Solid Particulates:

Sedimentation

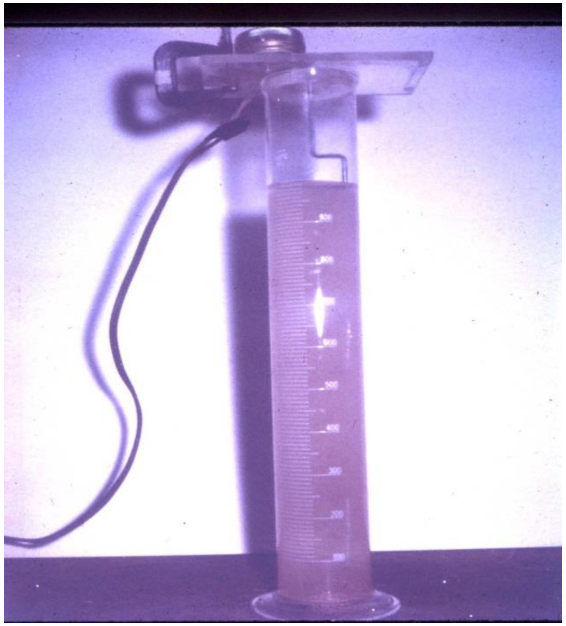
Dr. Motasem Saidan

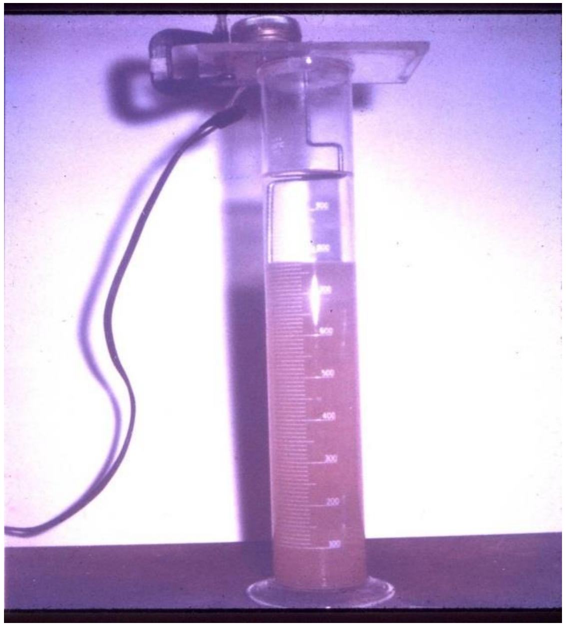
M. Saidan@gmail.com

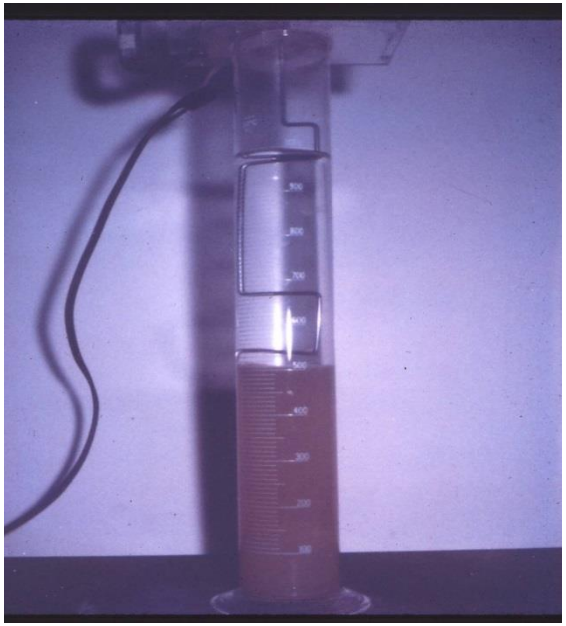
Introduction

- Sedimentation describes the motion of molecules in solutions or particles in suspensions in response to an external force such as gravity, centrifugal force or electric force.

- The separation of a dilute slurry or suspension by gravity settling into a clear fluid and s slurry of higher solids content is called sedimentation.



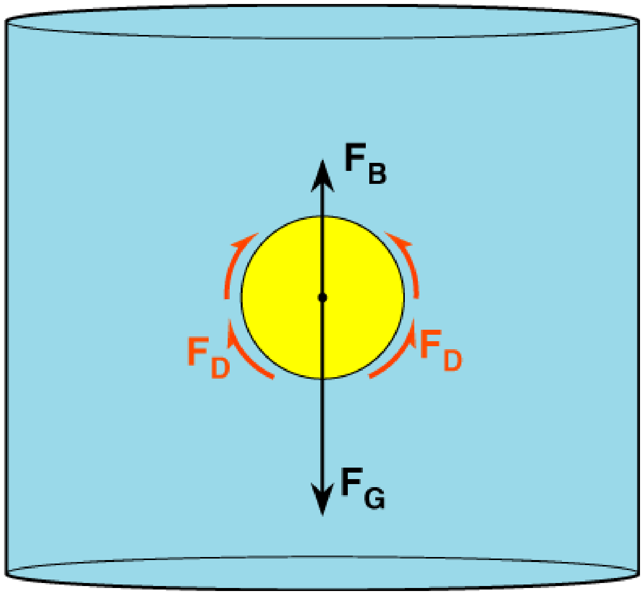




- When a particle is dropped into a column of fluid it immediately accelerates to some velocity and continues falling through the fluid at that velocity (often termed the *terminal settling velocity*).

