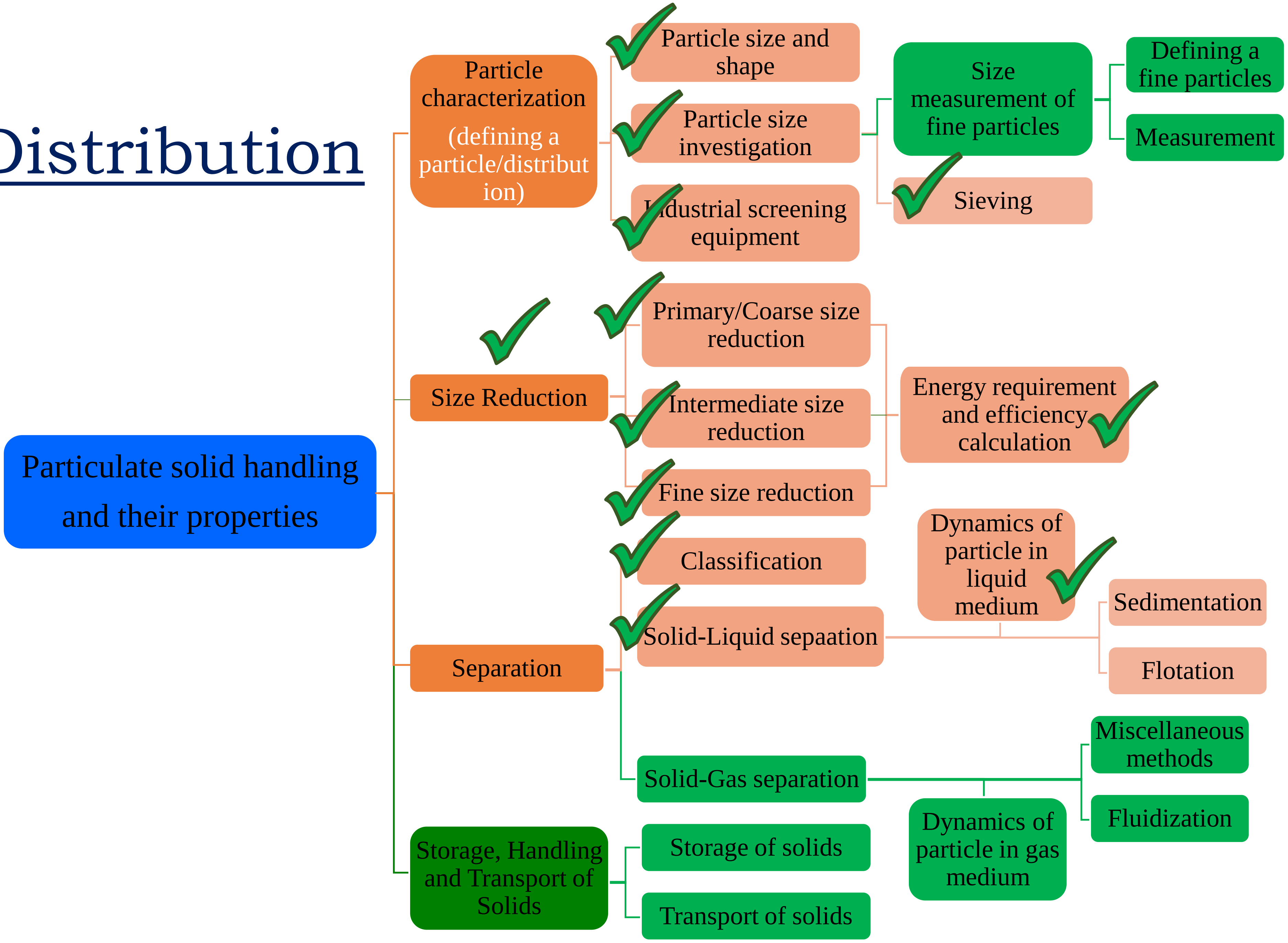
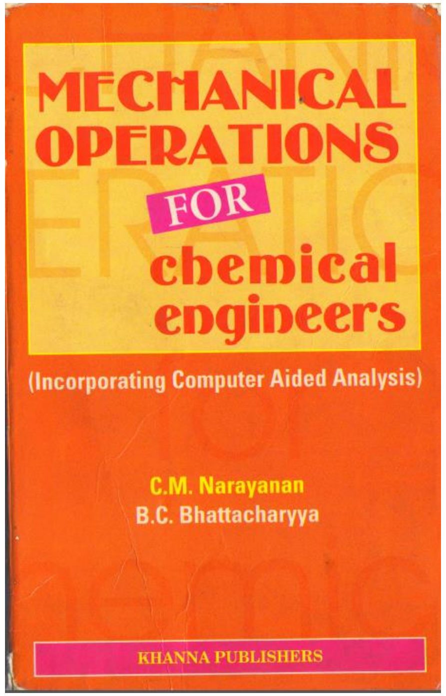
Course Distribution

