CHAPTER 3

SLUDGE THICKENING

Thickening is a procedure used to increase the solids content of sludge by removing a portion of the liquid fraction. To illustrate, if waste activated sludge, which is typically pumped from secondary tanks with a content of 0.8% solids, can be thickened to a content of 4% solids, then a fivefold decrease in sludge volume is achieved [1].

Thickening is generally accomplished by physical means including co-settling, gravity settling, flotation, centrifugation, gravity belt, and rotary drum [1].

The volume reduction obtained by sludge concentration is beneficial to subsequent treatment processes, such as digestion, dewatering, drying and combustion from the following standpoints:

1. Capacity of tanks and equipment required
2. Quantity of chemicals required for sludge conditioning
3. Amount of heat required by digesters and amount of auxiliary fuel required for heat drying or incineration, or both.

Volume reduction is very desirable when liquid sludge is transported by tank trucks for direct application to land as a soil conditioner [1].

Thickening Techniques Used in Sludge Processes

Most common techniques of thickening in sludge processing are given in Table 1.

Table 1. Thickening Techniques Used in Sludge Processes [2].

Method	Sludge type	Frequency and performance
Gravitational settling	Raw primary	Very good results.
Gravitational settling	Raw primary and W.A.S	Frequently used. Small facilities obtain 4-6% solids concentration. Not often used in large facilities.
Gravitational settling	W.A.S	Not frequently used. Low solids concentration (2-3%)
Dissolved Air Flotation (DAF)	Raw primary and W.A.S	Not frequently used. Results seem to gravitational settling
Dissolved Air Flotation (DAF)	W.A.S	Frequently used. Good results obtained (3.5-5% solids concentration)
Basket centrifuge	W.A.S	Limited use. Good results obtained (8-10% solids concentration)
Solid-bowl centrifuge	W.A.S	Usage is increasing. Good results obtained (4-6% solids concentration)
Gravity belt filter	W.A.S	Usage is increasing. Good results obtained (3-6% solids concentration)
Rotary drum	W.A.S	Limited use. Good results obtained (5-9% solids concentration)

Location of the thickener in a wastewater treatment plant is important. If sludge is to be digested, thickening a blend of primary and waste activated sludge is a good practice. If these sludges are to be dewatered, then they should be thickened separately and mixed immediately before dewatering [3].

Sludge Thickening vs. Dewatering

Both are methods of solids concentration and volume reduction. Only the degree of volume reduction is different. Generally thickeners concentrate sludge at lower than 15% concentration, the dewatering units concentrate the sludge to higher than 15% concentration [3]. Thickened sludge still behaves as a liquid and can be pumped. However, the dewatered sludge generally behaves as a solid and can be trucked in most cases.

Operation of a Thickener

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, the effluent exits over the weirs.

In a continuously operated thickener, there are different zones of concentration. The topmost dear 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 compaction zone.

Sludge blanket is defined as the top of the feed zone. The height of this blanket is the main operational control that the treatment plant operator has over the thickener. By increasing the underflow rate, the operator can lower the blanket, and hence the solids residence time is lowered, throughput of solids is increased and the solids concentration in the underflow is decreased. The operator then would have a higher reserve volume in case there is an unexpected heavy sludge load coming. A high sludge blanket will make the underflow solids concentration high due to high solids residence time. One problem with this approach is the gas formation due to the anaerobic activity. The gas formed will cause the flotation of the solids in the thickener. Chemicals like chlorine (CI_2) need to be added to inhibit the biological activity. A well operated thickener will have a solids recovery of about 95% [3].

Design of Thickeners

The thickening process takes place in a settling tank with long-enough solids retention time. For example in secondary clarifiers of activated sludge systems both clarification and thickening operations are carried out. Actually, the thickening of the sludge is a concern to the operator where he desires a high underflow solids concentration. So it is the general practice to design these processes for both thickening and clarification performance.