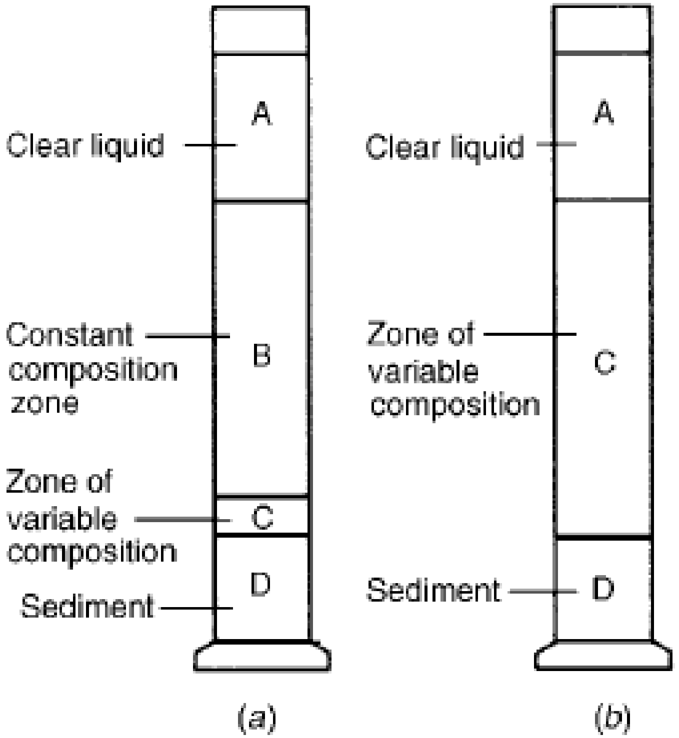
- The speed of the terminal settling velocity of a particle depends on properties of both the fluid and the particle:

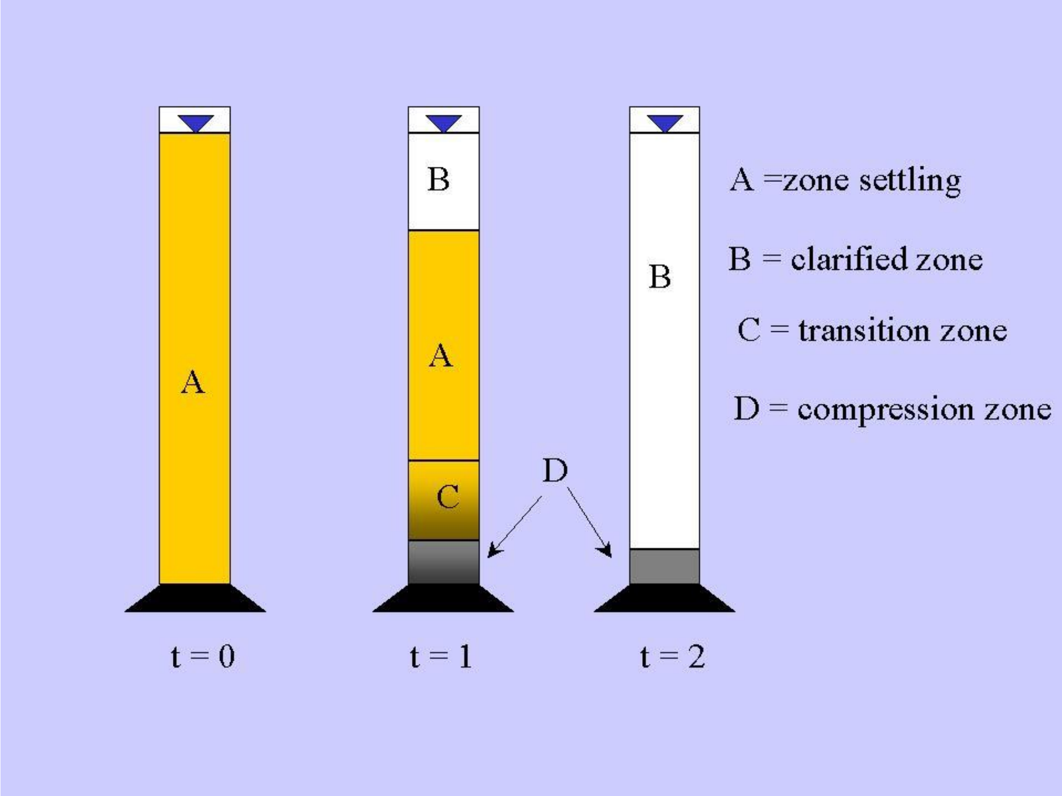
  - ✓ The size if the particle
  - ✓ The density of the material making up the particle
  - ✓ The shape of the particle
  - ✓ fluid properties: μ, Re



