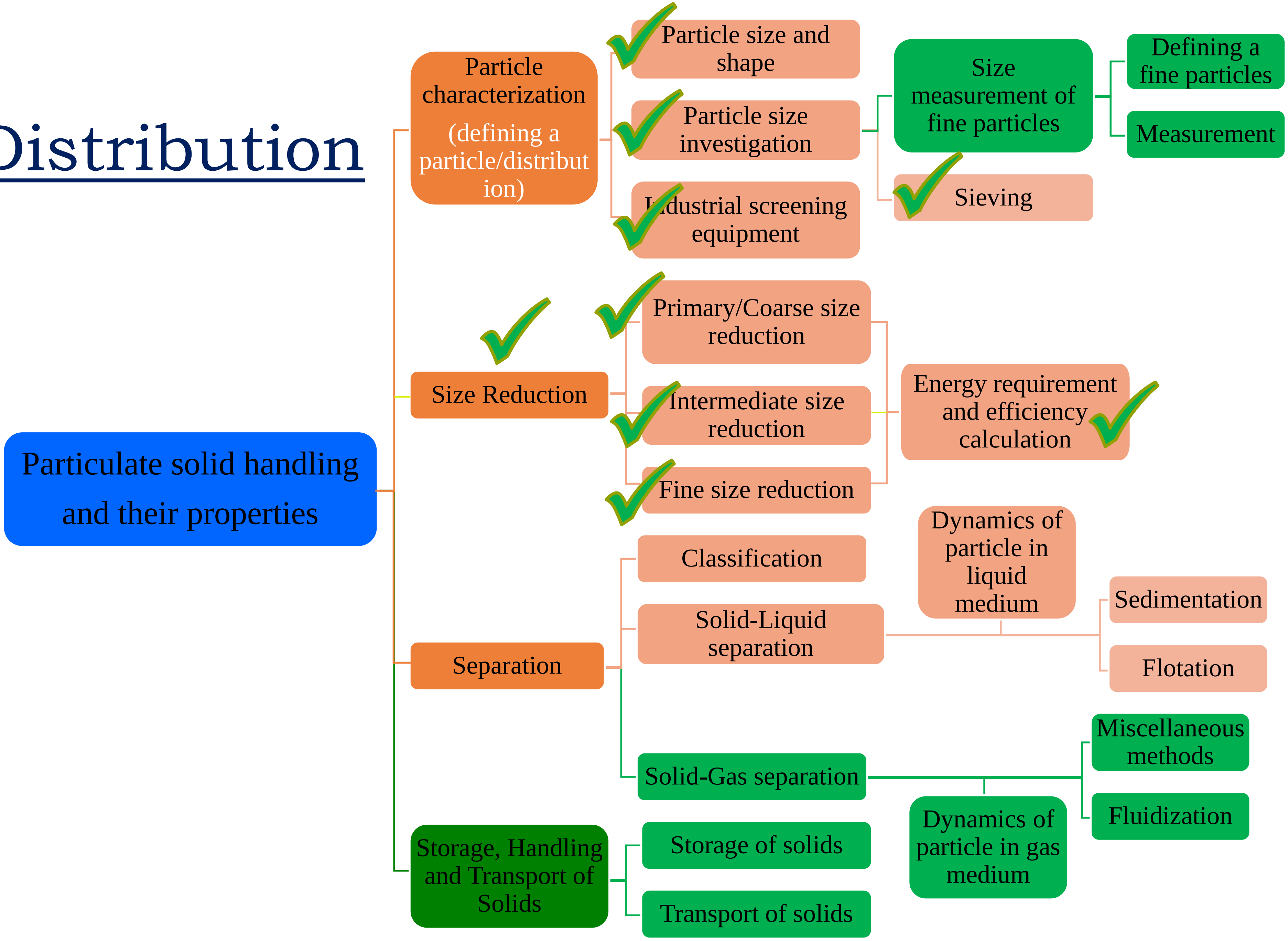
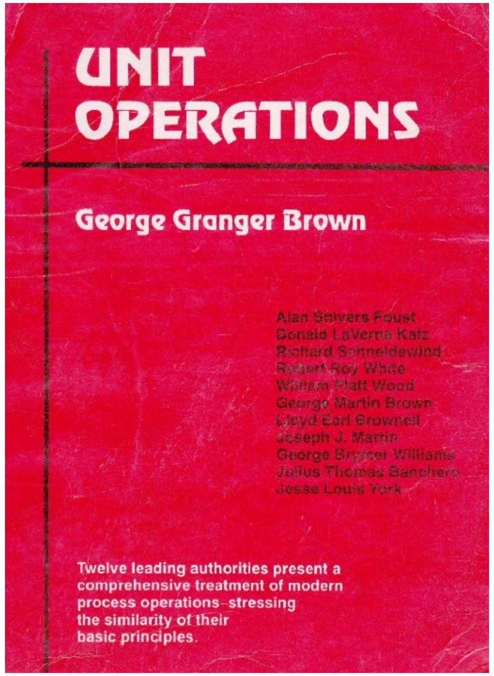
Course Distribution

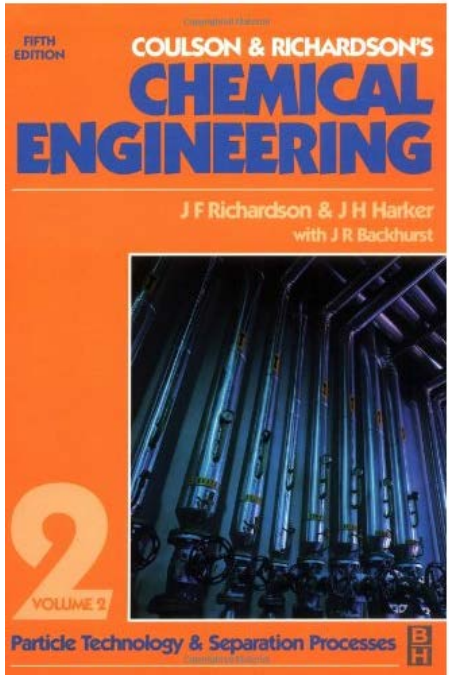


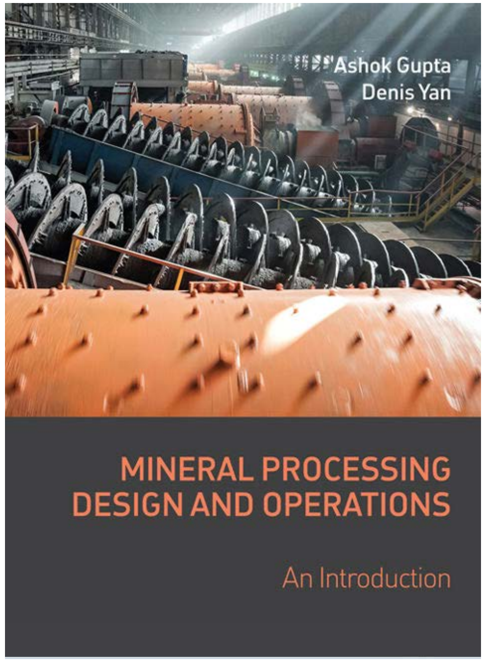
CLASSIFICATION

Resource

- **Books**



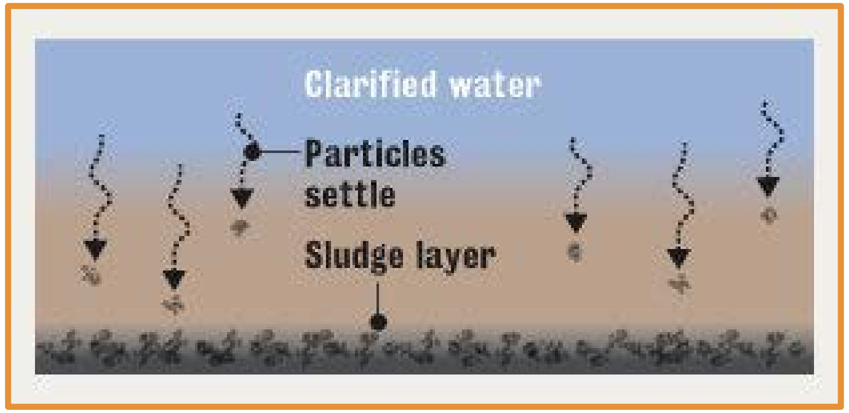




- **Relevant journal papers mentioned in the individual topics**

Introduction

Classification, generally is an operation in which a mass of grains of mixed sizes and different specific gravities is allowed or caused to settle through a fluid which may be either in motion or substantially at rest. The fluid ordinarily employed is water, but other liquid and air or other gases may be used.



- In classification particles of various sizes, shapes and specific gravities are separated by being allowed to settle in a fluid.
- The coarser, heavier and rounder grains settle faster than the than the finer lighter and more angular grains. The fluid is in motion, carrying away the slow settling grains while a sediment of fast settling grains is removed simultaneously from the classifier.

- The basic principle of classification is:

The coarser, heavier and rounder particles settle faster than the finer, lighter and more angular particles

- In classification, certain particles are only allowed to settle in the fluid medium in order to separate the particles into two/more fractions.

Classifiers achieve separation of large grain form a smaller one, a heavier from a lighter one. In general the following principles apply -

1. Two grains of the same material or similar shape the larger settles the faster.
2. Two grains of similar shape and size but different specific gravity-higher specific gravity will settle faster than lower one.
3. Two grains of similar shape but different specific gravity, but which settle at the same rate –the one with the higher specific gravity is always smaller than the one with lower specific gravity.

Basic principles of settling

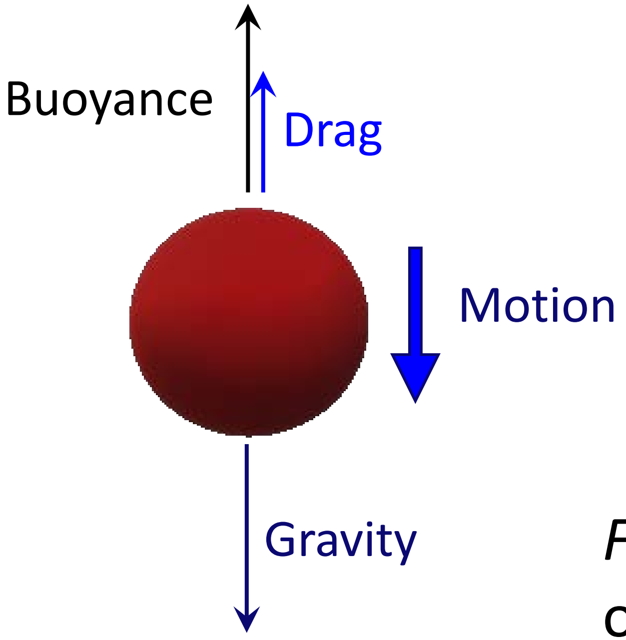
- The movement of a solid particle in a fluid depends on many parameters and the inter-relation among these parameters is very complex.

- A simplified analysis of the movement of the particle can be made by the following assumptions

1. The shape and size of the particle are defined. For the simplest case, it is assumed that the particle is sphere of diameter '*d*'.
2. The particle is non-porous and incompressible (i.e., its density remains constant). The particle is insoluble in the fluid and does not react chemically with it.
3. The density and viscosity of the fluid are constant.
4. The effect of surface characteristics or interfacial conditions between the solid and the fluid on the dynamics of the particle is neglected.
5. The particle is freely settling under gravity. Other particles are either absent or even if presents, do not directly interfere with the motion of the particle under consideration.
6. The fluid forms an infinite medium. In other words, the particle under consideration is at an infinite distance (very long distance) from the fluid boundaries and therefore the boundary effect or commonly called the wall effects on the dynamics of the particle can be neglected.
7. The fluid is a continuous medium, and the particle size is much larger than the mean free path of the fluid molecules. Thus the effect of slip between the particles and the fluid molecules can be neglected.

Basic principles of free settling

Consider a single homogeneous spherical particle of diameter '*d*' and density 'ρ_p' falling under gravity in a viscous fluid of density 'ρ_f' and viscosity 'μ_f'.



$$m_p g - m_f g - F_R = m_p \frac{dV}{dt} \quad \text{.......(1)}$$

F_R, (resistance to the motion), is the filler medium drag, which acts on the particle and is parallel and opposite direction of its motion.

When the acceleration of the particle is zero, the particle attains the terminal velocity.

$$F_R = \frac{\pi}{6} g d^3 (\rho_p - \rho_f) \quad ...(2)$$

Assuming the particle as sphere

The resistive force F_R can be expressed in general as,

$$F_R = AKC_D \quad ...(3)$$

Where, A = characteristic area of the system
K = characteristic kinetic energy per unit volume
C_D = a dimensionless parameter, coefficient of resistance

For the free fall of a particle in a fluid, A is defined as projected area of the particle, measured in a plane perpendicular to the direction of motion of the particle.

For the spherical particle

$$A = \frac{\pi d^2}{4} \quad \text{and} \quad K = \frac{1}{2} \rho_f V^2$$

where V is the relative velocity between the particle and the fluid.

The expression for resistive force F_R fro the free falling spherical particle will be

$$F_R = \frac{\pi d^2}{4}\frac{1}{2}\rho_f V^2 C_D \qquad \text{...(4)}$$

C_D drag coefficient

Terminal velocity (general expression) (From equation 2 and 4)

$$V_t = \sqrt{\frac{4}{3}\frac{gd}{C_D}\frac{(\rho_p - \rho_f)}{\rho_f}} \qquad \text{...(5)}$$

Laminar and turbulent flow regimes (depends on the particle Reynolds number)

If N_{Re} <1.0, the flow is laminar
If N_{Re} >1000, the flow is turbulent
If 1.0 > N_{Re} <1000, the flow is neither laminar nor turbulent (transition)

Where,

$$N_{\mathrm{Re}} = \frac{V_t \rho_f d}{\mu_f}$$ is called particle Reynolds number

FLUID RESISTANCE

- At low velocities, the resistance to the motion is due to the shear forces or viscosity of the fluid and is called **viscous resistance.**

- At high velocities, the main resistance is due to the displacement of fluid by the particle and is known as **turbulent resistance.**

1. Terminal velocity in Laminar flow regime

- If the particle velocity is quite low, the resistance to the motion is due to the shear forces

- Stokes deduced an expression for the drag force as $3\pi d\mu_f V$

$$V_t = \frac{d^2 g(\rho_p - \rho_f)}{18\mu_f} \quad ...(6)$$

Equation 6 describes settling of spherical particles under **laminar flow conditions only** where fluid viscosity provides the resistance to flow.

2. Terminal velocity in intermediate flow regime

- In the intermediate regime ($1 \leq N_{Re} < 1000$), the sphere drag coefficient continues to decrease with N_{Re} although the rate of decrease is lower than that at the Stokes' regime.