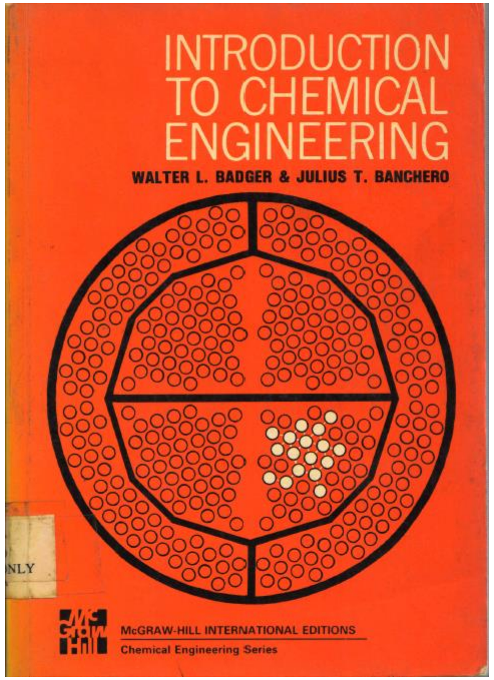


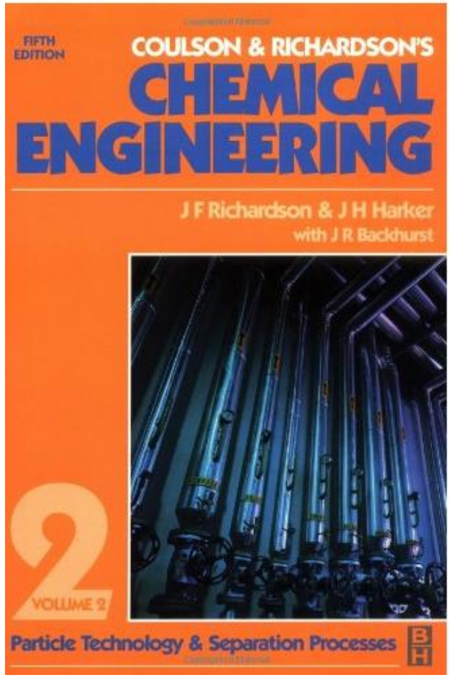

SEDIMENTATION

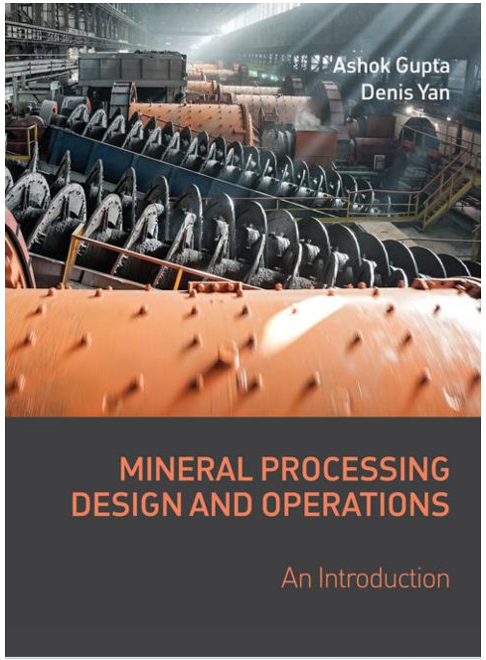
Resource

- **Books**







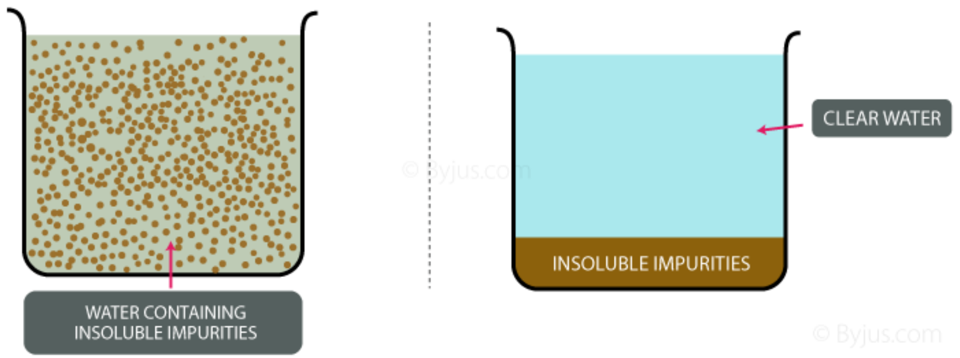


- **Relevant journal papers mentioned in the individual topics**

Introduction

- The separation of a suspension into a supernatant clear liquid and rather dense slurry containing a higher concentration of solid is called sedimentation

- Commercial sedimentation is conducted in a continuous process in "thickeners" or large tanks which receive a suspension or dilute slurry and permit the overflow of supernatant liquid and produce a sludge at the bottom of the tank



- A general conception of the operation may be gained from simple batch sedimentation