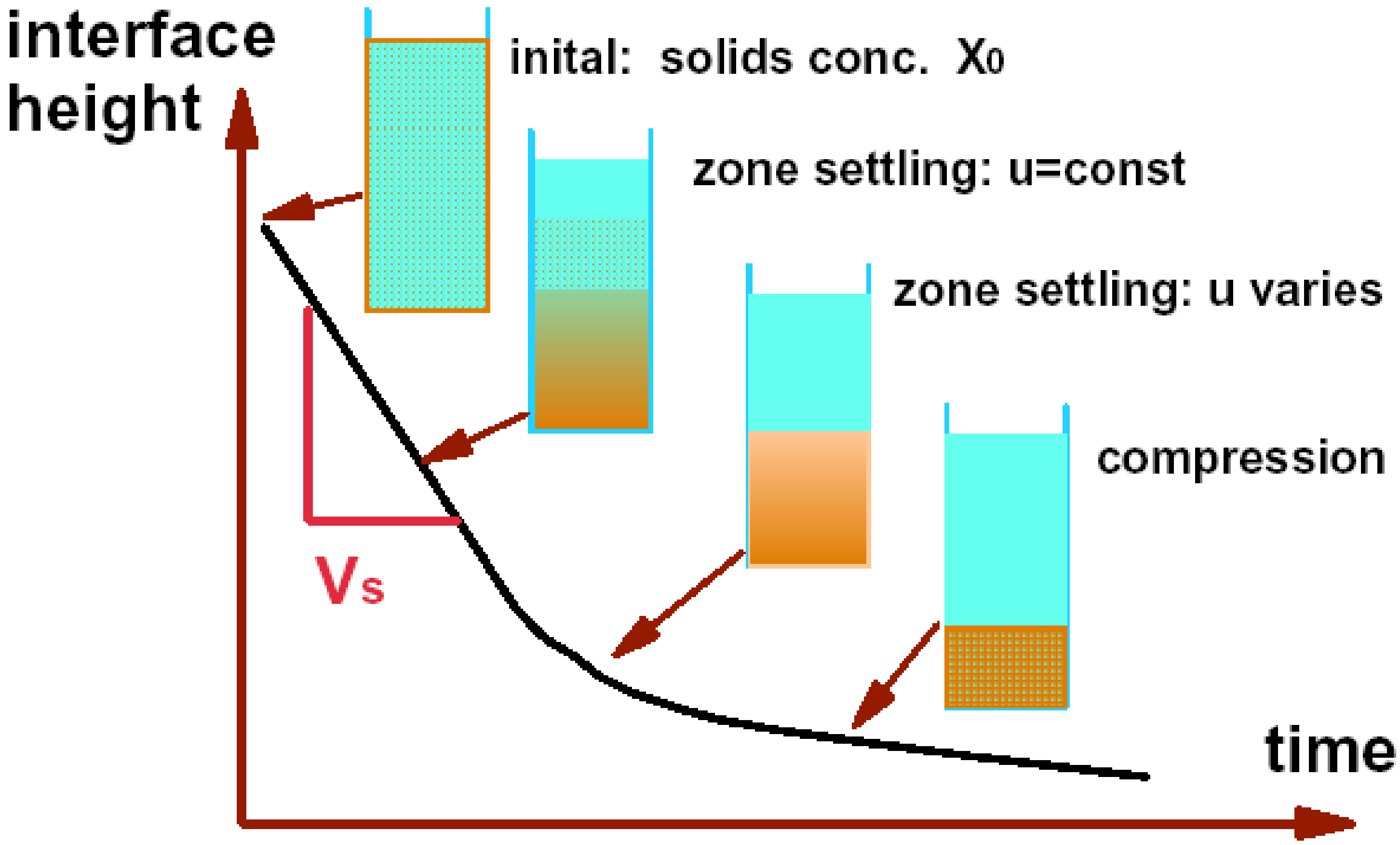
Sedimentation of fine particles

A is clear liquid, **B** is suspension of the original concentration, **C** is a layer through which the concentration gradually increases, and **D** is sediment.