- One of the most accurate correlations for predicting the drag coefficient of spherical particles at subcritical N_{Re} is the model of Clift and Gauvin

$$C_D = \frac{24}{N_{\mathrm{Re}}}\left(1+0.15N_{\mathrm{Re}}^{0.687}\right)+\frac{0.42}{1+\dfrac{42500}{N_{\mathrm{Re}}^{1.16}}} \quad \ldots(7) \qquad \text{for } N_{re} < 3\times10^{5}$$

R. Clift, W.H. Gauvin, Can. J. Chem. Eng. 49 (4) (1971) 439–448.

3. Terminal velocity in Newton's regime

In the Newton's regime the resistance is entirely due to turbulent resistance and deduced as $F_R = 0.055\pi d^2(V_t)^2\rho_f$

$$V_t = \sqrt{\frac{3gd(\rho_p - \rho_f)}{\rho_f}} \qquad \ldots(8)$$

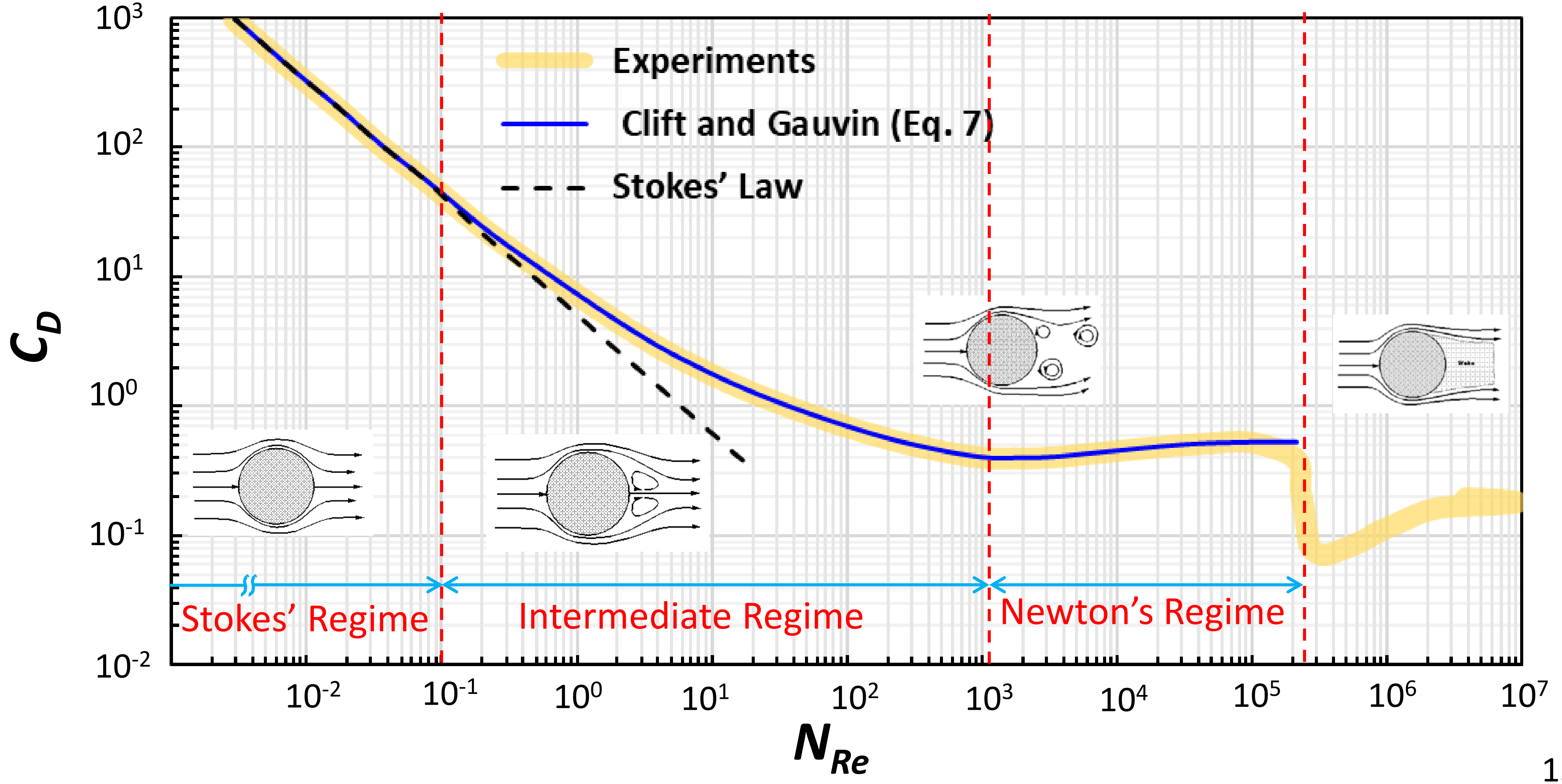
For ($1000 \le N_{re} < 3\times10^5$)

(with average $C_D \sim 0.44$)

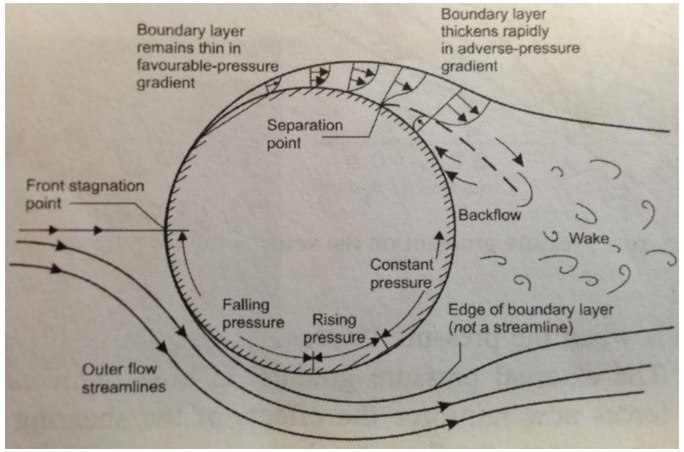
- Beyond 3×10^5, the coefficient of resistance decreases sharply.
- This is due to the formation of eddies in the fluid behind the particle which travels with particle, resulting in sharp decrease in the drag on the particle.

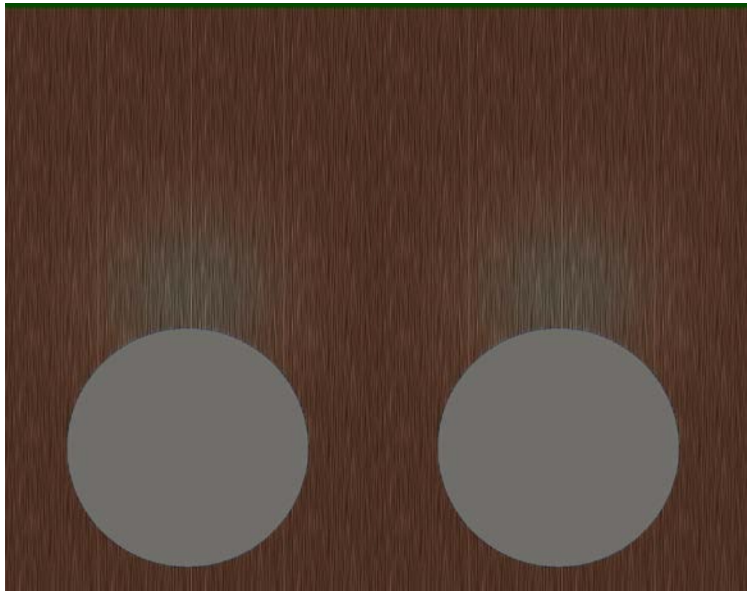
* Only valid for free settling of a spherical particle

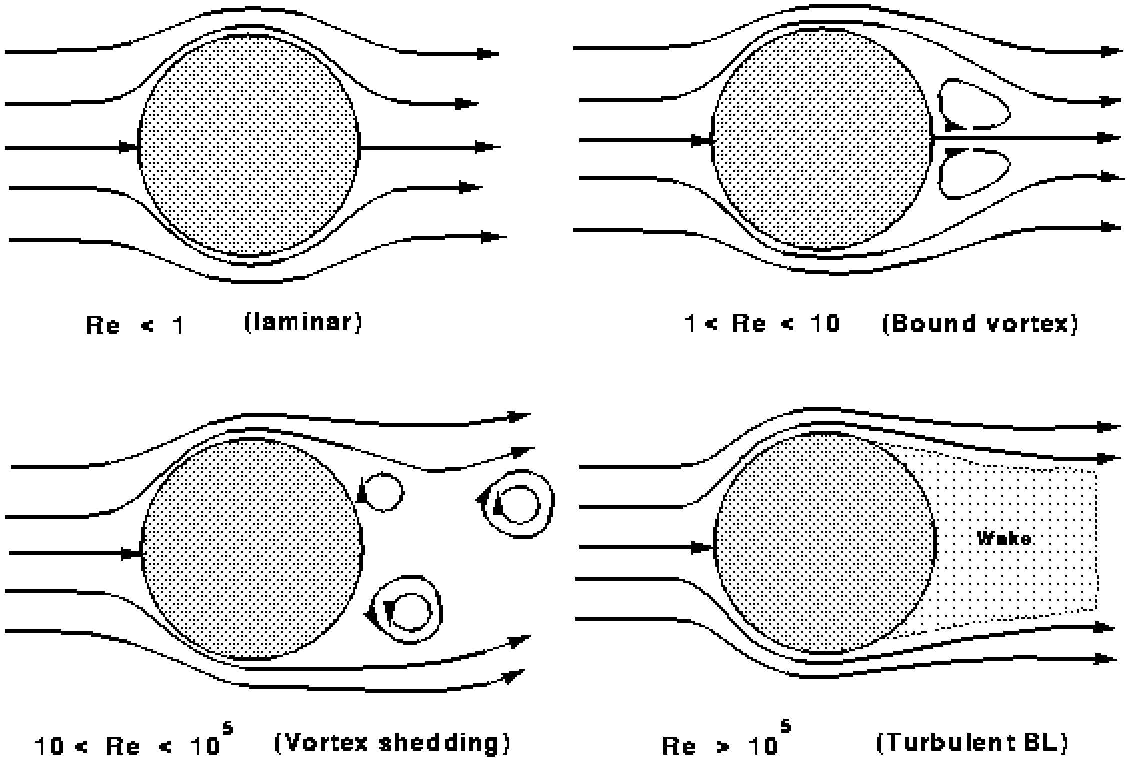
Change of C_D with N_{Re} for a sphere



Flow past a sphere and boundary layer separation







Problem 1

Spherical silica particle of density 2.65 gm/cm^3 and diameter of 0.1 cm is settling in water. Find out the terminal velocity. Density and viscosity of water is equal to 1.0 g/cm^3 and 0.01 poise respectively.

Solution:

First trial:

Assume the particle is setting in a laminar regime

Terminal velocity using Stokes' equation (equation 6).

$$V_t = \frac{d^2 g(\rho_p - \rho_f)}{18\mu_f} = \frac{(0.1)^2 \times 981 \times (2.65 - 1)}{18 \times 0.01} = 89.9\ cm/s$$

Calculate Reynolds number,

$$N_{\mathrm{Re}} = \frac{dV_t\rho_f}{\mu_f} = \frac{0.1 \times 89.9 \times 1.0}{0.01} = 899$$ This is > 1

- Therefore, Stokes' law is certainly not valid for such a large, fast-settling particle.
- However, the Reynolds number is approaching 1000, so it may be in the validity range for Newton's Law.

Second trial:

Calculate terminal velocity in Newton's regime (equation 8)

$$V_t = \sqrt{\frac{3gd(\rho_p - \rho_f)}{\rho_f}} = \sqrt{\frac{3 \times 981 \times 0.1 \times (2.65 - 1.0)}{1.0}} = 22.0\ cm/s$$

Calculate Reynolds number,

$$N_{\mathrm{Re}} = \frac{dV_t \rho_f}{\mu_f} = \frac{0.1 \times 22.0 \times 1.0}{0.01} = 220$$ This is < 1000

So particle is not falling in Newton's regime also

Third trial:

- Let us calculate the terminal velocity using the general equation (equation 5)
- Consider the C_D (≈ 0.7) corresponding to N_{re} = 220 (From the C_D vs N_{Re} plot for a sphere)

$$V_t = \sqrt{\frac{4}{3}\frac{gd}{C_D}\frac{(\rho_p - \rho_f)}{\rho_f}} = \sqrt{\frac{4\times 981\times(2.65-1.0)}{3\times 0.7\times 1.0}} = 17.56\ cm/s$$

Recalculate Reynolds number

$$N_{\mathrm{Re}} = \frac{dV_t\rho_f}{\mu_f} = \frac{0.1\times 17.56\times 1.0}{0.01} = 175$$ This is ≠ 220

- From the graph Consider the C_D (≈ 0.8) corresponding to N_{re} = 175 (From the C_D vs N_{Re} plot for a sphere)

- Calculate the terminal velocity using same equation (equation 5)

$$V_t = \sqrt{\frac{4}{3}\frac{gd}{C_D}\frac{(\rho_p - \rho_f)}{\rho_f}} = \sqrt{\frac{4\times 981\times(2.65-1.0)}{3\times 0.8\times 1.0}} = 16.4\, cm/s$$

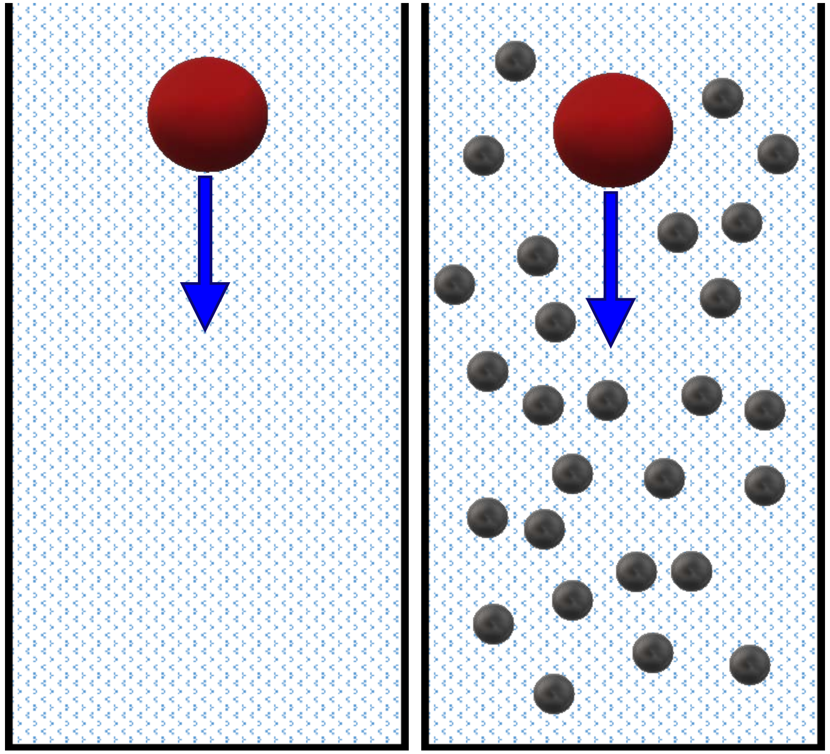
Recalculate Reynolds number

$$N_{\mathrm{Re}} = \frac{dV_t\rho_f}{\mu_f} = \frac{0.1\times 16.4\times 1.0}{0.01} = 164$$ This is close to 175

- From the graph at N_{re} = 164, C_D will come close to 0.8.

