \% = \left( \frac{0.04 - 0.009}{0.04} \right) \times 100\%
\]

Removal, \% = 77.5%

Review

- A gravity thickener can produce a total solids concentration of 10% when thickening primary sludge.
- A dissolved air flotation (DAF) unit can produce a total solids concentration in the floating sludge of 5%.
- Operational control parameters for a DAF unit include the air to solids ratio, solids loading and hydraulic loading.
- The differential scroll speed effects the time the solids will be under centrifugal force (more time/higher concentration vs shorter time/lower concentration). The higher the speed, the lower the time, thus lower concentrations.
- The purpose of sludge thickening is to reduce the water content and sludge volume to be handled by the next process.
- A DAF unit normally operates with an Air to Solids in the range of 0.01 to 0.1.
- If a DAF unit is producing good quality sludge with high solids carryover, the operator should reduce the flow to the unit and increase the flight speed.
Of the various processes used to thicken secondary sludge, the centrifuge can produce the highest solids concentration.
- The operator of a DAF unit using polymer to condition the feed sludge should expect to recover 90% to 98% of the solids.
- A gravity belt thickener is used to thicken secondary sludge prior to digestion.
- A gravity thickener is used to thicken primary sludge.
- Dissolved Air Floatation is a form of sludge thickening that utilizes air bubbles to concentrate lightweight sludge on the water surface.
- Increasing the differential scroll speed on a centrifuge will produce a lower solids concentration.
- Increasing the bowl speed on a centrifuge will produce a higher solids concentration.
- The problem of rising sludge in a gravity thickener caused by gases produced within the sludge can be solved by increasing the sludge removal rate.
- If a gravity thickener has thin underflow sludge and high solids on the liquid surface which are carrying over, the operator should reduce influent sludge flow.
- A float blanket that is too thick in a DAF unit can cause solids to carryover in the effluent.
- Thin sludge coming from a DAF unit having good quality effluent is usually the result of a thin float sludge blanket.
- A basket centrifuge thickener that has good quality centrate but dilute discharge solids is often caused by the feed rate being too low.
- A basket centrifuge thickener that has poor quality centrate and dilute solids being discharged is normally the result of high loading.
- To solve problems of poor quality centrate and dilute discharge solids in a basket centrifuge thickener, the operator should lower the flow rate.
- If the discharge solids are good but the centrate quality is poor in a scroll centrifuge thickener, the likely cause is the hydraulic loading is too high.
- The likely solution for a scroll centrifuge thickener that has poor quality and dilute discharge solids is to increase the chemical dosage.
- The most likely cause for the cake solids being too wet coming from a gravity belt thickener is the belt speed is too high.

**Assignment**

Please complete the assignment for this lesson. You must be logged into Canvas to complete this assignment.

**Quiz**

Answer the questions in the lesson quiz. You will need to log into Canvas to take the quiz. You may take the quiz 3 times, if needed, and an average will be taken from your attempts for final grade calculation.