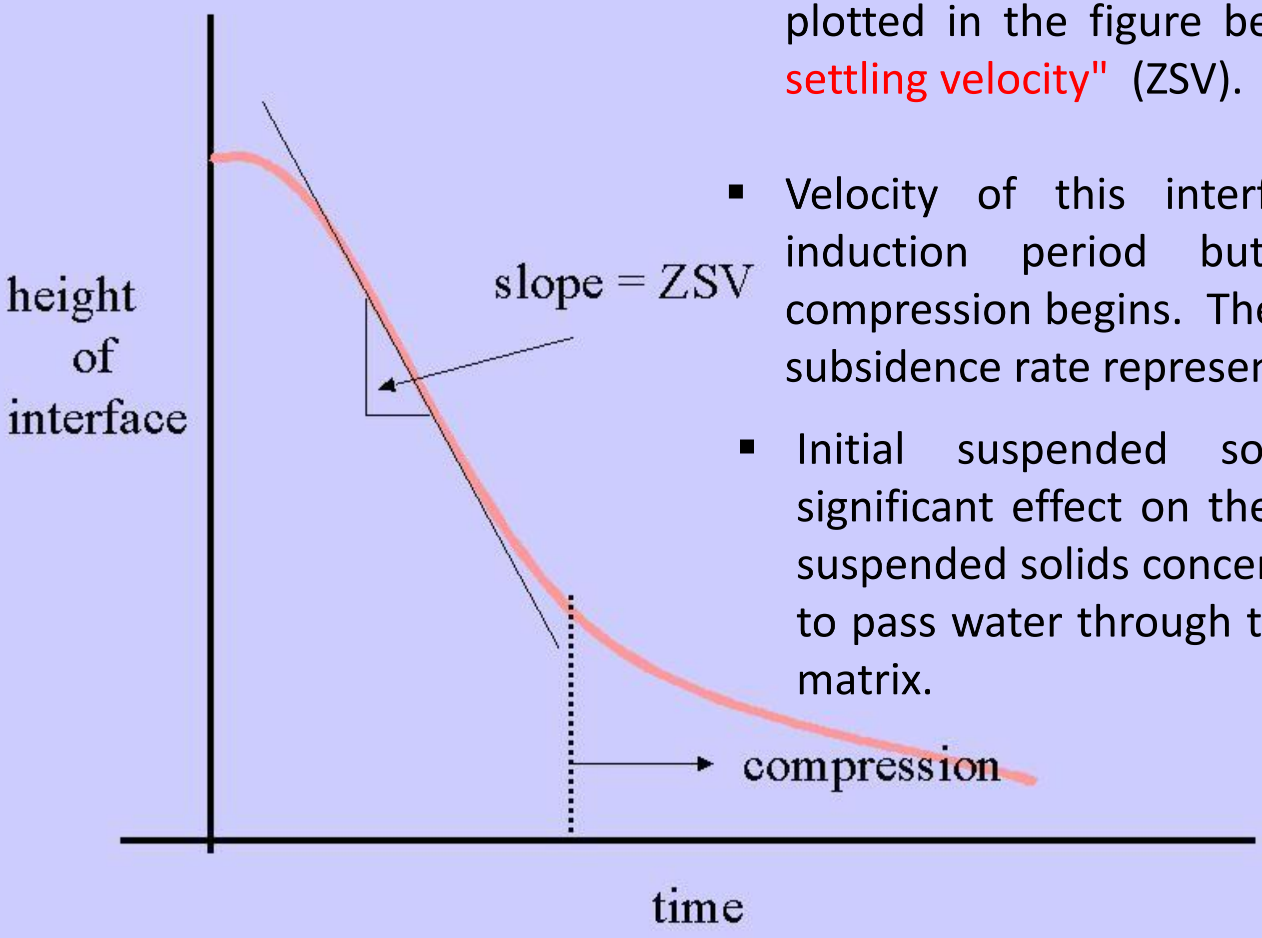




Zone Settling & Compression



Zone settling velocity



- The height of the interface (between the clarified zone and the zone settling zone) versus time is plotted in the figure below to determine the "zone settling velocity" (ZSV).
- Velocity of this interface is steady after some induction period but changes with time as compression begins. The slope of the steady interface subsidence rate represents zone settling velocity.
- Initial suspended solids concentration has a significant effect on the ZSV because the higher the suspended solids concentration the more difficult it is to pass water through the pore spaces in the settling matrix.

Settling velocity: concentrated suspension

ROBINSON suggested a modification of Stokes' law and used the density (ρc) and viscosity (μc) of the suspension in place of the properties of the fluid to give:

$$u_c = \frac{K'' d^2 (\rho_s - \rho_c) g}{\mu_c}$$

$$(\rho_s - \rho_c) = \rho_s - \{\rho_s(1 - e) + \rho e\} = e(\rho_s - \rho)$$

where e is the voidage of the suspension.

$$\mu_c = \mu(1 + k''C)$$

where: k'' is a constant for a given shape of particle (2.5 for spheres),
C is the volumetric concentration of particles, and
μ is the viscosity of the fluid.

This equation holds for values of C up to 0.02. For more concentrated suspensions,

$$\mu_c = \mu\, e^{k''C/(1-a'C)}$$

in which a' is a second constant, equal to $(39/64) = 0.609$ for spheres.

Velocity of the particle relative to the fluid

The velocity of the particle relative to the fluid u_p

$$u_p = \frac{d^2(\rho_s - \rho_c)g}{18\mu}\mathrm{f}(e) \qquad \mathrm{f}(e) = 10^{-1.82(1-e)}$$

$$u_p = u_c + u_c\frac{1-e}{e} = \frac{u_c}{e}$$

$$u_c = \frac{e^2 d^2(\rho_s - \rho)g}{18\mu}10^{-1.82(1-e)}$$

$$u_p = \frac{u_c}{e} = \frac{d^2(\rho_s - \rho_c)g}{18\mu_c}$$

Factors affecting the sedimentation process

- ***Height of suspension:***

The height of suspension does not generally affect either the rate of sedimentation or the consistency of the sediment ultimately obtained.

- ***Diameter of vessel***

If the ratio of the diameter of the vessel to the diameter of the particle is greater than about 100, the walls of the container appear to have no effect on the rate of sedimentation. For smaller values, the sedimentation rate may be reduced because of the retarding influence of the walls.

- ***Concentration of suspension***

The higher the concentration, the lower is the rate of fall of the sludge line because the greater is the upward velocity of the displaced fluid and the steeper are the velocity gradients in the fluid.