- So, the terminal settling velocity is approximately 16.4 cm/sec. (Ans)

Hindered settling



Free settling **Hindered settling**

- When the particles settle in a fluid crowded in the pulp/other particles. Such settling process is called **Hindered settling.**

- Under hindered settling conditions, the settling velocity or rate of settling of each individual particle will be considerably less than that for the free settling conditions.

- It must be noted that each particle is in fact settling through a suspension of other particles in the liquid rather than through the simple liquid itself.

- Hindered settling velocity can be approximately estimated from Stokes' equation or Newton's equation after replacing ρ_f and μ_f by ρ_{sl} and μ_{sl}

- Density of the slurry, ρ_{sl} , can be determined as a function of the volume fraction of the solids, C_v

C_v = Fraction of solids by volume
= Volume of the particles / Volume of the slurry

$$\rho_{sl} = C_V \rho_p + (1 - C_V)\rho_f \quad \ldots(9)$$

$$C_V = \frac{\rho_{sl} - \rho_f}{\rho_p - \rho_f}$$

- To be precise, slurries are non-Newtonian fluids.

- The apparent viscosity of the slurry is a function of the shear rate and depends on its rheological characteristics.

- The viscosity (μ_{sl}) of the slurry containing spherical particles is related to the volume fraction of the solids in the slurry as

$$\frac{\mu_{sl}}{\mu_f} = \frac{10^{1.82C_V}}{1 - C_V} \qquad \ldots(10)$$

Brown, G.G. & Associates: Unit Operations, *Wiley, New York,* 1950.

In the Stokes' regime (using equation 6)

$$V_H = \frac{d^2 g(\rho_p - \rho_{sl})}{18\mu_{sl}}$$

So,

$$\frac{V_H}{V_t} = \frac{(1-C_V)^2}{10^{1.82C_V}} = F_s \qquad F_s < 1$$

Similarly, an expression for hindered settling velocity V_H for coarse particles can be obtained by replacing ρ_f by ρ_{sl} in the Newton's regime

EQUAL SETTLING PARTICLES

- Particles are said to be equal settling if they have the same terminal velocities in the same fluid and in the same field of force.

SETTLING RATIO

- Settling ratio is the ratio of the sizes of two particles of different specific gravities fall at equal rates.

<u>In Stokes' regime</u> **(N_{re} < 1.0)**

Using equation 6

$$V_t = \frac{d_1^2\, g(\rho_{p_1} - \rho_f)}{18\mu_f} = \frac{d_2^2\, g(\rho_{p_2} - \rho_f)}{18\mu_f} \quad \Rightarrow \quad \frac{d_1}{d_2} = \left(\frac{\rho_{p_2} - \rho_f}{\rho_{p_1} - \rho_f} \right)^{1/2} \quad \text{...(11)}$$

d_1 and ***d_2*** are the diameters of lighter and heavier particles and ***ρ_{p1}*** and ***ρ_{p2}*** are the densities of lighter and heavier particles.

In Newton's regime   (1000 ≤ N_{re} < 3×10^5)

Using equation 8

$$V_t = \sqrt{\frac{3gd_1(\rho_{p_1} - \rho_f)}{\rho_f}} = \sqrt{\frac{3gd_2(\rho_{p_2} - \rho_f)}{\rho_f}} \quad \Rightarrow \quad \frac{d_1}{d_2} = \left(\frac{\rho_{p_2} - \rho_f}{\rho_{p_1} - \rho_f}\right) \quad \text{...(12)}$$

General expression for free-settling ratio

$$\frac{d_1}{d_2} = \left(\frac{\rho_{p_2} - \rho_f}{\rho_{p_1} - \rho_f}\right)^n \qquad (0.5 \le n \le 1)$$

Problem 2

Mixture of galena (density 7.5 gm/cc) and quartz (density 2.65 gm/cc) particles settling in water.

(a) Find the free settling ratio for fine particles (settling in Stokes' regime) and coarse particles (settling in Newton's regime)

(b) Find the Hindered settling ratio (with pulp SG 1.5) for fine particles (settling in Stokes' regime) and coarse particles (settling in Newton's regime)

What can we conclude from the observations?

Solution:

(a) Free settling ratio

(i) For fine particles (settling in Stokes' regime)

ρ_{p2} = density of galena =7.5 gm/cc

ρ_{p1} = density of quartz =2.65 gm/cc

ρ_f = density of water =1 gm/cc

Using equation 11

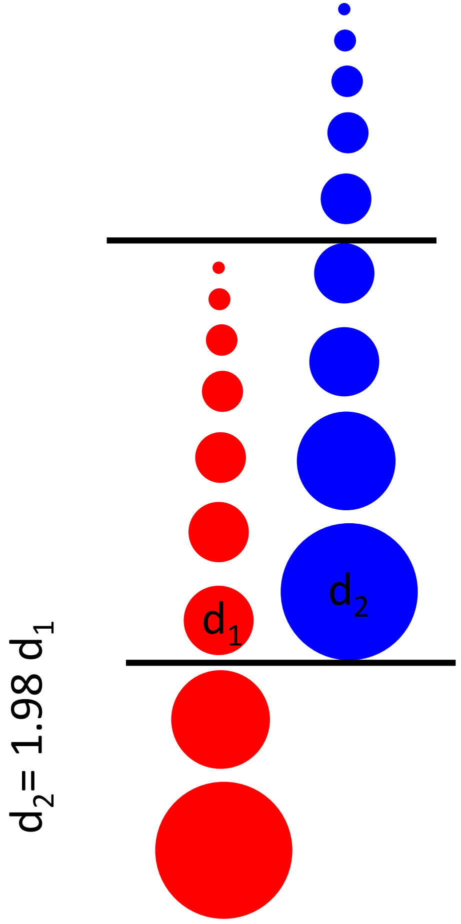
$$\frac{d_1}{d_2} = \left(\frac{\rho_{p2} - \rho_f}{\rho_{p1} - \rho_f}\right)^{1/2} = \left(\frac{7.5 - 1}{2.65 - 1}\right)^{1/2} = 1.98$$

(ii) For coarse particles (settling in Newton's regime)

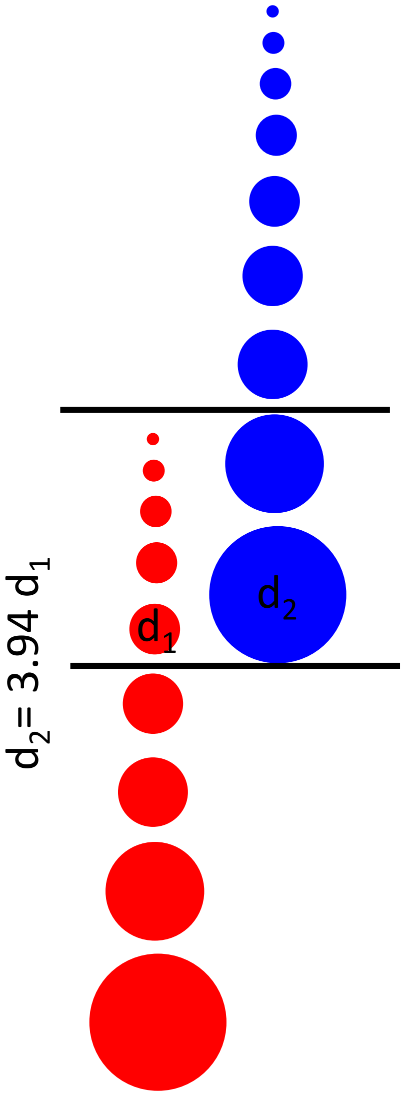
Using equation 12

$$\frac{d_1}{d_2} = \left(\frac{\rho_{p2} - \rho_f}{\rho_{p1} - \rho_f}\right) = \left(\frac{7.5 - 1}{2.65 - 1}\right) = 3.94$$

Free settling



(A) Fine particles



(B) Coarse particles

- A fine galena particle will settle at the same rate as fine quartz particle of diameter 1.98 times larger than galena particle.
- Coarse galena particle will settle at the same rate as coarse quartz particle of diameter 3.94 times larger than galena particle
- The free settling ratio for coarse particles is larger than for fine particles.
- This means that density difference between the particles has more effect at coarser size ranges when they settle.

Quartz particle with density =2.65 gm/cc

Galena particle with density =7.5 gm/cc

(b) Hindered settling ratio

(i) For fine particles (settling in Stokes' regime)

Using equation 11

ρ_{sl} = density of slurry =1.5 gm/cc

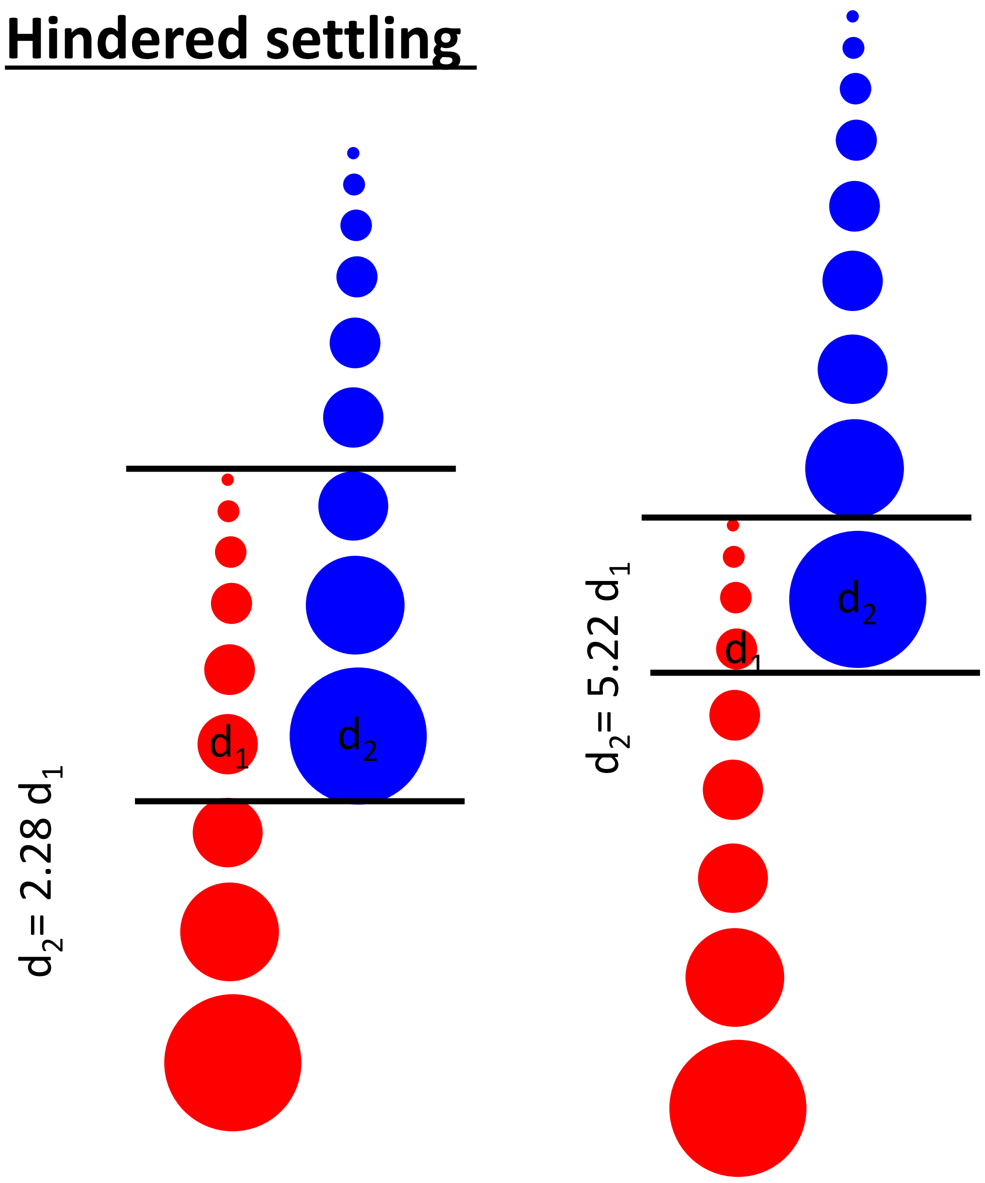
$$\frac{d_1}{d_2} = \left(\frac{\rho_{p2} - \rho_{sl}}{\rho_{p1} - \rho_{sl}}\right)^{1/2} = \left(\frac{7.5 - 1.5}{2.65 - 1.5}\right)^{1/2} = 2.28$$

(ii) For coarse particles (settling in Newton's regime)

Using equation 12

$$\frac{d_1}{d_2} = \left(\frac{\rho_{p2} - \rho_{sl}}{\rho_{p1} - \rho_{sl}}\right) = \left(\frac{7.5 - 1.5}{2.65 - 1.5}\right) = 5.22$$

Hindered settling

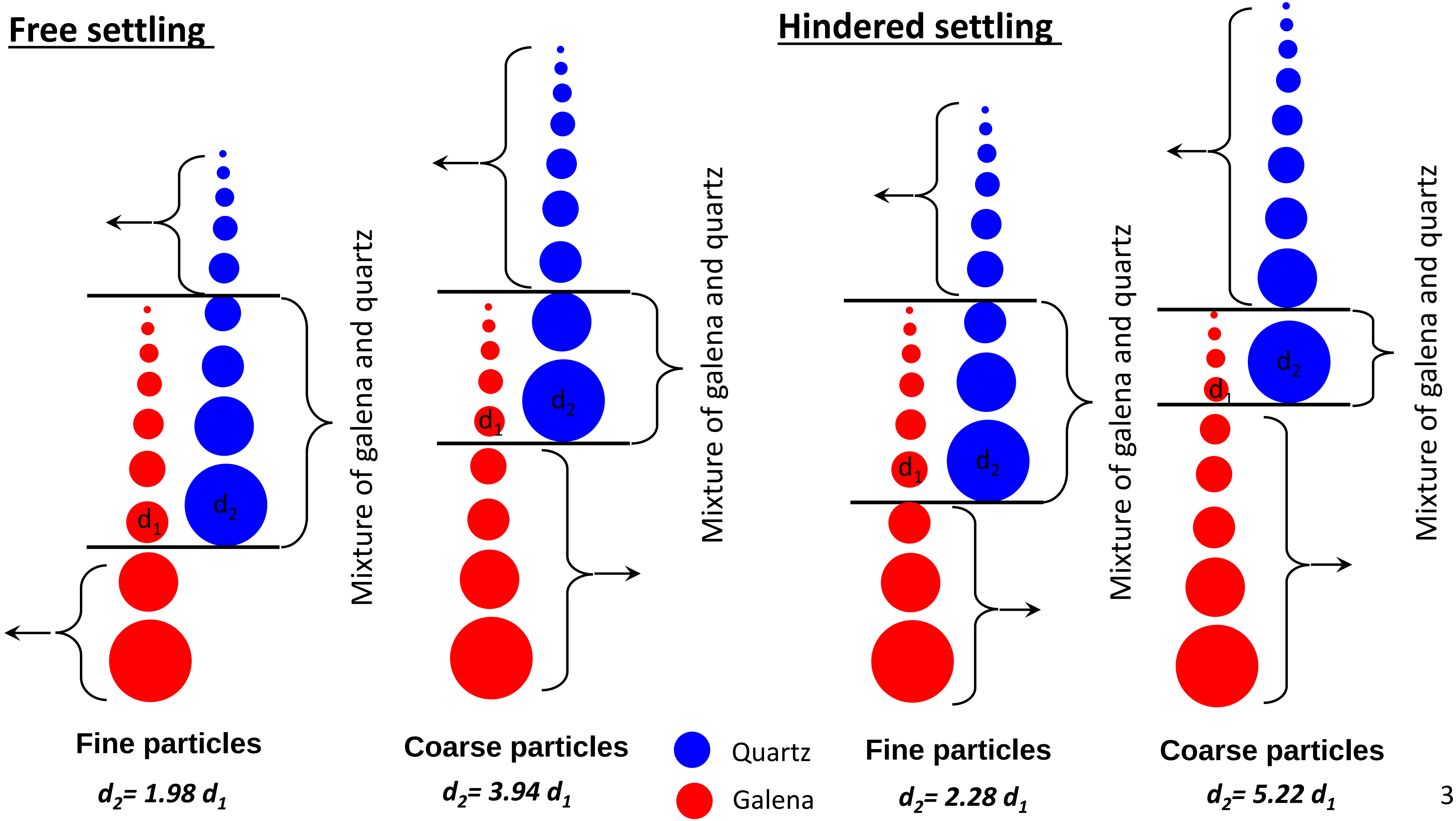


(A) Fine particles (B) Coarse particles.