Batch sedimentation

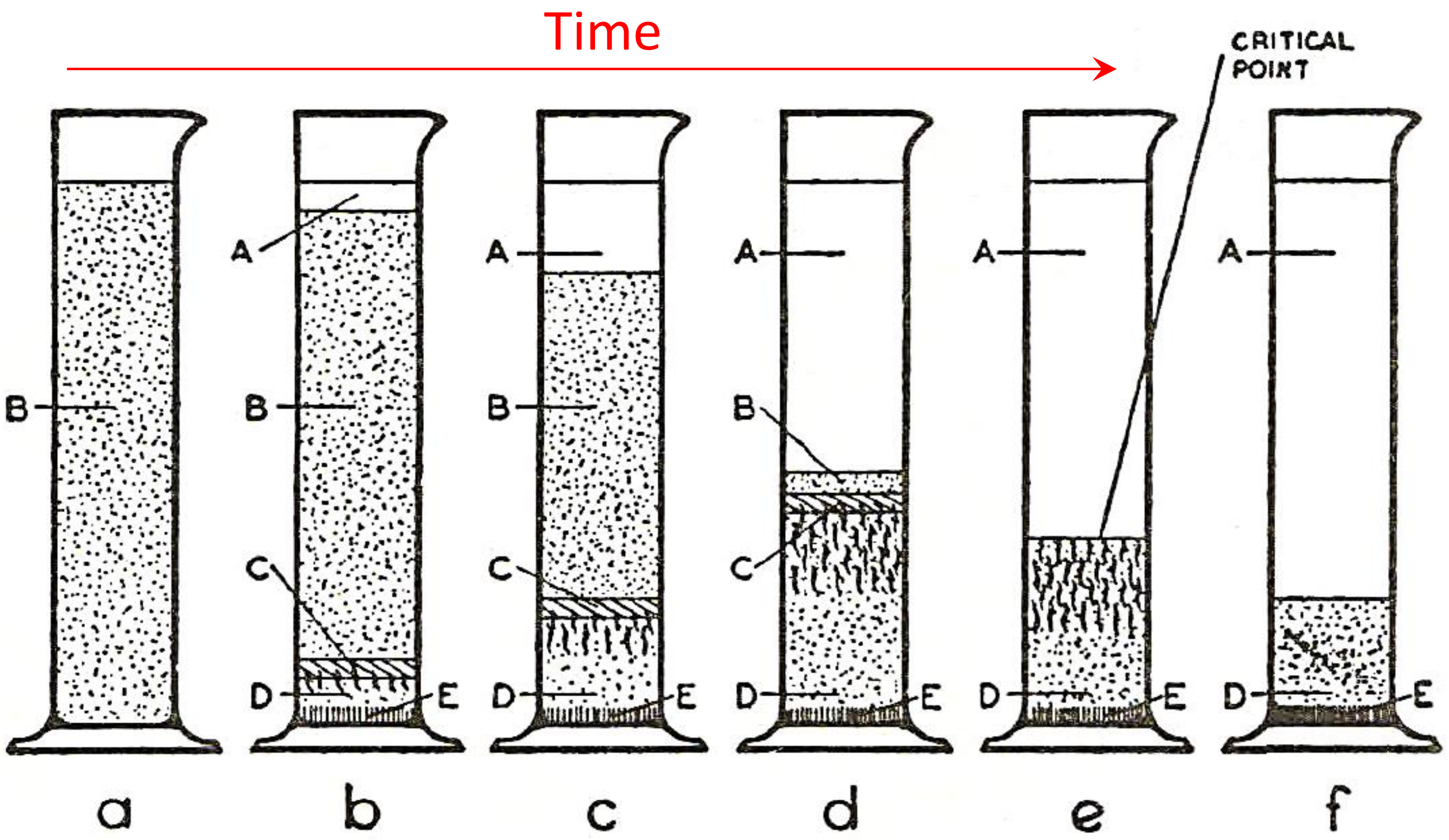


FIG. 1 Typical slurry-settling tests: *A*, clear liquid; *B*, slurry at original concentration; *C*, transition zone; *D*, thickened slurry in compression zone; *E*, coarse sand.

➢ The boundary between C and D is usually obscure and is marked by vertical channels through which water is escaping from the lower layer which is under compression.

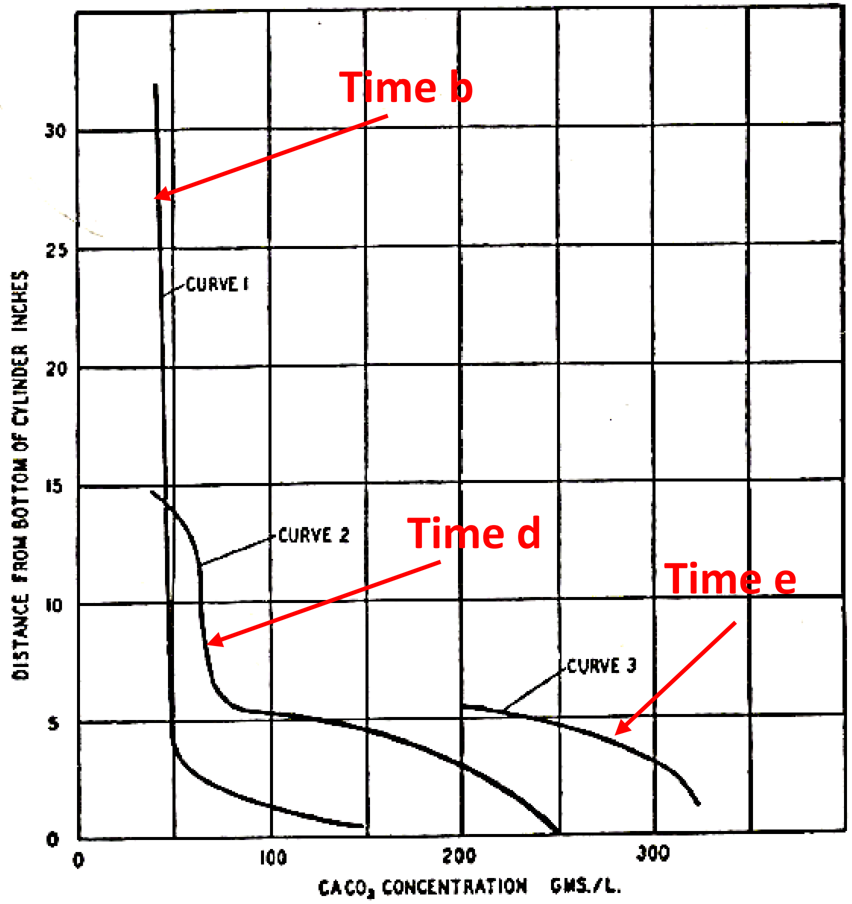


FIG. 2 Relation between concentration and depth in slurry-settling tests. Curves 1, 2, and 3 are at successive times.