- ***Shape of vessel***

It is possible to obtain an accelerated rate of settling in an inclined tank by inserting a series of inclined plates.

Coagulation and Flocculation

- Coagulation concentrations are the electrolyte concentrations required just to coagulate a sol.
- This can be achieved by increasing the ionic strength of the solution by adding salts with multivalent ions.

- The behavior of suspensions of fine particles is very considerably influenced by whether the particles flocculate. The overall effect of flocculation is to create large conglomerations of elementary particles.

- The aggregation of colloids is known as coagulation, or flocculation. Particles dispersed in liquid media collide due to their relative motion; and the stability (that is stability against aggregation) of the dispersion is determined by the interaction between particles during these collisions. Attractive and repulsive forces can be operative between the particles; these forces may react in different ways depending on environmental conditions, such as salt concentration and *pH*.

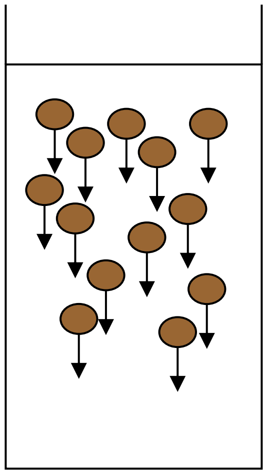
The Kynch theory of sedimentation

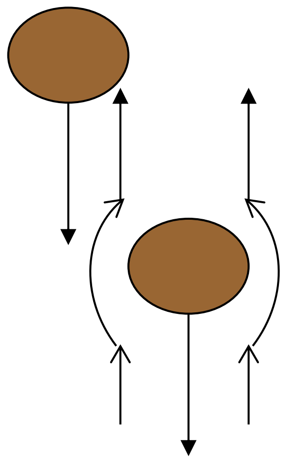
The behavior of concentrated suspensions during sedimentation

a) Particle concentration is uniform across any horizontal layer,
b) Wall effects can be ignored,
c) There is no differential settling of particles as a result of differences in shape, size, or composition,
d) The velocity of fall of particles depends only on the local concentration of particles,
e) The initial concentration is either uniform or increases towards the bottom of the suspension, and
f) The sedimentation velocity tends to zero as the concentration approaches a limiting value corresponding to that of the sediment layer deposited at the bottom of the vessel.

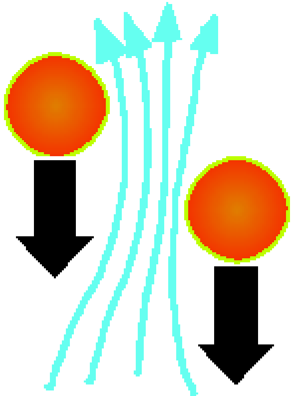
Hindered Settling

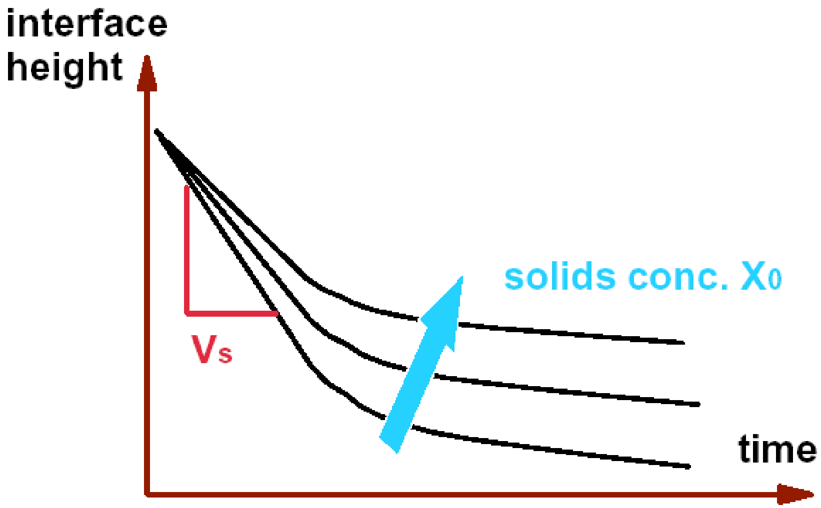
If the settling is carried out with high concentrations of solids to liquid so that the particles are so close together that collision between the particles is practically continuous and the relative fall of particles involves repeated pushing apart of the lighter by the heavier particles it is called hindered settling.