- Hindered settling ratio of 5.22 is compared with the free settling ratio of 3.94.
- It is evident that **hindered settling reduces the effect of size, while increasing the effect of density.**
- More heavy (or light) particles can be separated in hindered settling.
- Hindered settling ratio is always greater than the free settling ratio.

Free settling

Hindered settling



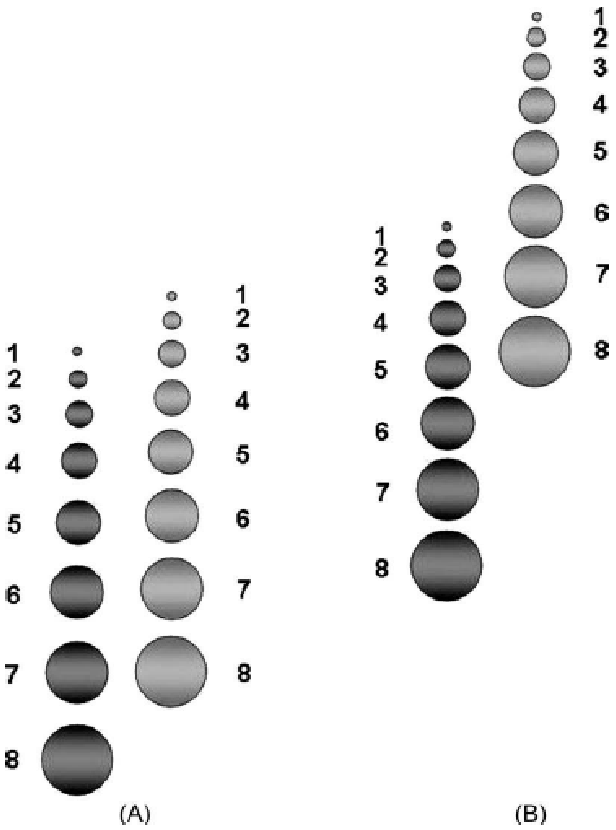
CLASSIFIERS

- The units in which the separation of solids in fluid medium is carried out are known as classifiers.

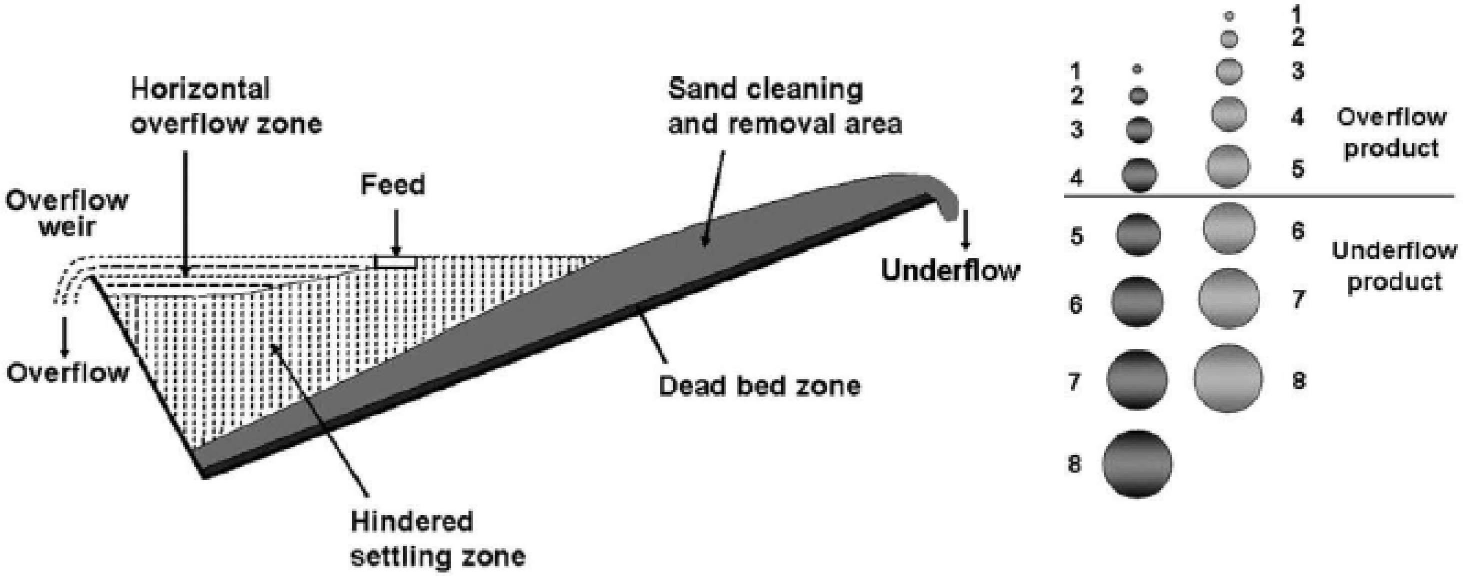
- These classifiers may be grouped into three broad classes based on the operation technique as

1. Sizing classifiers
2. Sorting classifiers
3. Centrifugal classifiers

Sizing classifiers



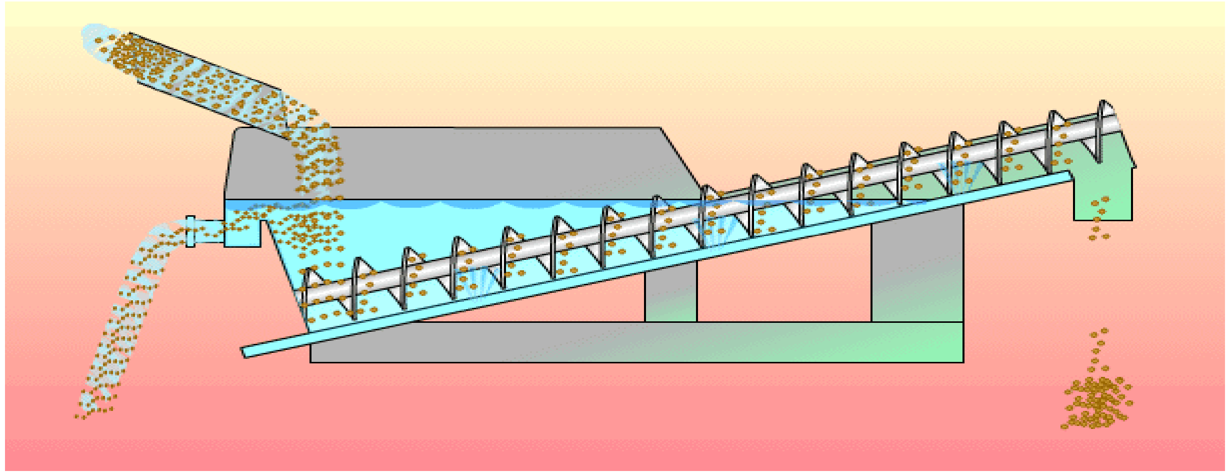
(A) Free settling and (B) Hindered settling

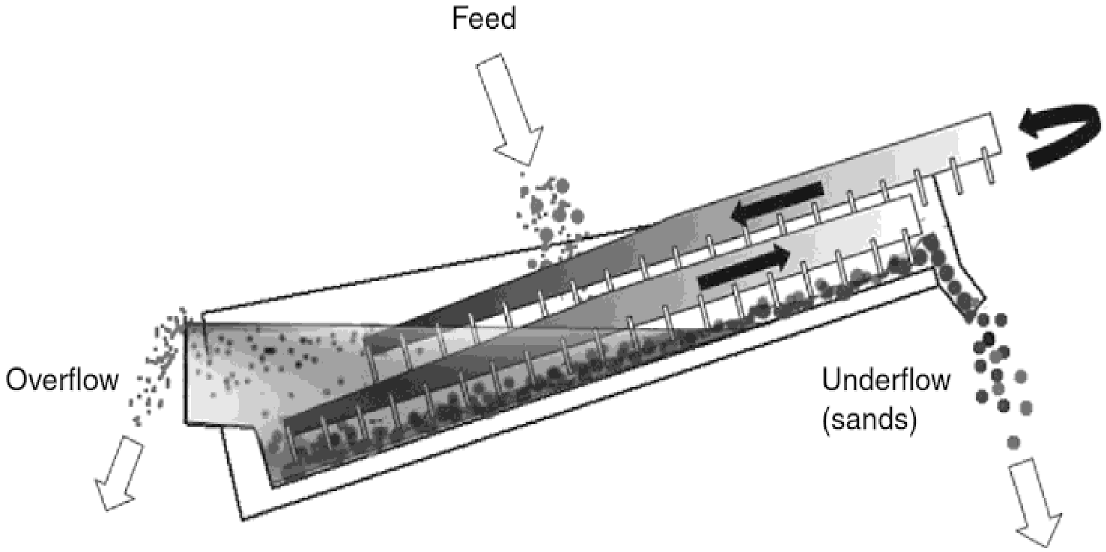


Separation in sizing classifier

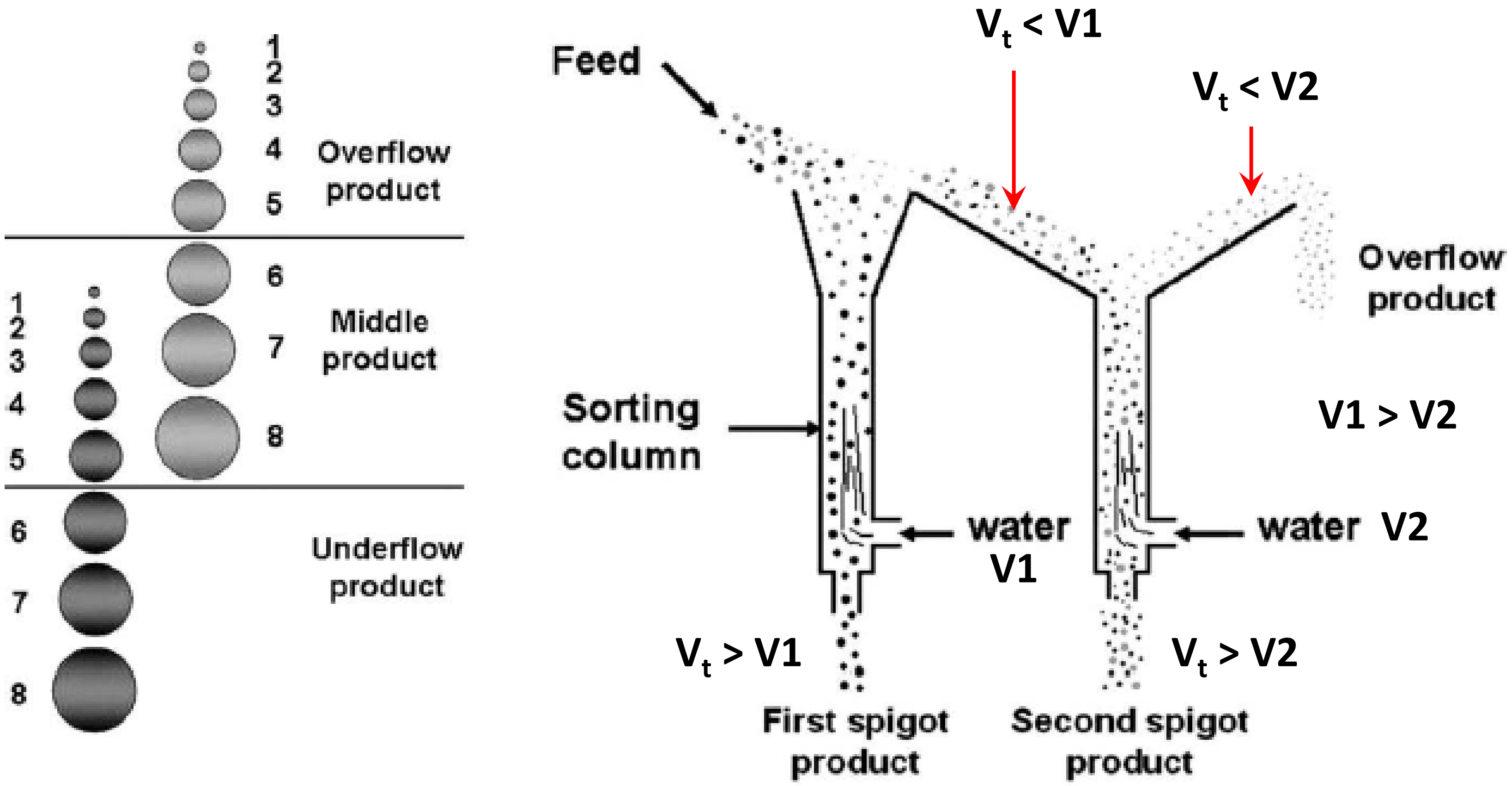
- Each fraction contains both light and heavy particles and almost of the same size or closely sized particles.
- All the particles are separated into two size fractions.
- This type of classification is a sizing classification
- Classifier used is called **sizing classifier.**
- These are also called mechanical classifiers, free settling classifiers, horizontal current classifiers and pool classifiers.
- Extensively used in closed circuit with a ball mill where underflow coarse product is fed to the ball mill.

Rake classifier





Sorting classifier



Separation in sorting classifier with two sorting columns

- A typical sorting classifier consists of a series of sorting columns.
- A current of water known as hydraulic water is introduced at the bottom of the sorting column.
- All those particles having settling velocity less than that of rising water velocity will not settle and rise to the top of the column and fed to the second column.