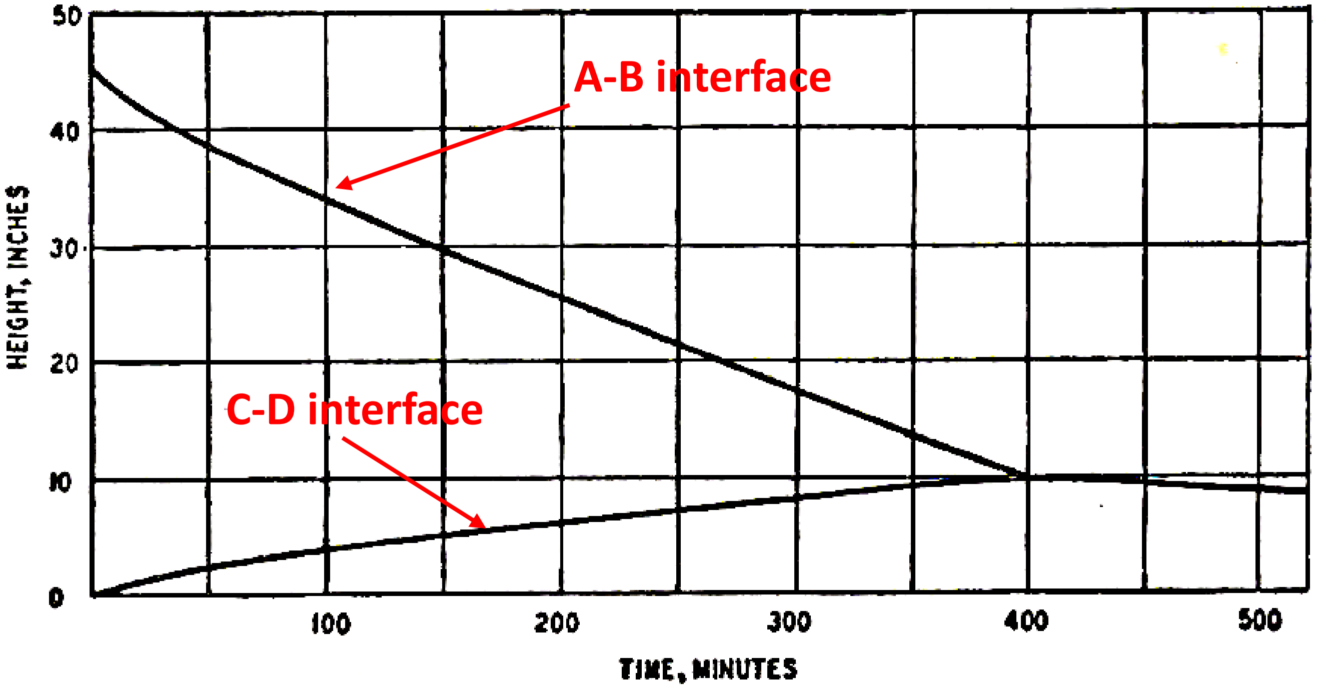
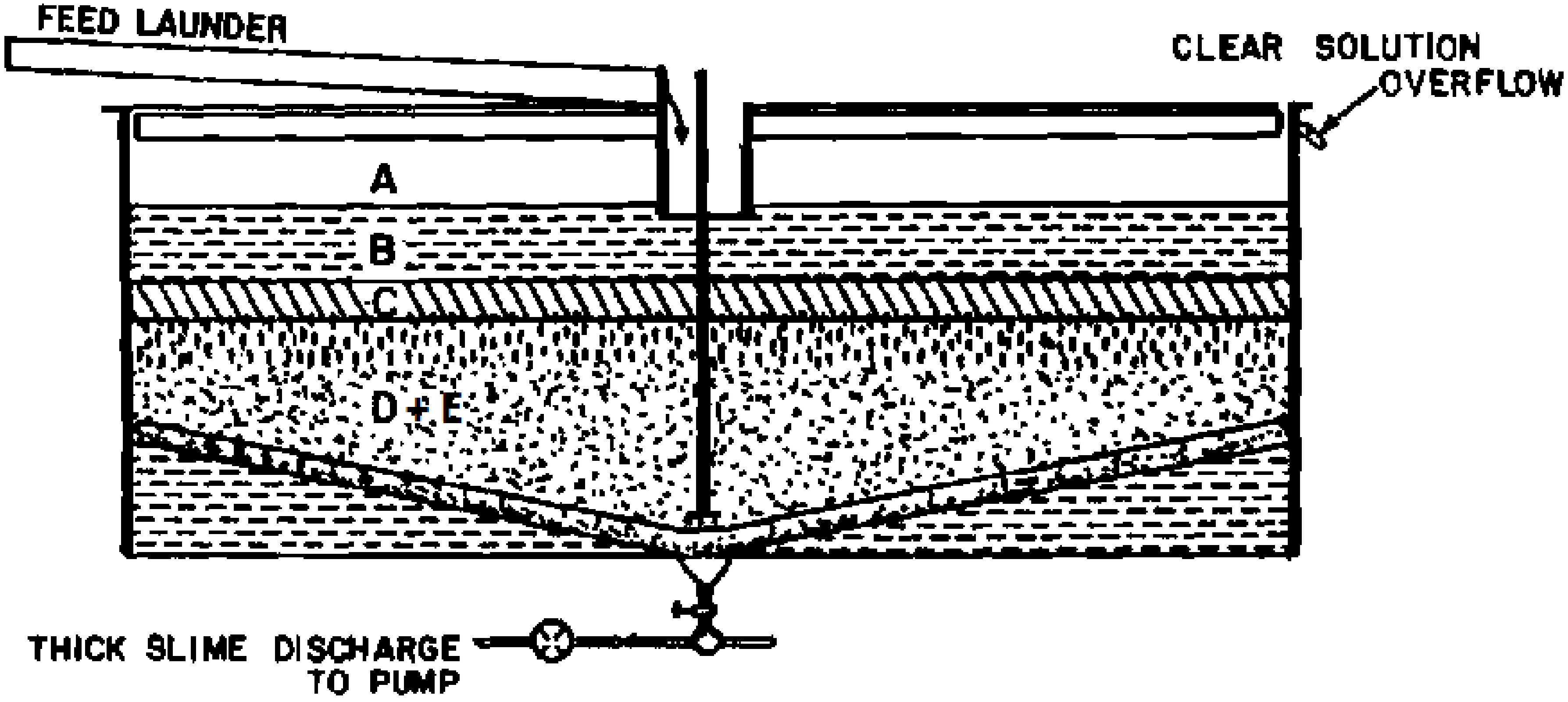