Similar to the digesters, there are two design approaches in thickeners too:

1. Design based on experience.

2. Design based on laboratory data.

1. Design based on experience

Solids throughput is an important criterion in the design of thickeners. The design is mostly based on the solids flux, i.e. kg solids/h/m^2. Typical flux values are given in Table 2.

Table 2. Typical flux values (kg solids/h/m^2)[3].

Activated Sludge	0.8 - 1.0
Trickling Filter Humus	1.8
Raw Primary Sludge	4.5 - 5.1
Raw Primary & WAS	1.6 - 2.4
Pure O2 activated sludge	2.0

The design involves selecting a typical solids flux and calculating the required surface area by dividing the anticipated solids feed by the flux [3].

Area of the thickener:

$$A = \frac{Q}{Flux} = \frac{kg/h}{kg/h.m^2} = m^2$$

2. Design based on laboratory data

First Approach:
It is the best technique if the laboratory data is available. Typical test is done by using a 1000mL-graduated cylinder. Sludge is mixed homogenously and let to settle in the cylinder. In seconds an interface separating the solids and the clear water on top is formed with a certain settling velocity. This velocity of the interface is measured with respect to time. Interface height is plotted against time and the zone settling velocity (ZSV) is calculated from the initial slope of the graph. The graph is given in Figure 1.
The velocity with which solids settle out will depend on the concentration of solids. Right after time zero, there are two interfaces moving towards each other. One from the bottom up due to the building up layers of sludge from the bottom, the other interface is moving down from top to bottom, this is the blanket of settling sludge, settling velocity, v. At time t_2, these will meet and settling will slow down. Then the settling will cease over time and compaction begins [3]. Figure 2 shows the illustration of interfaces during settling test.

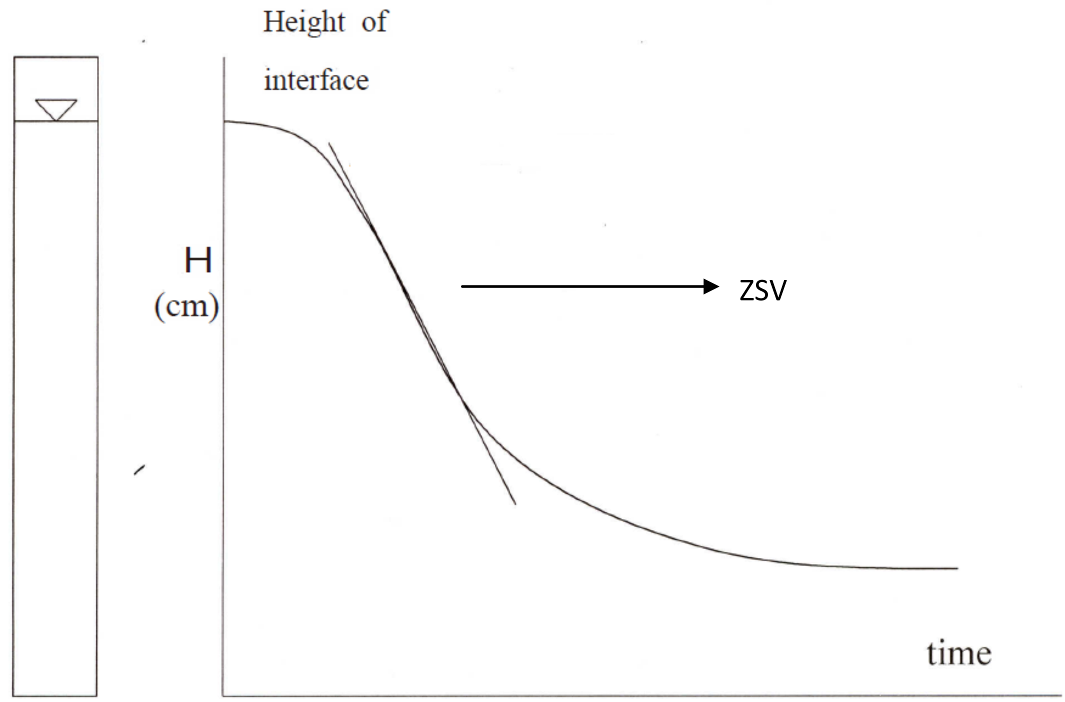


Figure 1. Interface heights [3].