- **Free settling** conditions are to be maintained **to separate the mixed density and mixed size particles according to their sizes** which increases the effect of size and decreases the effect of density on separation

- **Hindered settling** conditions are to be maintained **to separate the mixed density and mixed size particles according to their densities** which increases the effect of density and decreases the effect of size on separation

- Even though **sorting classifiers are not truly sizing classifiers**, they are sometimes used to sort out the particles in close size range by maintaining the free settling conditions

Problem 3

An ore consists of valuables of 5.8 specific gravity and gangue of 2.6 specific gravity having size range of 10–25 microns is separated in a mechanical classifier. Can all valuables be separated in underflow and will they be gangue free? Explain.

Solution:

Given

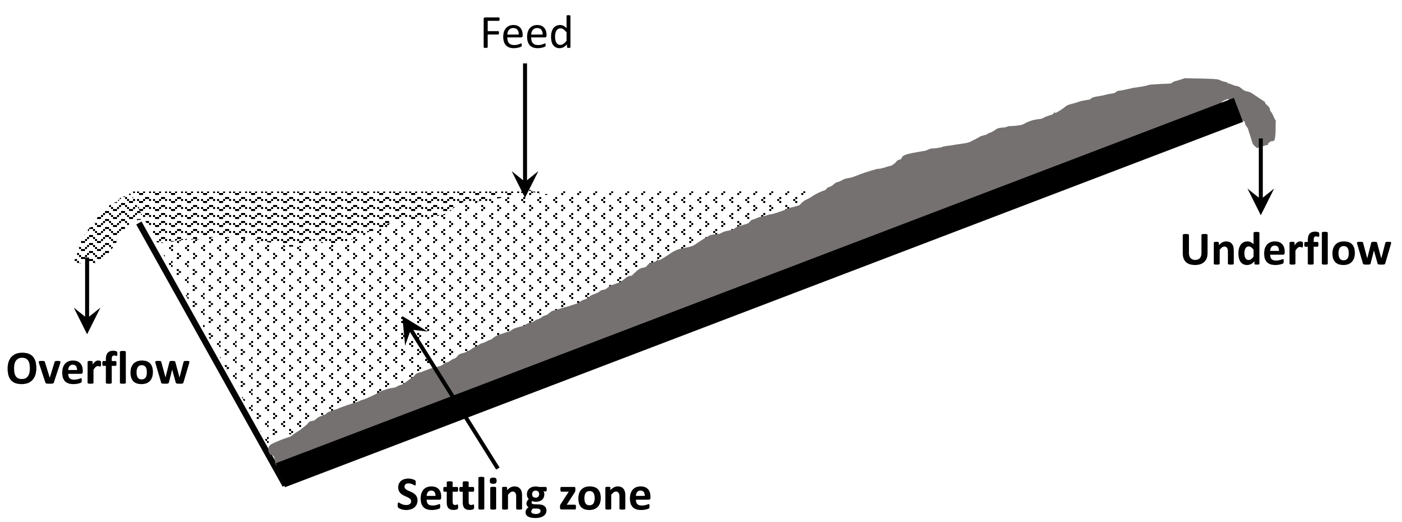
Density of gangue = ρ_g =2.6 gm/cc

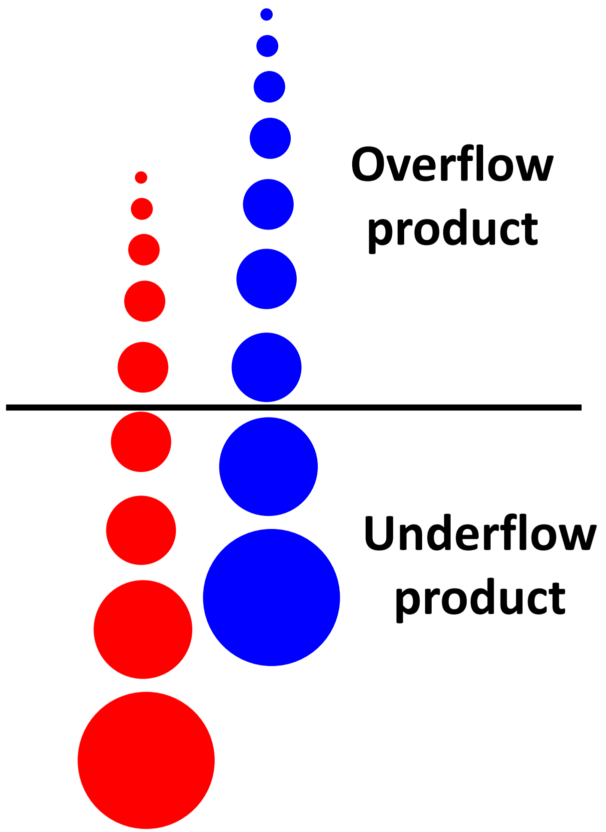
Density of valuables = ρ_v =5.8 gm/cc

Density of water = ρ_w =1.0 gm/cc

Size range of the particles = 10 to 25 microns

Mechanical classifiers





- ➢ All the particles are separated into two size fractions.
- ➢ This type of classification is a sizing classification

To estimate the settling regime

Assuming Stokes' law

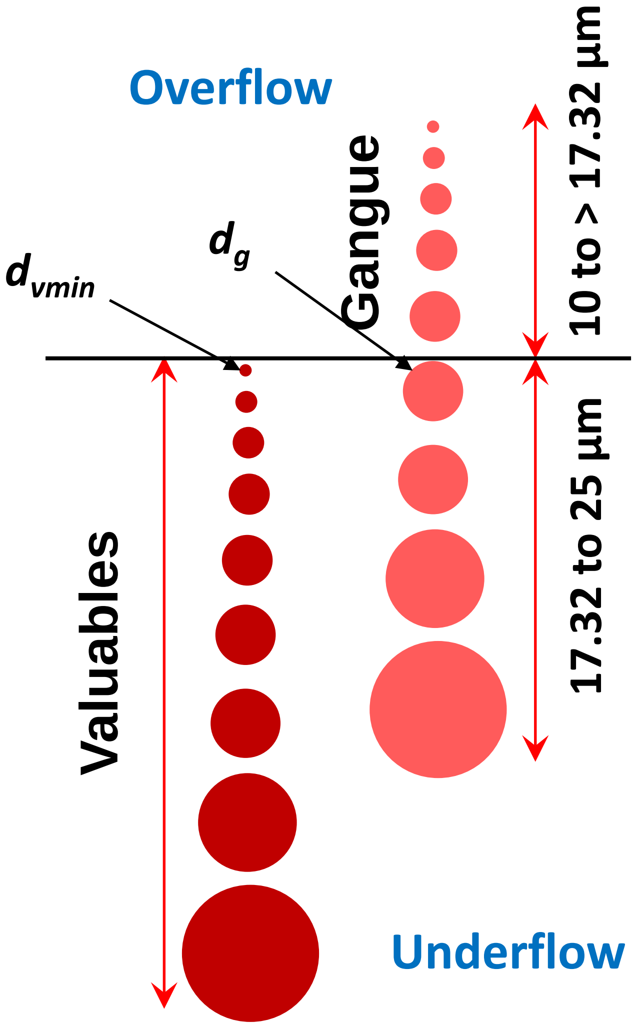
Settling velocity of **coarsest heavy particle** (valuables) (using equation 6)

$$V_t = \frac{d_v^2\, g(\rho_v - \rho_w)}{18\mu_w} = \frac{(0.0025)^2 \times 981 \times (5.8 - 1.0)}{18 \times 0.01} = 0.164\, cm/s$$

Check for the N_{Re}

$$N_{\mathrm{Re}} = \frac{d_v V_t \rho_w}{\mu_w} = \frac{0.0025 \times 0.164 \times 1.0}{0.01} = 0.041 < 1$$

As Reynolds number (N_{Re}) for coarsest heavy particle is less than 1, all particles settle in Stokes' regime.



Free settling ratio of the smallest valuable (d_{vmin}) particle with the equivalent gang particle (d_g)

$$\frac{d_g}{d_{v\min}} = \left(\frac{\rho_v - \rho_w}{\rho_g - \rho_w}\right)^{1/2} = \left(\frac{5.8-1}{2.6-1}\right)^{1/2} = 1.732$$

Now $d_{v\min} = 10\ \mu m$

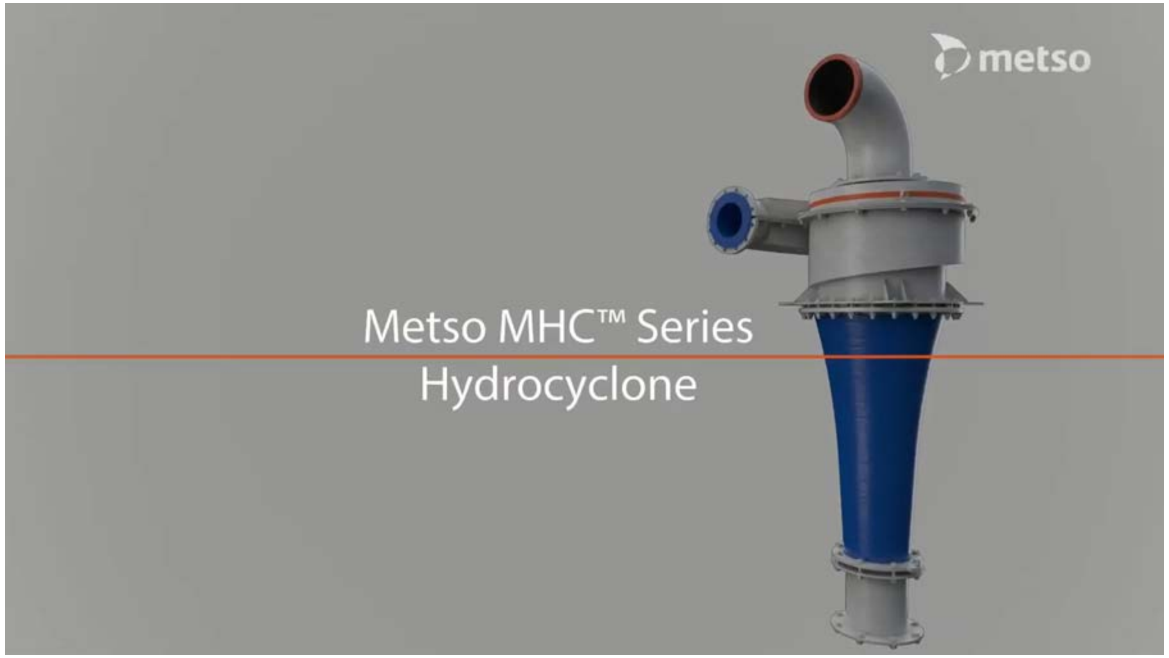
- So the size of the gangue particle that settles equally with the smallest valuable particle

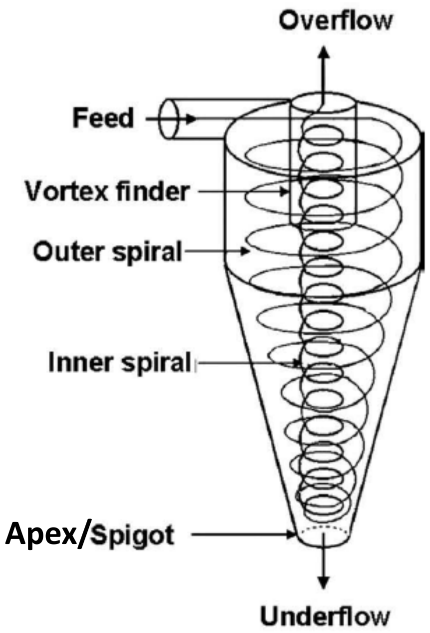
$$d_g = 10 \times 1.732 = 17.32\ \mu m$$

- Gangue particles of size 17.32 to 25 microns will also settle by the time smallest valuable particle settle.
- Underflow is not gangue free.
- Overflow is valuable free and will contain 10 to 17.32 µm gangue particles

Centrifugal classifiers

- As particles are ground smaller they reach a size where the surface drag against the surrounding fluid almost neutralizes the gravitational pull, with the result that the particle may need hours, or even days, to fall a few inches through still water.
- By superimposing centrifugal force, the gravitational pull can be increased from 50 to 500 times depending on the pressure at which the pulp is fed and the size of the vessel.
- The hydrocyclone is one which utilizes centrifugal force to accelerate the settling rate of particles.





Slurry properties

C_w = fraction of solids by weight= Weight of the particles / Weight of the slurry

C_v = fraction of solids by volume= Volume of the particles/ Volume of the slurry

C_w , C_v can be calculated Knowing the densities of the slurry (ρ_{sl}), fluid (ρ_f) and dry solids (ρ_p)

$$C_w = \frac{\rho_p(\rho_{sl} - \rho_f)}{\rho_{sl}(\rho_p - \rho_f)}$$

Dilution ratio

It is the ratio of the weight of the water to the weight of the solids in the slurry.

$$DR == \frac{1 - C_w}{C_w}$$

Efficiency of separation in hydrocyclone

The commonest method of representing the efficiency of operation and separation of hydrocyclone is by a ***performance or partition or efficiency curve***.

This curve is drawn between **weight fraction different particle size in underflow** and **the average particle size**.

Example:

The slurry is being classified in a hydrocyclone. The percent solids in feed, underflow and overflow are 70.4, 83.5 and 64.2 respectively. The size analyses of underflow and overflow solids are given in Table

Draw partition curves and evaluate the performance of hydrocyclone.

Size analyses data of underflow and overflow of hydrocyclone.

	Weight%	
Size μm	*underflow*	*overflow*
+1180	00.3	–
−1180 + 850	03.6	–
−850 + 600	20.7	00.1
−600 + 425	21.3	00.6
−425 + 300	13.1	02.2
−300 + 212	07.0	04.7
−212 + 150	03.7	05.9
−150 + 106	03.4	06.7
−106 + 75	02.7	07.0
−75 + 53	01.7	04.7
−53	22.5	68.1

Step1: Start with a basis of solid feed flow rate 100 kg/hr (on dry basis).

Find the dilution ratio (weight of the water/weight of the solids) of feed (DR_f), underflow (DR_u) and overflow (DR_o)

Given, $C_w|_F = 70.4$, $C_w|_U = 83.5$, $C_w|_O = 64.2$

$DR_f = 0.42$; $DR_u = 0.20$; $DR_o = 0.56$

Step2:

Solid balance $F = U + O$

Where, F be the rate of dry solids fed to the hydrocyclone, U and O be the rate of dry solids of underflow and overflow from hydrocyclone respectively.

Water balance $0.42F = 0.20U + 0.56O$

$$\frac{U}{F} = 0.389$$

i.e. the underflow is 38.9% of the feed and the overflow is 61.1% of the feed (For solids).

Step3:

Partition coefficient calculations.