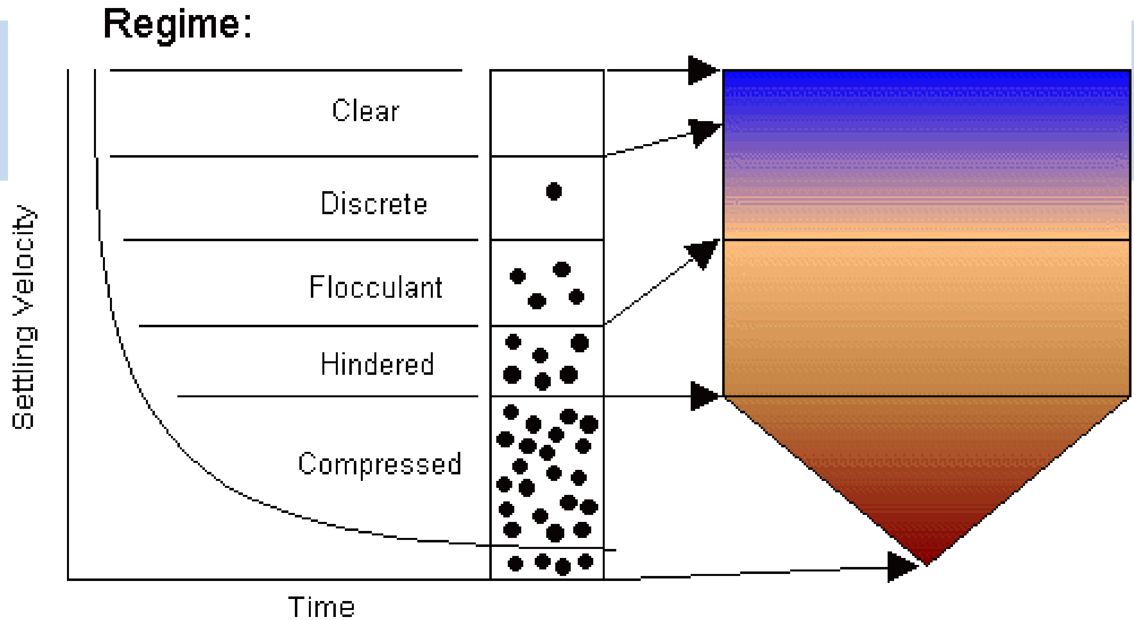
higher solids concentration reduces velocity





The thickener

- The thickener is the industrial unit in which the concentration of a suspension is increased by sedimentation, with the formation of a clear liquid.



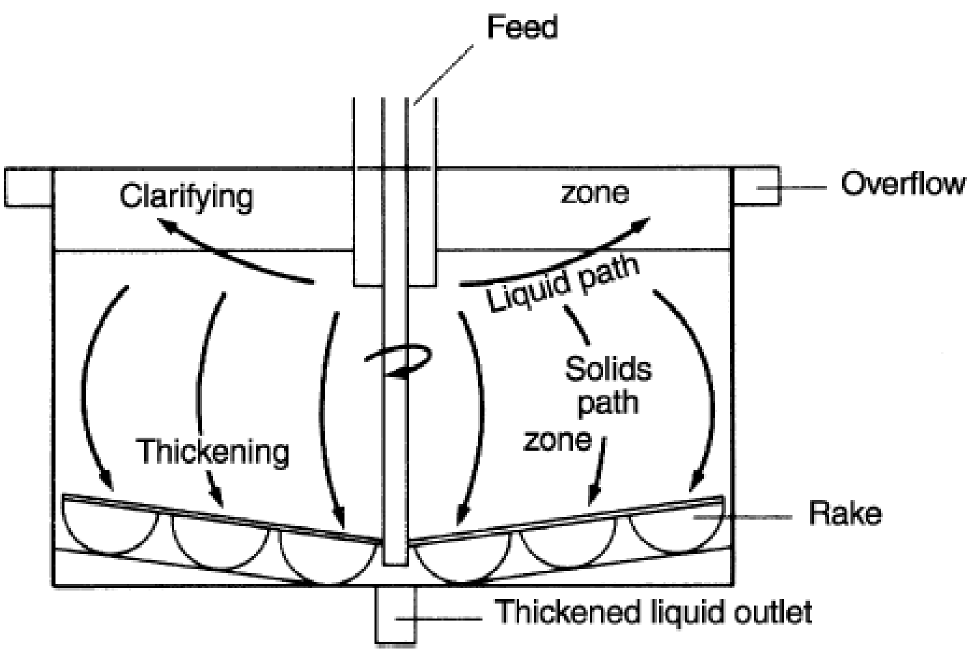
- In most cases, the concentration of the suspension is high and hindered settling takes place.
- Thickeners may operate as batch or continuous units, and consist of tanks from which the clear liquid is taken off at the top and the thickened liquor at the bottom.
- In a thickener of given size, the rate of sedimentation should be as high as possible. The rate may be artificially increased by the addition of small quantities of an electrolyte, which causes precipitation of colloidal particles and the formation of flocs.
- The suspension is also frequently heated because this lowers the viscosity of the liquid, and encourages the larger particles in the suspension to grow in size.
- The thickener frequently incorporates a slow stirrer, which causes a reduction in the apparent viscosity of the suspension