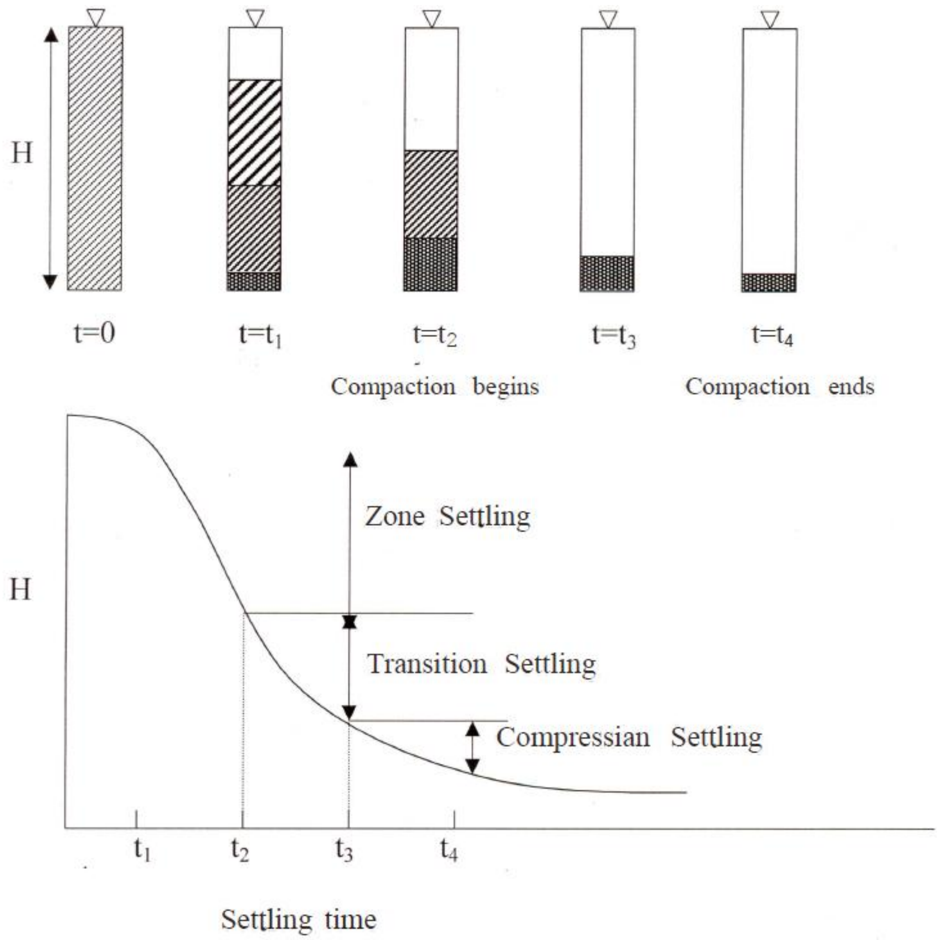


Figure 2. Illustration of interfaces during settling test [3].

Talmage and Fitch Procedure to find the Required Area

The graph (Figure 3) and the procedure are given below to select the required area of the thickener.