A	B	C	D	E	F	G	H	I	J
	Weight%		Wt% of feed		Recons-tituted Feed	Nominal size	Partition coefficient	Corrected Partition coefficient	
Size μm	U/F	O/F	U/F $B \times 0.389$	O/F $C \times 0.611$	$D + E$		$y_a = \frac{D}{F} \times 100$	$Y_c = \frac{y_a - R_f}{100 - R_f} \times 100$	$\frac{d}{d_{50c}}$
$+1180$	00.3	–	0.12	–	0.12	–	100.0	100.0	–
$-1180 + 850$	03.6	–	1.40	–	1.40	1015	100.0	100.0	3.4
$-850 + 600$	20.7	00.1	8.05	0.06	8.11	725	99.3	99.1	2.5
$-600 + 425$	21.3	00.6	8.29	0.37	8.66	512.5	95.7	94.7	1.7
$-425 + 300$	13.1	02.2	5.10	1.34	6.44	362.5	79.2	74.5	1.2
$-300 + 212$	07.0	04.7	2.72	2.87	5.59	256	48.7	37.1	0.9
$-212 + 150$	03.7	05.9	1.44	3.60	5.04	181	28.6	12.4	0.6
$-150 + 106$	03.4	06.7	1.32	4.09	5.41	128	24.4	07.2	0.4
$-106 + 75$	02.7	07.0	1.05	4.28	5.33	90.5	19.7	01.5	0.3
$-75 + 53$	01.7	04.7	0.66	2.87	3.53	64.0	18.7	00.2	0.2
-53	22.5	68.1	8.75	41.61	50.36	–	–	–	–
			38.90	61.10	100.00				

Column B row 1

$$\frac{M_{+1180}}{U}$$

Column C row 1

$$\frac{M_{+1180}}{O}$$

Column D row 1

$$\frac{M_{+1180}}{U} \times \frac{U}{F} = \left[\frac{M_{+1180}}{F}\right]_U$$

Column E row 1

$$\frac{M_{+1180}}{O} \times \frac{O}{F} = \left[\frac{M_{+1180}}{F}\right]_O$$

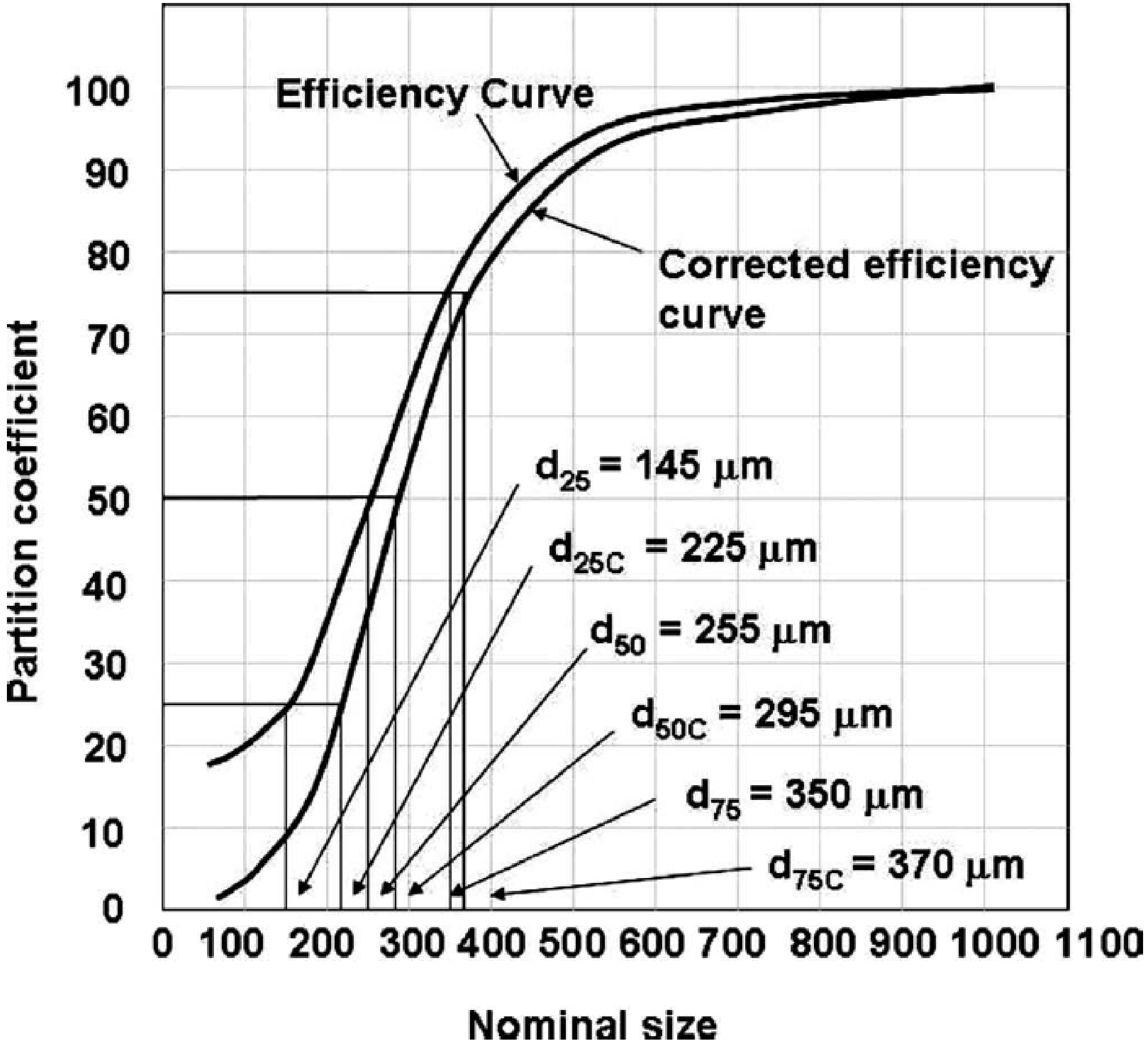
Column F row 1

$$\left[\frac{M_{+1180}}{F}\right]_U + \left[\frac{M_{+1180}}{F}\right]_O$$

Column H row 1
(**Partition coefficient**)

$$y_a = \frac{\left[\frac{M_{+1180}}{F}\right]_U}{\left[\frac{M_{+1180}}{F}\right]_U + \left[\frac{M_{+1180}}{F}\right]_O} \times 100$$

Step 4:



Efficiency Curve
Corrected efficiency curve
d_{25} = 145 μm
d_{25C} = 225 μm
d_{50} = 255 μm
d_{50C} = 295 μm
d_{75} = 350 μm
d_{75C} = 370 μm
Partition coefficient
Nominal size
0 10 20 30 40 50 60 70 80 90 100
0 100 200 300 400 500 600 700 800 900 1000 1100

- From the graph, d_{50} is determined corresponding to 50% of feed reporting to the underflow. d_{50} is a cut point or separation size, and is defined as the point on the curve for which 50% of particles in the feed of that size report to the underflow.

- It means that the particles of that size have an equal chance of going either with the overflow or underflow. d_{50} in this example is 255 microns.

Note:

- ✓ The curve does not pass through the origin.
- ✓ It is due to a fraction of the ***slurry bypassing the cyclone*** without classification called ***dead flux***.
- ✓ Thus if 5% of the feed slurry bypassed or short circuited the unit, then, only 95% of the slurry would be subjected to the classification.
- ✓ Thus the d_{50} obtained by the above method has to be corrected.

Correction

It is suggested that the ***fraction of the solids in each size fraction that is bypassed from the feed to the underflow*** is in the same ratio as the **fraction of liquid feed** reported to the underflow, *i.e.* ***flow ratio*** (or) fluid flow ratio, R_f

Take the example of +1180 size fraction

$$R_f = \frac{Bypassed\left[\dfrac{M_{+1180}}{F}\right]_U}{\left[\dfrac{M_{+1180}}{F}\right]_U + \left[\dfrac{M_{+1180}}{F}\right]_O} = \frac{[M_L]_U}{[M_L]_F}$$

For the example

$$R_f = \frac{[M_L]_U}{[M_L]_F} = \frac{0.2\times U}{0.42\times F} = \left(\frac{0.2}{0.42}\right)\times\frac{U}{F} = \left(\frac{0.2}{0.42}\right)\times 0.389 = 0.185 \qquad \Rightarrow 18.5\%$$

The corrected weight% of each size particles reporting to underflow called ***corrected partition coefficient*** and determined as

$$y_c = \frac{\frac{y_a}{100} - R_f}{1 - R_f} \times 100$$

For the example of +1180 size fraction

$$y_c = \frac{\dfrac{\left[\dfrac{M_{+1180}}{F}\right]_U}{\left[\dfrac{M_{+1180}}{F}\right]_U + \left[\dfrac{M_{+1180}}{F}\right]_O} - \dfrac{\text{Bypassed}\left[\dfrac{M_{+1180}}{F}\right]_U}{\left[\dfrac{M_{+1180}}{F}\right]_U + \left[\dfrac{M_{+1180}}{F}\right]_O}}{1 - \dfrac{\text{Bypassed}\left[\dfrac{M_{+1180}}{F}\right]_U}{\left[\dfrac{M_{+1180}}{F}\right]_U + \left[\dfrac{M_{+1180}}{F}\right]_O}} \times 100 = \frac{\left[\dfrac{M_{+1180}}{F}\right]_U - \text{Bypassed}\left[\dfrac{M_{+1180}}{F}\right]_U}{\left[\dfrac{M_{+1180}}{F}\right]_U + \left[\dfrac{M_{+1180}}{F}\right]_O - \text{Bypassed}\left[\dfrac{M_{+1180}}{F}\right]_U} \times 100$$

$$= \frac{\text{Actual mass of solid classified in underflow}}{\text{Mass of solid feed classified}} \times 100$$

- The corrected efficiency curve is plotted between nominal size and corrected partition coefficient.
- This curve represents the efficiency of separation of only that portion of slurry which is subjected to classification.
- From this curve d_{50C} (corrected d_{50}) can be read. The value of d_{50C} is 295 µm in this example.
- The sharpness of the cut depends on the slope of the central portion of the efficiency curve.
- The slope of the curve can be expressed by taking the points at which 75% and 25% of the feed particles report (let d_{75} and d_{25} sizes respectively) to the underflow.
- **Probable Error** (or **Ecart Terra**) is defined as $= \dfrac{d_{75C} - d_{25C}}{2}$
- $\dfrac{d_{25C}}{d_{75C}}$ is known as Sharpness Index

- The efficiency of separation, or **Imperfection**, ***I***, is expressed as the ratio of Probable Error to the cut size

$$I = \frac{\text{Probable error}}{\text{Cut size}} = \frac{(d_{75C} - d_{25C})}{2d_{50C}}$$

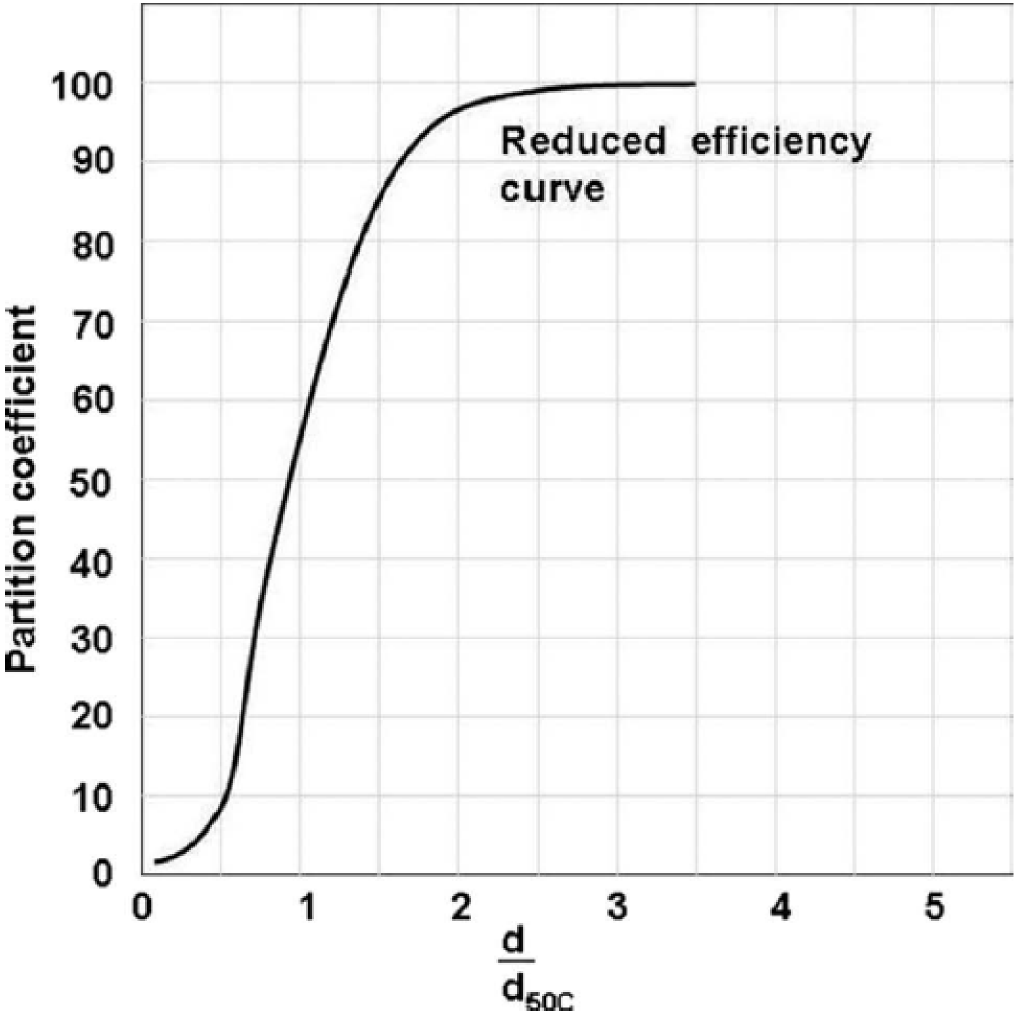
- The smaller the imperfection, the better the classification. For hydrocyclones, the range is from 0.2 to 0.8 with an average of about 0.3–0.4.

- For the measurement of sharpness at extremely fine cut sizes **Grade Efficiency** (defined as the ratio of d_{75C} to d_{25C}) or **Sharpness Index (**or **Selectivity Index**), S_I (reciprocal of grade efficiency) is used.

Reduced efficiency curve

- The corrected efficiency curve can be normalized by dividing each particle size, *d*, by d_{50C}
- It is concluded that for geometrically similar cyclones, the reduced efficiency curve is the function of the material classified and is independent of size of hydrocyclone.
- Lynch and Rao* have given the following equation for the reduced efficiency curve

$$y_c = \frac{e^{\alpha \frac{d}{d_{50C}}} - 1}{e^{\alpha \frac{d}{d_{50C}}} + e^{\alpha} - 2}$$



α is typically 3–4 for a single stage cyclone

*The operating characteristics of hydrocyclone classifiers, *Indian J. Technol.* 1967.