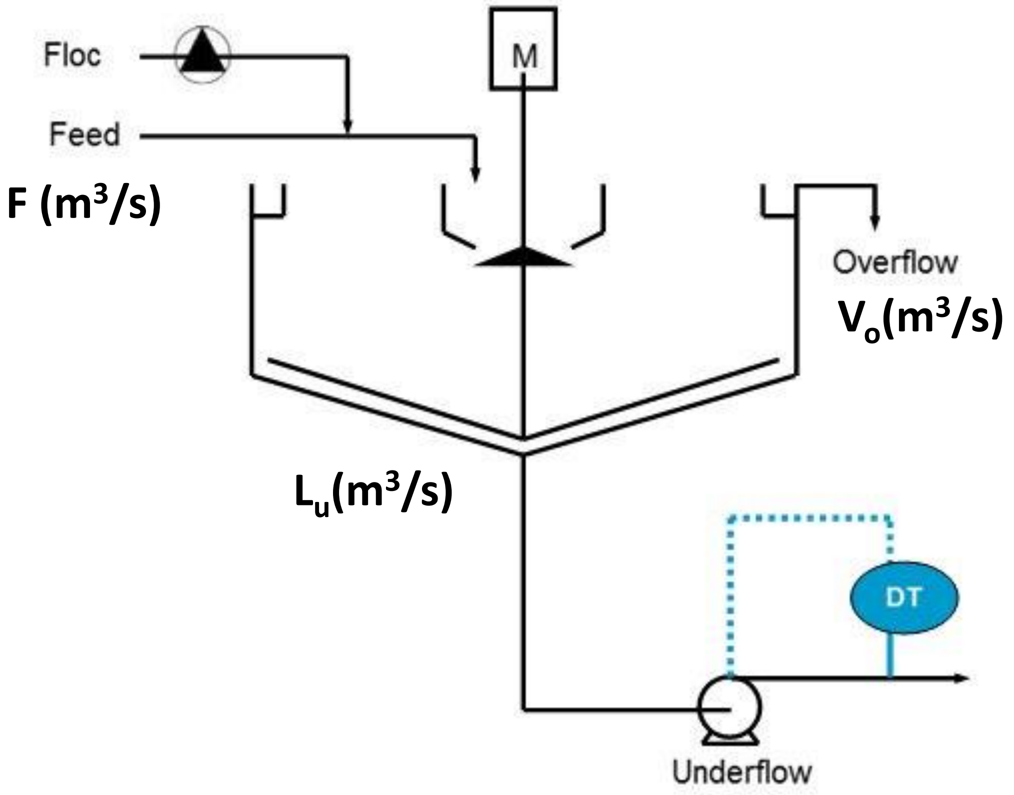