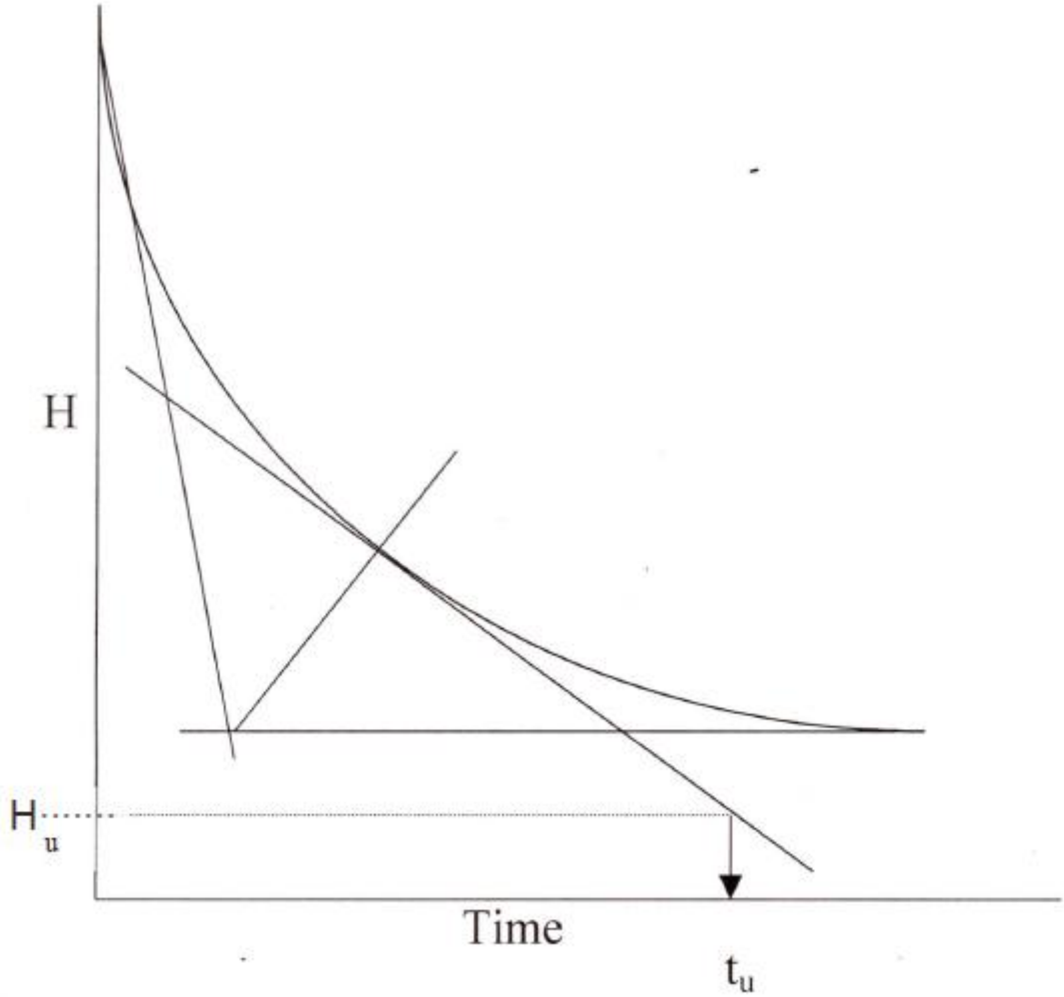


Figure 3. Graph to select the required area according to Talmage and Fitch procedure [3].

Procedure:

1. Determine the slope of the zone settling region (ZSV) (this is the settling velocity for clarification).

2. Extend the tangents from the ZSV region and compression region and bisect the angle formed to locate point 1.

3. Draw a tangent to the curve at point 1.

4. Knowns: Co, Ho, and select Cu, then make a mass balance

Cu.Hu = Co.Ho, calculate Hu from:

$$H_u = \frac{C_0 H_0}{C_u}$$

5. Draw a horizontal line from Hu until it intersects with the tangent line and determine t_u. This is the time required to reach an underflow concentration.