Classifying the classifier equipments

A. Mechanical Classifiers

i. Rake classifier

ii. Spiral classifier

iii. Drag classifier (Esperanza classifier)

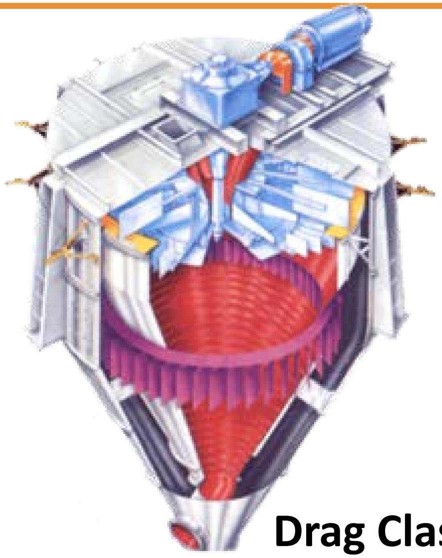
iv. Hardinge counter current classifier

v. Bowl classifier

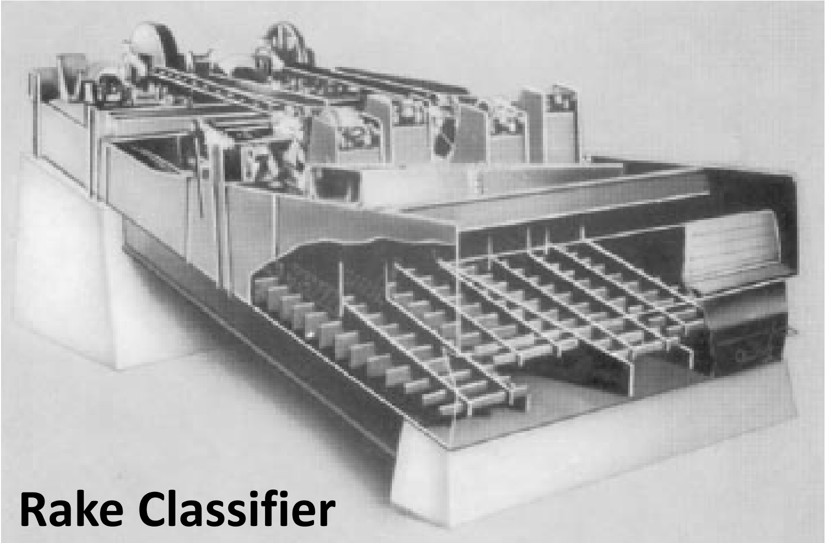
a) Hydro bowl classifier

b) Door bowl rake classifier

c) Hydroseparator (Dorrco)