Thickner Function

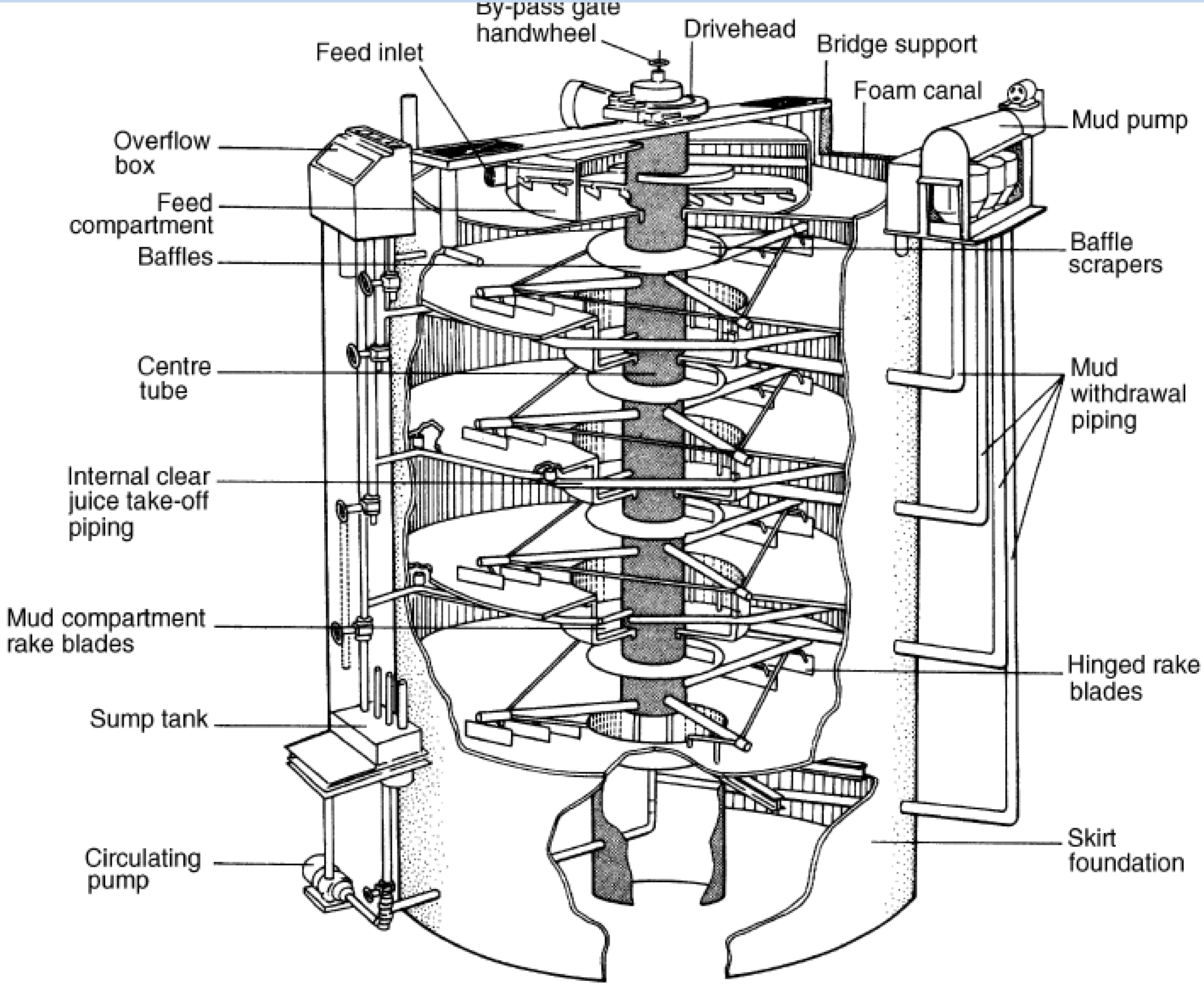
The thickener has a twofold function:

1. it must produce a clarified liquid, and therefore the upward velocity of the liquid must, at all times, be less than the settling velocity of the particles. Thus, for a given throughput, the clarifying capacity is determined by the diameter of the tank.

2. the thickener is required to produce a given degree of thickening of the suspension. This is controlled by the time of residence of the particles in the tank, and hence by the depth below the feed inlet.



There are therefore two distinct requirements in the design—**first**, the provision of an adequate diameter to obtain satisfactory clarification and, **secondly**, sufficient depth to achieve the required degree of thickening of the underflow


By-pass gate
handwheel
Feed inlet
Drivehead
Bridge support
Foam canal
Mud pump
Overflow
box
Feed
compartment
Baffles
Baffle
scrapers
Centre
tube
Mud
withdrawal
piping
Internal clear
juice take-off
piping
Mud compartment
rake blades
Hinged rake
blades
Sump tank
Circulating
pump
Skirt
foundation

Thickening zone

- In the design of a thickener, it is therefore necessary to establish the concentration at which the total flux is a *minimum* in order to calculate the required area.

- The total solids flux (volumetric flowrate per unit area) at any level does not exceed the rate at which the solids can be transmitted downwards.

The total flux ψ_T may be expressed as the product of the volumetric rate per unit area at which thickened suspension is withdrawn (u_u) and its volumetric concentration C_u.