FIG. 3 Progress of settling with time. Upper curve, boundary between layers A and B. Lower curve, upper boundary of layer D (see Fig. 14-20).

Continuous thickener



Design of continuous thickener



Solid material balance

$$Fc_F = L_u\, c_u \qquad .....(1)$$

C_F , C_u are concentrations of solids (kg. of solids per m^3 of slurry) in feed slurry and underflow sludge

Liquid balance

$$F\left[1-\frac{c_F}{\rho_s}\right]-L_u\left[1-\frac{c_u}{\rho_s}\right]=V_o \qquad .....(2)$$

ρ_s = density of solids, kg/m^3

Dividing both side by the cross sectional area A of the tank, we get

$$\frac{Fc_F}{A}=\frac{\left(\frac{V_o}{A}\right)}{\left[\left(\frac{1}{c_F}\right)-\left(\frac{1}{c_u}\right)\right]}=\frac{v}{\left(\frac{1}{c_F}\right)-\left(\frac{1}{c_u}\right)} \qquad .....(3)$$

When the thickener is operated at maximum capacity the lowest settling rate (*v*, terminal velocity of the particle) must be equal to or grater then V/A (the upward velocity of the liquid) otherwise some solids will leave the overflow.

- As the overflow does not contain any solid particles, the upward velocity of liquid must be less than or equal to the settling velocity of particle *v.*

- *Equation 3* is only valid for the perfectly mixed vessels in which the concentration inside the vessel can be taken to that in the outlet stream.

- Not precisely true since the sedimentation is a slow and time dependent process.

- The equation can be rewrite considering a ***capacity-limiting layer*** (which is the concentration layer requiring maximum area to pass a unit quantity of solids) .

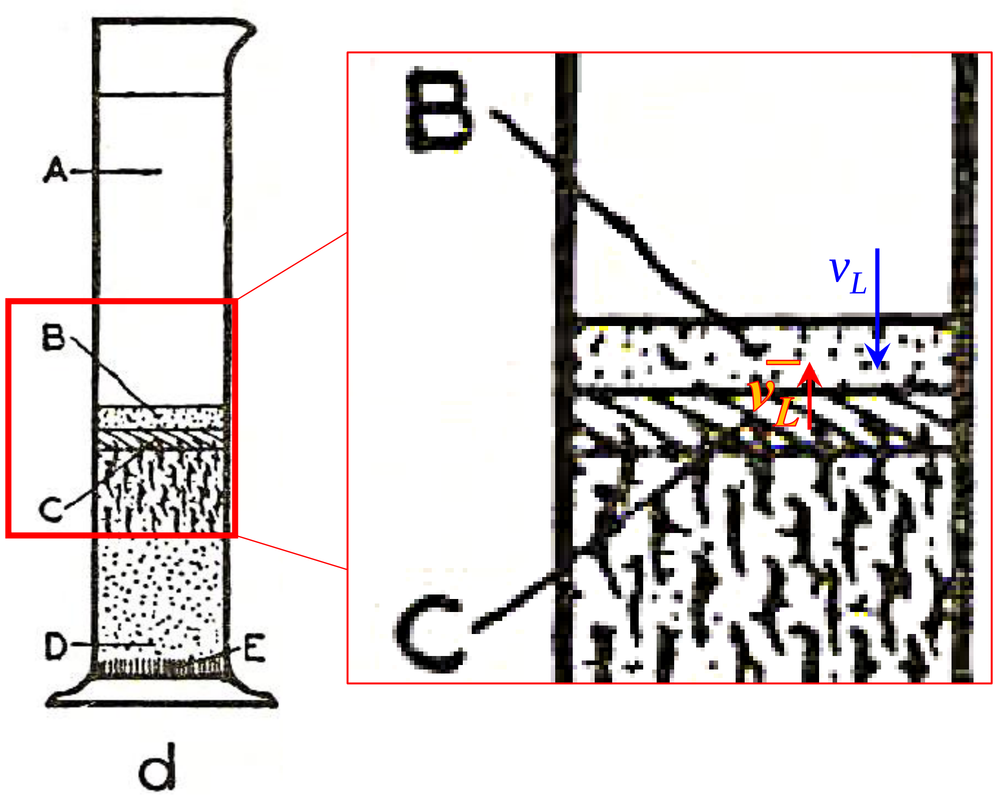
- If such a layer exists and if C_L is the concentration of solids in that layer.

$$\frac{Lc_L}{A} = \frac{v}{\left(\frac{1}{c_L}\right) - \left(\frac{1}{c_u}\right)} \qquad .....(4)$$

Kynch Theory

Assumptions

- Solid particles are all small with respect to the container, and of the same size, shape and density
- Incompressible
- No mass transfer between components
- ***Settling velocity is a function of the local concentration only***
- One-dimensional the concentration of particles is constant at any cross-section of the vessel



- The concentration of solids in the zone C must range between that of the initial slurry concentration of zone B and that of the final slurry in zone D.

- If the solid handling capacity is lowest at some intermediate concentration, a zone of such concentration mush start building up, since the rate at which solids enter this zone will be less than the rate at which they will leave this zone .

- Consider the test at the instant of time when the layer corresponding to the limiting settling rate has reached the interface between the clear supernatant liquid and the pulp (Figure 1 e).

- All the solids in the initial pulp must have passed through the layer as the layer was propagated upward from the bottom of the column.

- If concentration of this layer is c_L and the time instant at which the layer reaches the interface is θ_L then

$$c_L A(v_L + \overline{v}_L)\theta_L = c_0 A z_0 \quad .....(7)$$

Where v_L is the settling velocity of the particle in a zone having particle concentration c_L