6. Determine the area required for thickening (At)

$$A_t = 1.5(Q + R)\frac{t_u}{H_0}$$

where

Q = flowrate to the aeration tank excluding the recycle flow
R = recycled sludge flow
Q+R = total flow to the clarifier
1.5 = scale-up factor

7. Determine the area required for clarification (A_c)

$$A_c = 2.0\frac{Q}{ZSV}$$

Q = the effluent flow over the weir (same as above)
2.0 = scale-up factor

"***Whichever area is larger will govern the design and will be the design area***."

Second Approach

Second approach in the design of thickeners is the solids flux approach.

Settling velocity, ZSV, is a function of solids concentration. If we plot that, the relationship will look like:

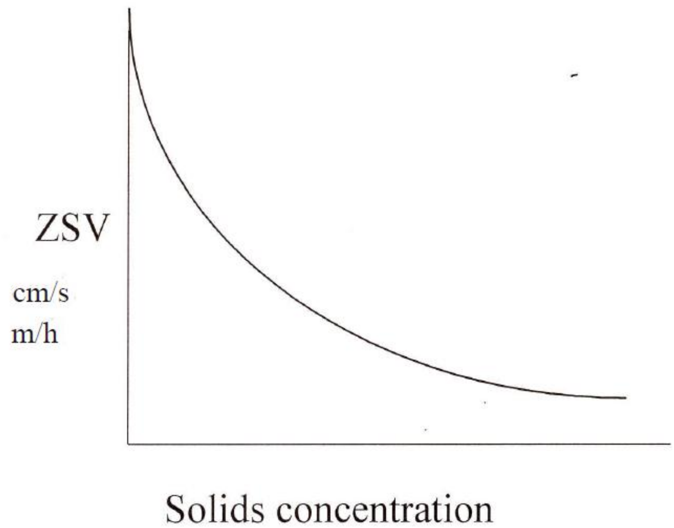


Figure 4. ZSV vs solids concentration [3].

From this relationship we can multiply the velocity with the concentration to obtain the solids flux (m/h*kg/m^3 = kg/m^{2}h = flux unit). If we plot flux versus concentration, then batch settling solids flux graph will be obtained (Figure 5).

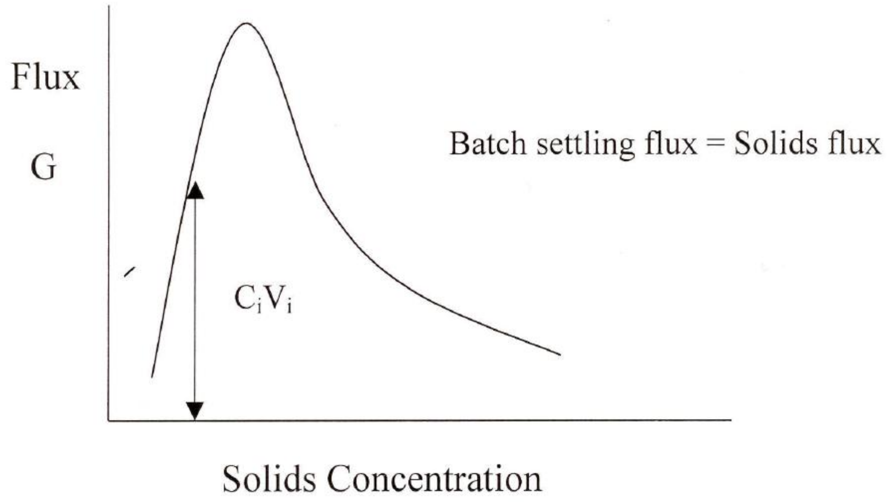
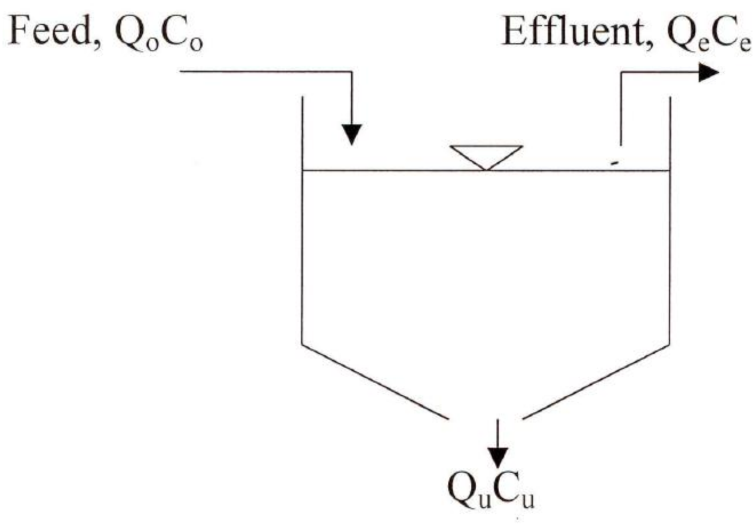