Thus:

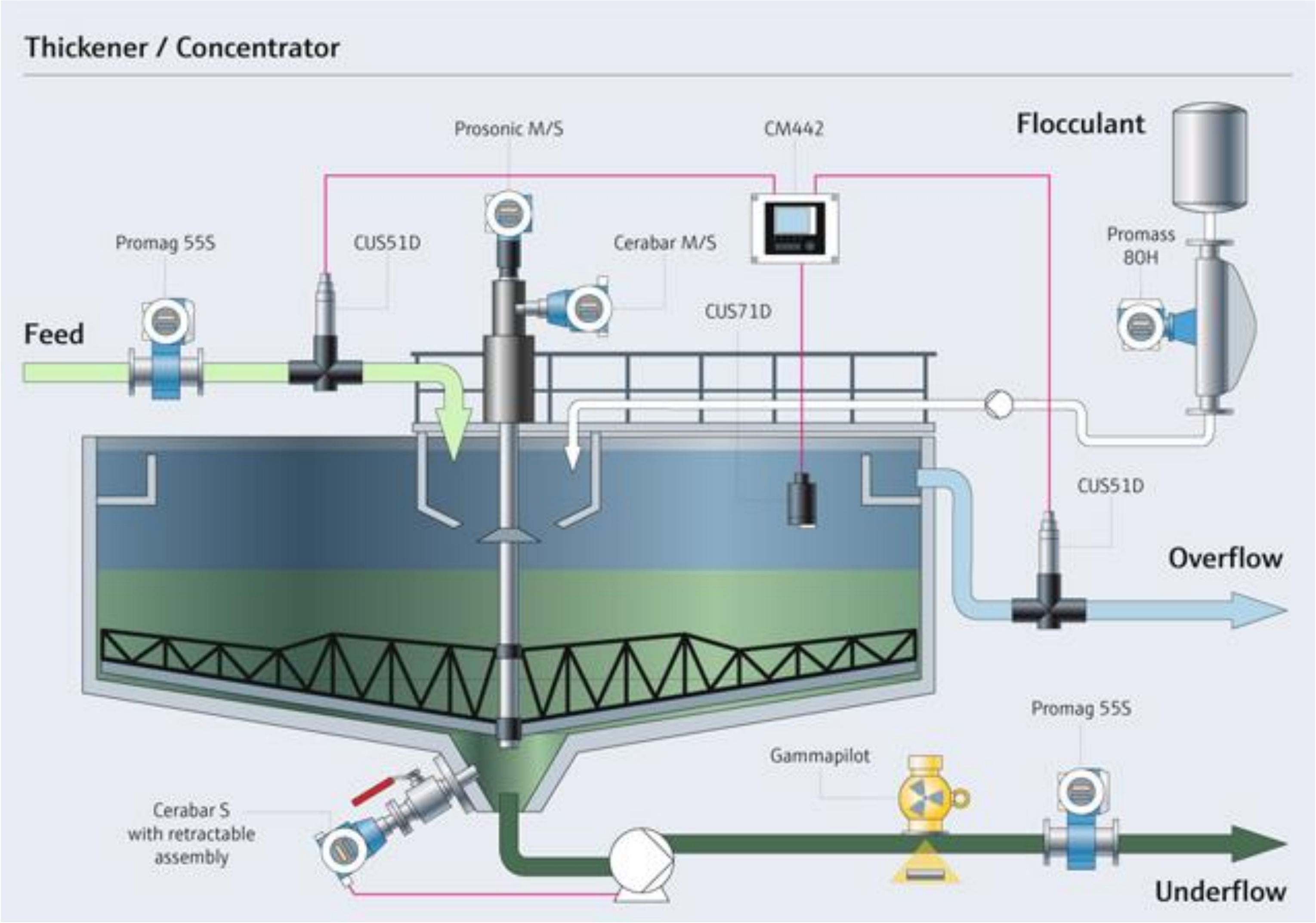
$$\psi_T = u_u C_u \tag{5.42}$$

This flux must also be equal to the volumetric rate per unit area at which solids are fed to the thickener.

Thus:

$$\psi_T = \frac{Q_0}{A} C_0 \tag{5.43}$$

where: Q_0 is the volumetric feed rate of suspension,
A is the area of the thickener, and
C_0 is the volumetric concentration of solids in the feed.


Thickener / Concentrator
Prosonic M/S
CM442
Flocculant
Promag 55S
CUS51D
Cerabar M/S
Promass
80H
CUS71D
Feed
CUS51D
Overflow
Promag 55S
Gammapilot
Cerabar S
with retractable
assembly
Underflow

Continuous Thickener: Overflow

- The liquid flowrate in the overflow ***(Q´)*** is the difference between that in the feed (***Q_o***) and in the underflow.

$$\frac{Q'}{Q_0} = 1 - \frac{C_0}{C_u}$$

the required area is therefore given by

$$A = Q_0 \frac{1}{u_c}\left[1 - \frac{C}{C_u}\right]$$

It is therefore necessary to calculate the ***maximum* value** of ***A*** for all the values of ***C*** which may be encountered.

The previous equation can be rearranged in terms of the mass ratio of liquid to solid in the feed *(Y)* and the corresponding value *(U)* in the underflow to give:

$$Y = \frac{1-C}{C}\frac{\rho}{\rho_s} \quad \text{and} \quad U = \frac{1-C_u}{C_u}\frac{\rho}{\rho_s}$$

Then:

$$C = \frac{1}{1+Y(\rho_s/\rho)} \quad C_u = \frac{1}{1+U(\rho_s/\rho)}$$

and:

$$A = \frac{Q_0}{u_c}\left\{1 - \frac{1+U(\rho_s/\rho)}{1+Y(\rho_s/\rho)}\right\}$$

$$= \frac{Q_0(Y-U)C\rho_s}{u_c\rho}$$

Example

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 concentration sof 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.