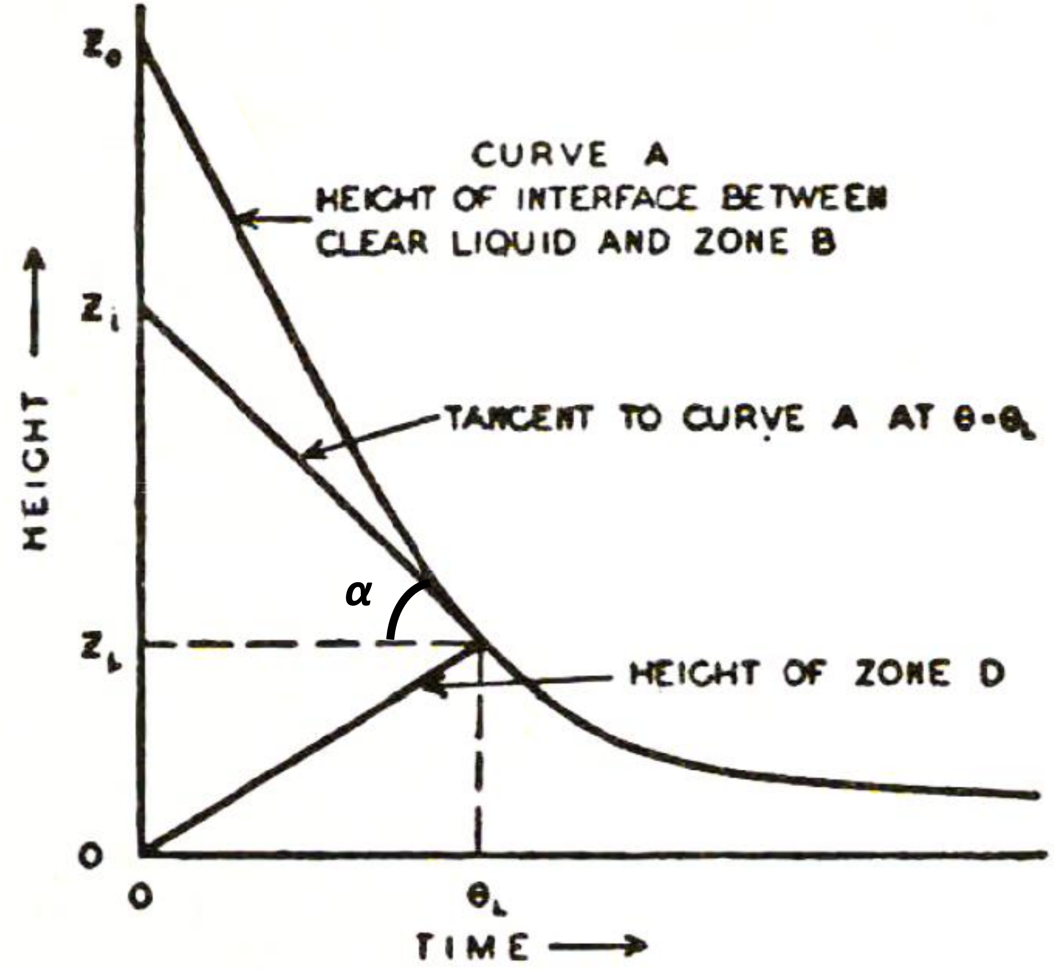
$\overline{v}_L$ is the upward propagation velocity of the zone having particle concentration c_L

$$\bar{v}_L = \frac{z_L}{\theta_L}$$

Where z_L is the height of the interface at time θ_L

Substituting

$$c_L = \frac{c_0 Z_0}{z_L + v_L \theta_L} \qquad \text{.....(8)}$$



The value of the settling velocity v_L is the slope of the tangent to curve A at $\theta=\theta_L$

Terminal velocity v_L of the particles at the zone of solid concentration c_L at time θ_0 is the slope of the tangent to curve A

$$\mathrm{v}_L = \tan\alpha = \frac{z_i - z_L}{0 - \theta_L}$$

$$z_i = z_L + \theta_L \, \mathrm{v}_L \qquad \text{.....(9)}$$

Gives,

$$c_L z_i = c_0 z_o \qquad \text{Or} \qquad c_L = \frac{c_0 z_o}{z_i} \qquad \text{.....(10)}$$

Continuous thickener design steps

Given: Batch settling data; Height of A-B interface (z) with time, Initial concentration (c_F) and height of the liquid air interface (z_0), Feed flow rate (F, volume/time)/ Underflow rate (L_u)

Step 1 : Find the rate of interface ($v|_t = dz/dt$) from the batch settling data (z vs t) at different time

Step 2 : Find the corresponding c_L using equation (10)

$$c_L\,\Big|_t = \frac{c_0 z_o}{z_i\,\big|_t}$$

z_i can be obtained by taking a slope at any time t as shown in the graph

Step 3 : Find $\left|\dfrac{Lc_L}{A}\right|_{c_L}$ using $v|_t$ and $c_L\,\big|_t$ information from equation 4

$$\left|\frac{Lc_L}{A}\right|_{c_L} = \frac{v\,|_t}{\left(\dfrac{1}{c_L\,|_t}\right) - \left(\dfrac{1}{c_u}\right)}$$

c_u can be obtained using equation 1 as

$$c_u = Fc_F / L_u$$

Step 4 : Plot $\left.\frac{Lc_L}{A}\right|_{c_L}$ with v information from equation 4

- It can be seen that (Lc_L/A) decreases with increase in v reaching a minimum value and then increases.
- From the minimum value of (Lc_L/A), **A is computed**.

Note:

- For actual industrial design the computed thickener area (A) is multiplied by two safety factors (SF_1 and SF_2).
- SF_1 takes care of the variation in feed characteristic (temperature, pH, particle size, solid concentration *etc.*) and magnitude varies form 1.10-1.25.
- SF_2 takes care of the turbulence at the feed inlet and magnitude varies form 1.10-1.5.

Estimating Height (Depth) of the Compression Layer

The height, *H*, of the layer would depend on the total volume of the solids and liquid in the compression zone and inversely as the area of the vessel. That is

$$H_c = \frac{V_c}{A}$$

where V_C = the total volume of the liquid and the solids in the compression layer.