Figure 5. Flux vs solids concentration graph of a batch settling flux [3].

The thickener design based on the solids flux data obtained in the laboratory involves the selection of the solids flux that will limit the operation of the thickener in other words, the maximum solids loading.

The thickener given here will operate successfully as long as the rate of solids applied to the top does not exceed the rate at which solids are transmitted to the bottom.



There are two ways the solids can move to the bottom:

1. Under the influence of their settling velocity, bulk downward
2. Due to the continuous removal of sludge at the bottom as underflow.

The first is also called the batch settling flux, this is due to the settlement of solids and as expected is a function of solids concentration and the settling velocity of particles. We can call this as the G_b and G_b is:

$$G_b = V_i C_i$$

where, V_i and C_i are the velocity and concentration at a layer "i" in the thickener, respectively.

The second mechanisms of movement is independent of the solids settling in the thickener, whether the solids settle or not, there pumping of the sludge from the bottom of the tank. Let's call this flux as G_u (underflow flux); the G_u is:

$$G_u = u.C_i$$

where, u= the velocity created by the underflow sludge removal.

At some time, at some level "i" in the thickener, the total flux G_i is the sum of these two fluxes, i.e. the underflow flux and the batch settling flux:

$$G_i = G_u + G_b$$

or

$$G_i = u.C_i + V_i C_i$$

If this equation is plotted the graph below would be obtained (Figure 6).