So, V_C = total volume of (solid + liquid) in the compression layer.

$= V_s + V_L$

$$V_s = V_s + V_L$$

$$= \frac{Q_{V(F)} C_F t_D}{\rho_S} + \frac{Q_{V(F)} C_F t_D}{\rho_L} \left(\frac{\rho_c - C_c}{C_c} \right)$$

where, $C = \frac{\text{mass of solid}}{\text{total volume}}$ *e.g.* $C_c = \frac{\text{mass of solid}}{\text{volume of compression zone}}$

ρ_s, ρ_L and ρ_c are the densities of solid, liquid and sludge in the compression zone.

Q_V is the volume flow rate and td is the residence time of particle in compression zone .

$$H_c = \frac{Q_{V(F)} C_F t_D}{A \rho_S} \left(1 + \frac{\rho_S}{\rho_L} \left(\frac{\rho_c - C_c}{C_c} \right) \right)$$

Problem 1

The data given below were obtained from single batch sedimentation test on an ore slurry. The true density of the solids in the slurry was 2.5 gm / cc and the density of the liquid was 110 g / cc. Determine the area required for a thickener to handle 100 metric tons of solids per day from a feed concentration of 64.5 g / liter to an underflow concentration of 485 g / liter.

Data from batch sedimentation

Concentration in gm of solid per liter of slurry	Settling rate cm / hr
64.5	139.9
70.9	103.9
94.3	71.9
111.7	49.4
139.9	27.1
173.9	16.5
222.0	10.0
331.0	6.4

Ans: 46.58 m^2

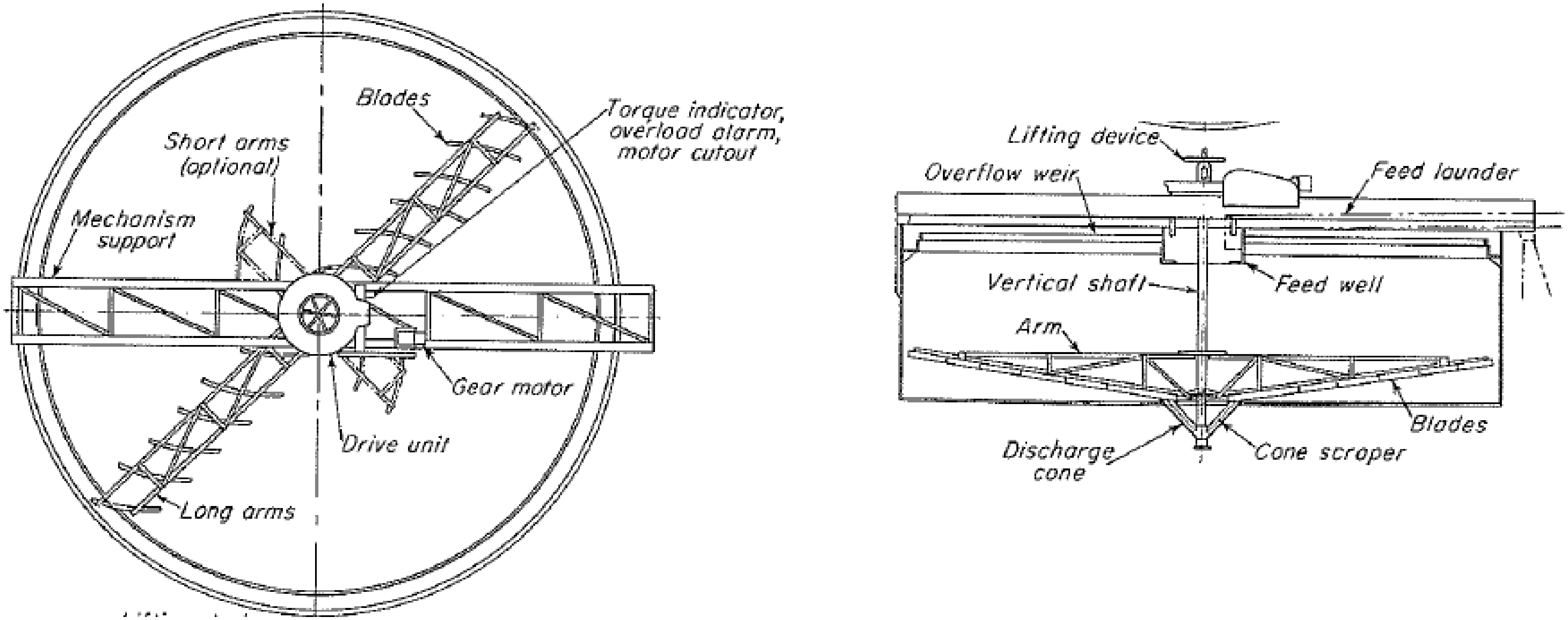
Problem 2

A slurry containing 5 kg of water/kg of solids is to be thickened to a sludge containing 1.5 kg of water/kg of solids in a continuous operation. Laboratory tests using five different concentrations of the slurry yielded the following data:

Concentration (kg water/kg solid)	5.0	4.2	3.7	3.1	2.5
Rate of sedimentation (mm/s)	0.20	0.12	0.094	0.070	0.050

Calculate the minimum area of a thickener required to effect the separation of a flow of 1.33 kg/s of solids.

Ans: 31.12 m^2



Gravity Thickener