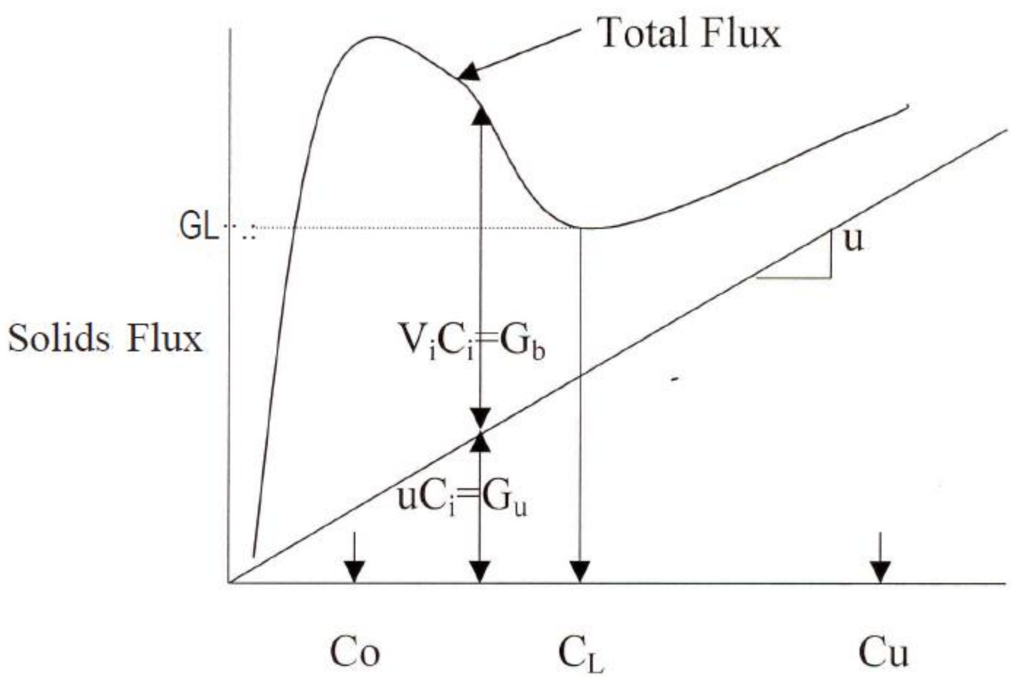


Figure 6. Total flux curve [3].

Note that the total flux curve has a minimum value (G_L) between the influent solids concentration (Co) and underflow solids concentration (Cu). This minimum flux is the maximum allowable solids loading for the thickener to work successfully. When flux is at minimum, we calculate for the maximum area required. If this limit is exceeded, the solids will overflow in the effluent. So the design of a thickener is thus reduced to the point of determining this flux.

Then to find G_L, a graphical method which is called Yoshika Construction is used. Figure 7 shows the construction.

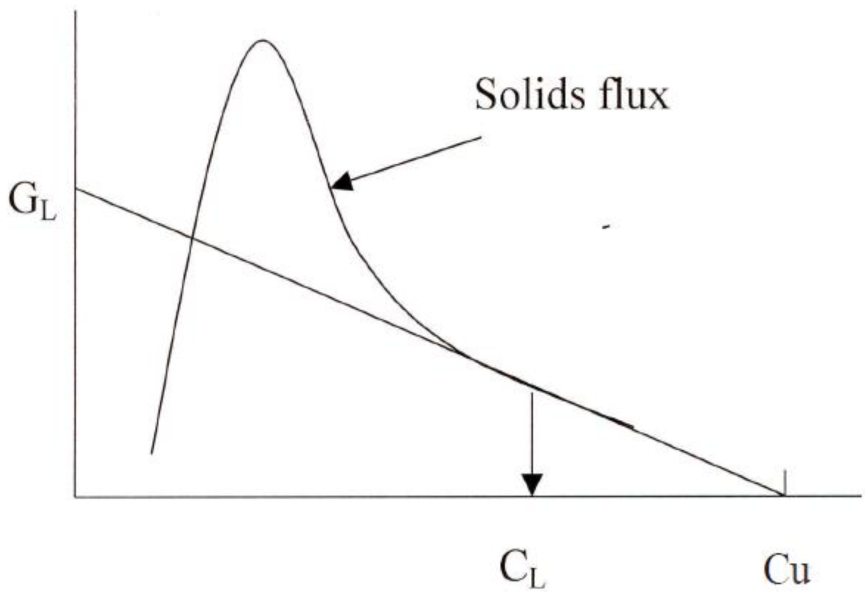


Figure 7. Yoshika Construction method to find G_L [3].

Draw a tangent from the desired underflow concentration to the solids flux curve (not the total flux curve) as given above. The intersection point on y-axis is the limiting flux (G_L).

After finding GL, use the eqn. given below to find the area:

$$A = \frac{Q_0 C_0}{G_L}$$

A= required area for thickening,
Qo = flow rate,
Co = feed solids concentration

Nominator of the above eqn. is the maximum mass loading rate (kg/h), the denominator is the max loading rate allowable per unit area.

References:

[1] Metcalf and Eddy, 1997. Wastewater Engineering, Treatment, Disposal and Reuse. McGraw Hill, New York.

[2] http://web.deu.edu.tr/atiksu/ana58/bolum08.pdf

[3] Enve 422, Treatment and disposal of water and wastewater sludge, METU.