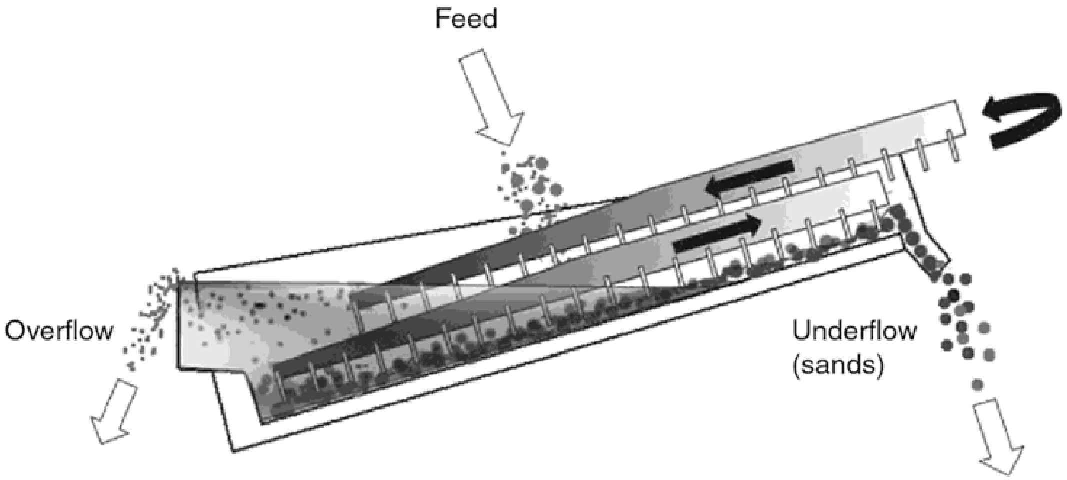


Drag Classifier

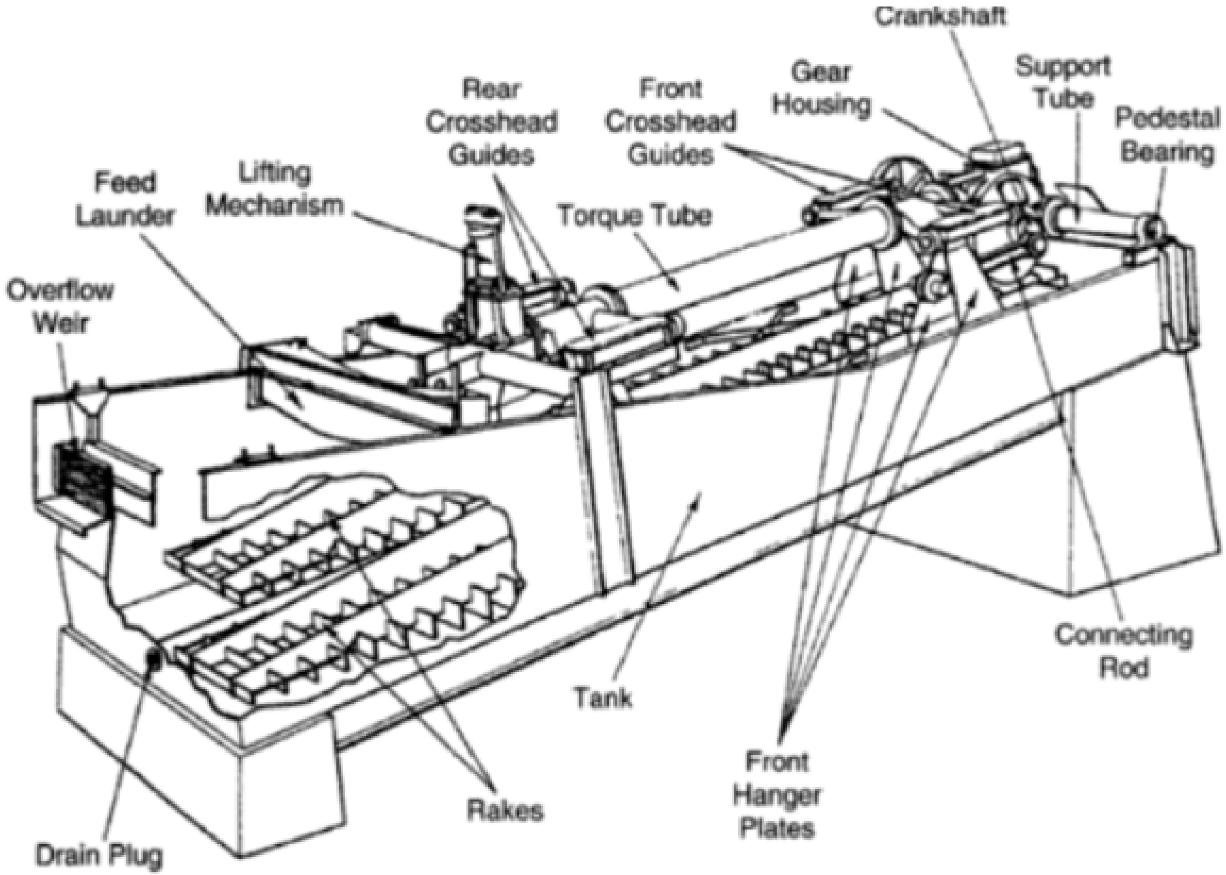


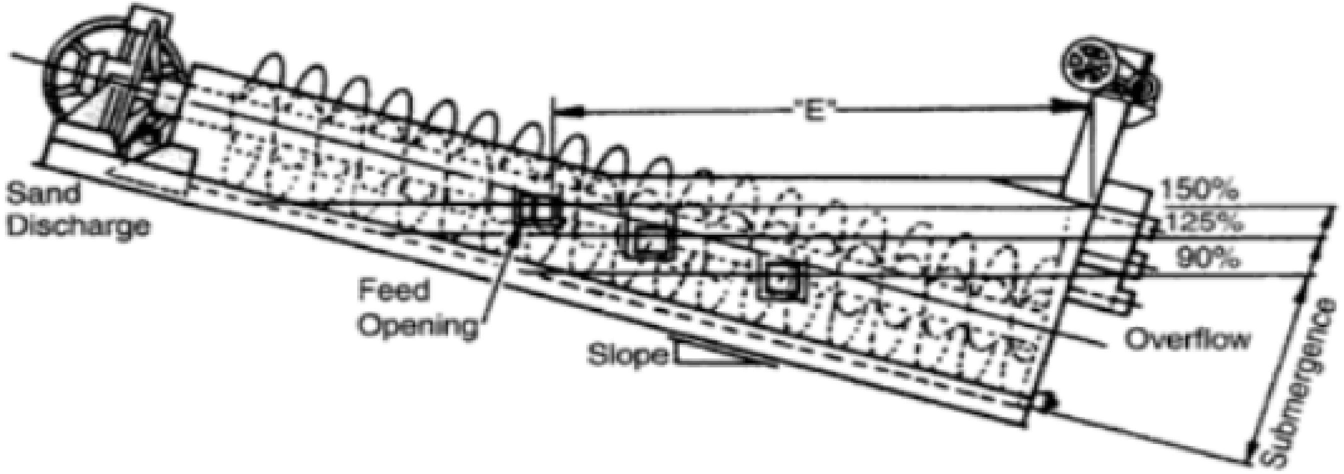
Rake Classifier

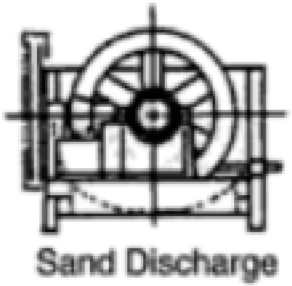
Spiral Classifier

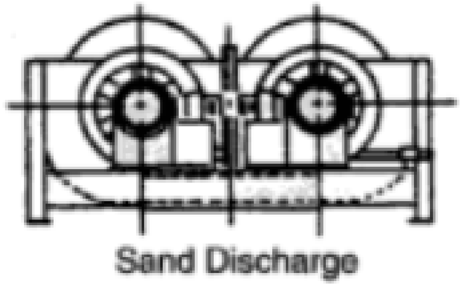


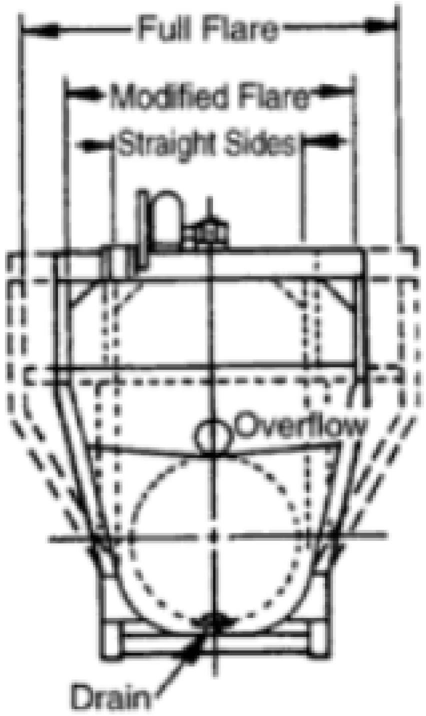
Rake Classifier

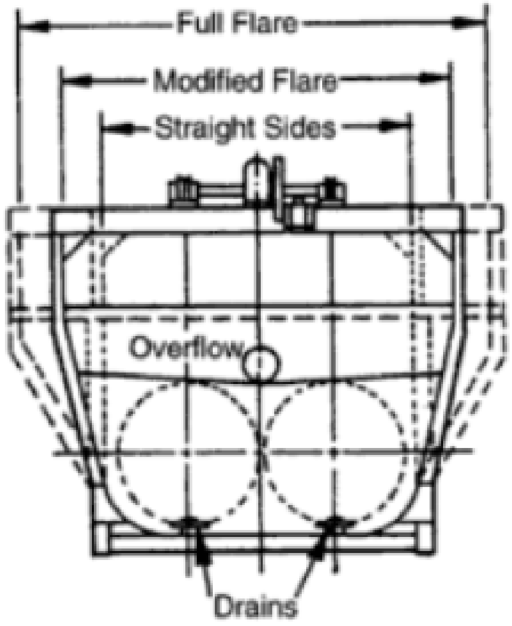




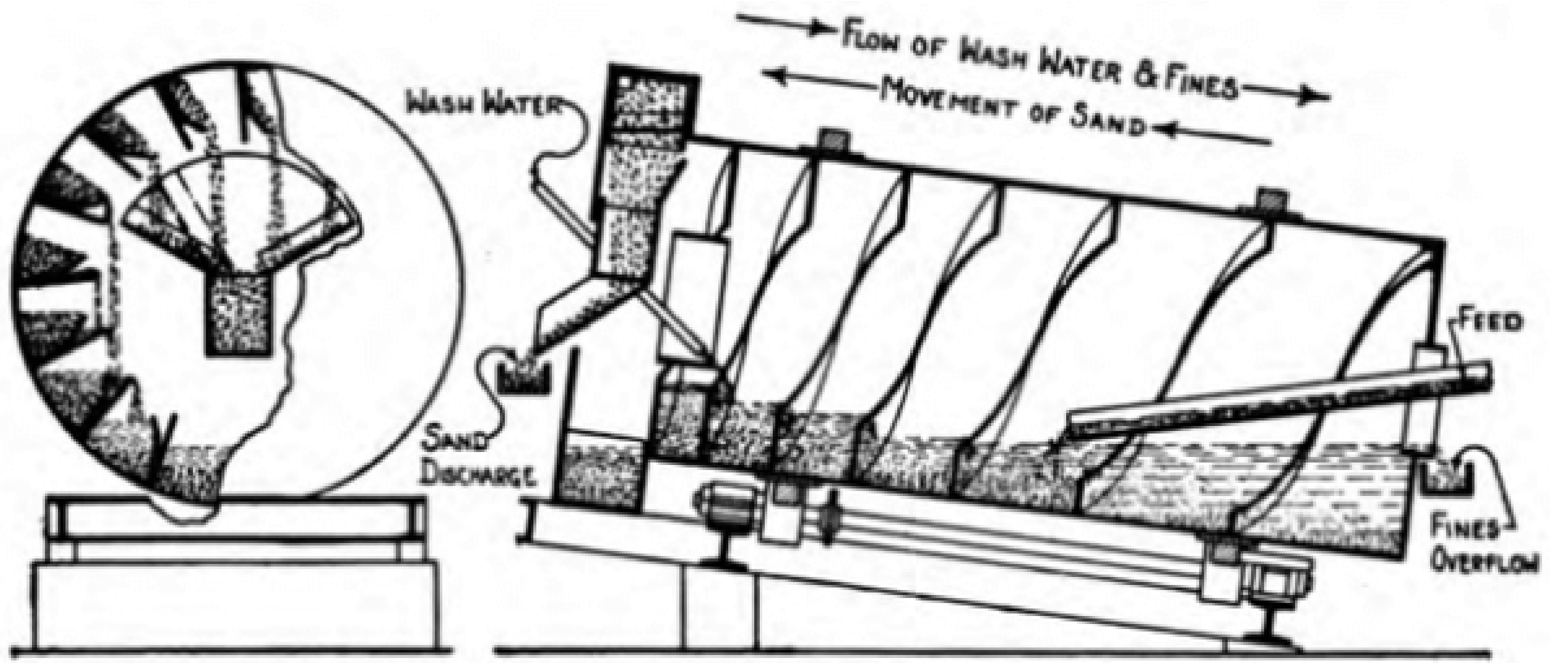




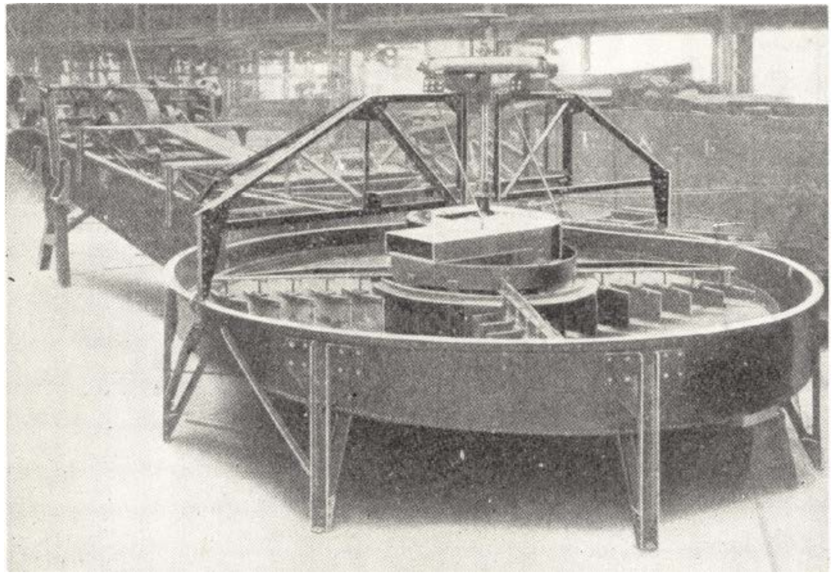




Rake and Spiral Classifiers



Countercurrent classifier



Door bowl rake classifier

Mechanical classifiers are widely used in closed circuit wet grinding. Machines are available to rake as much as **1000 ton per day** of sands per foot of tank width, which satisfies the circulating demand of any present day grinding mill.

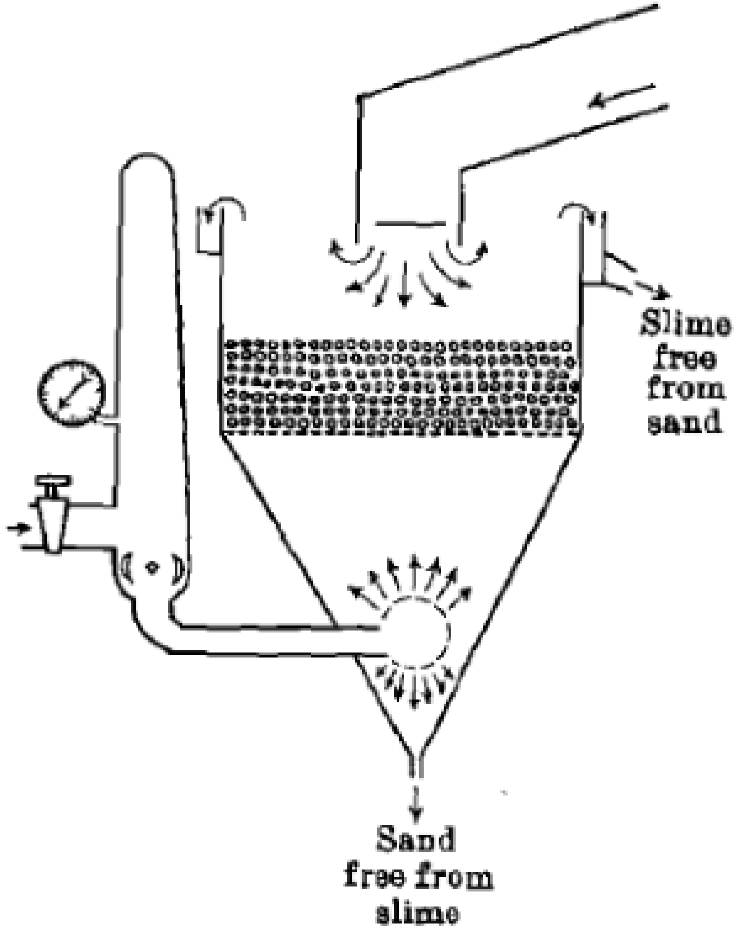
B. Non-mechanical Classifiers

i. Sand tanks

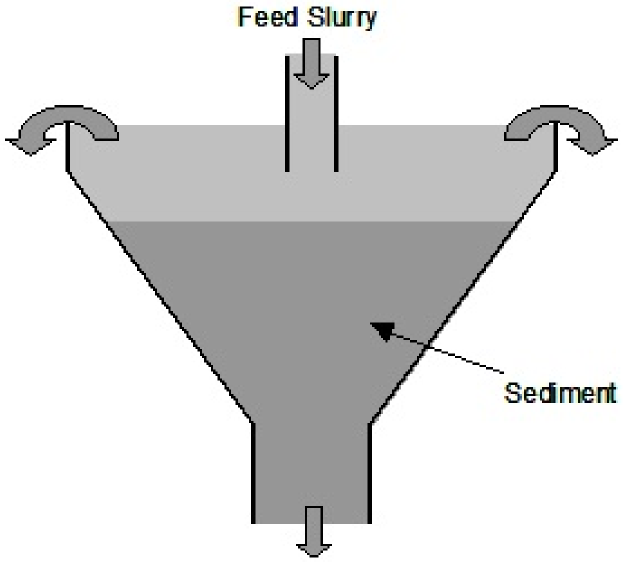
- a) Whole current classifier
- b) Caldecott cone
- c) Automatic cone
- d) Allen cone
- e) Boylan automatic cone
- f) Nord bergwood classifier

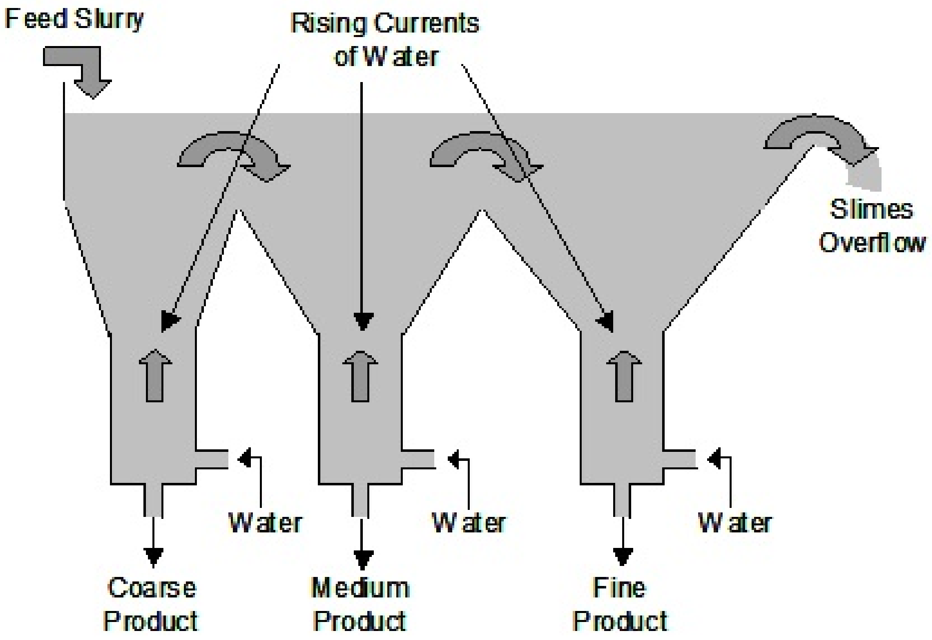
ii. Slime tanks

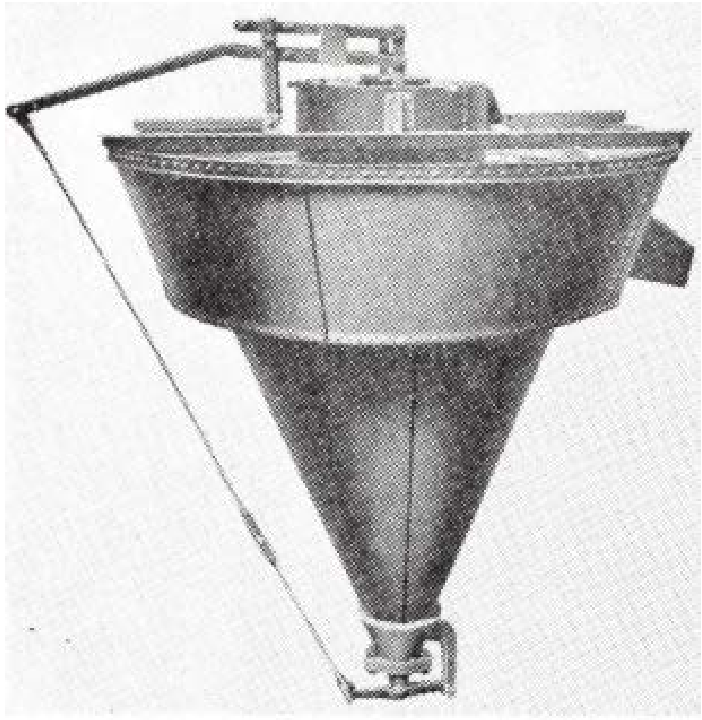
- a) Surface current classifiers
- b) Rittinger spitzkasten
- c) Desliming cone (6 0 apex angle)
- d) Callow tank
- e) Reichert cone classifier
- f) Hukki screen cell



–PULSATOR PEBBLE-CONE SAND-SLIME SEPARATOR.



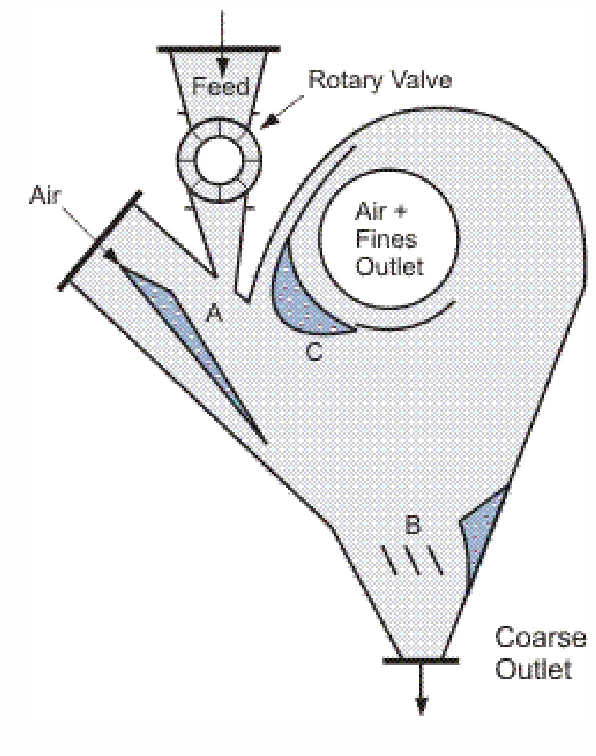




Allen Cone Classifier

Spitzkasten Slime Tank

Reichert cone classifier



Larox classifier (Hukki, 1976).

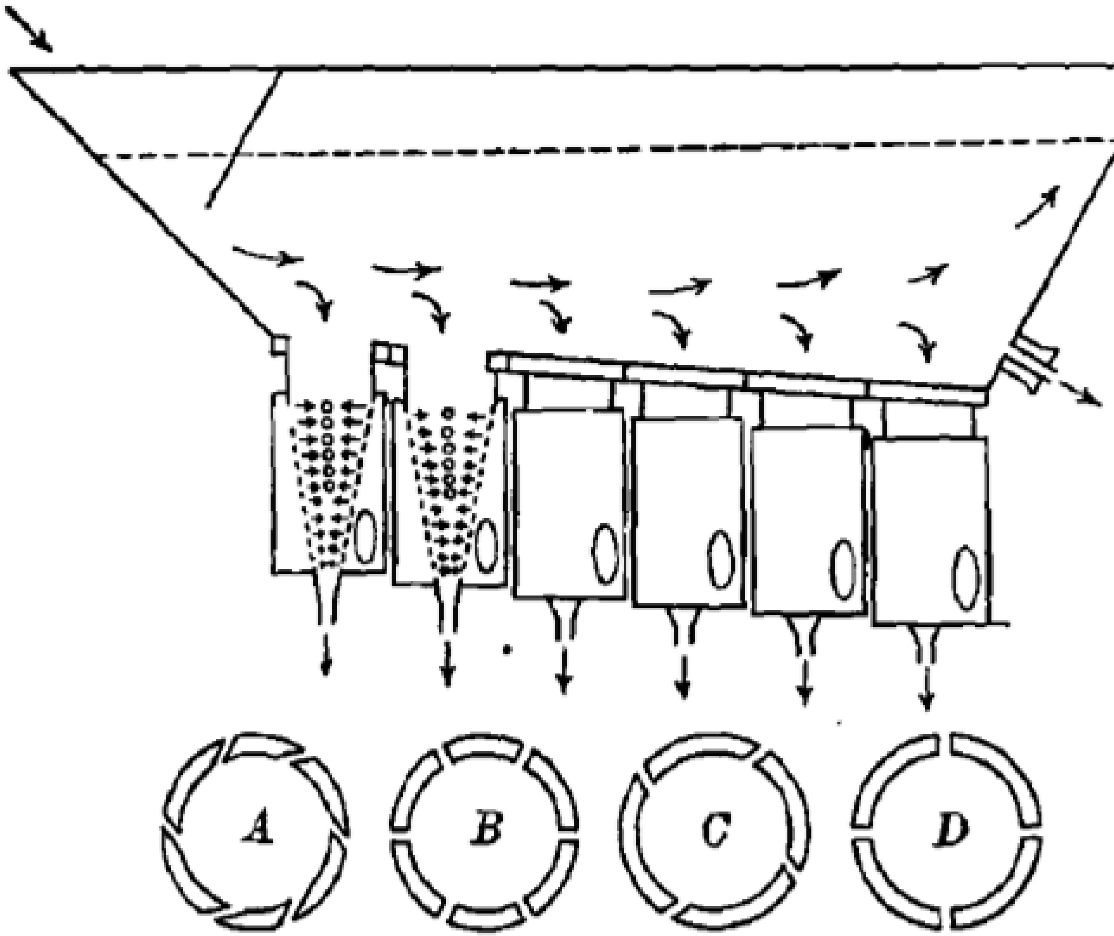
C. Hydraulic Classifiers

i. Free settling hydraulic classifiers

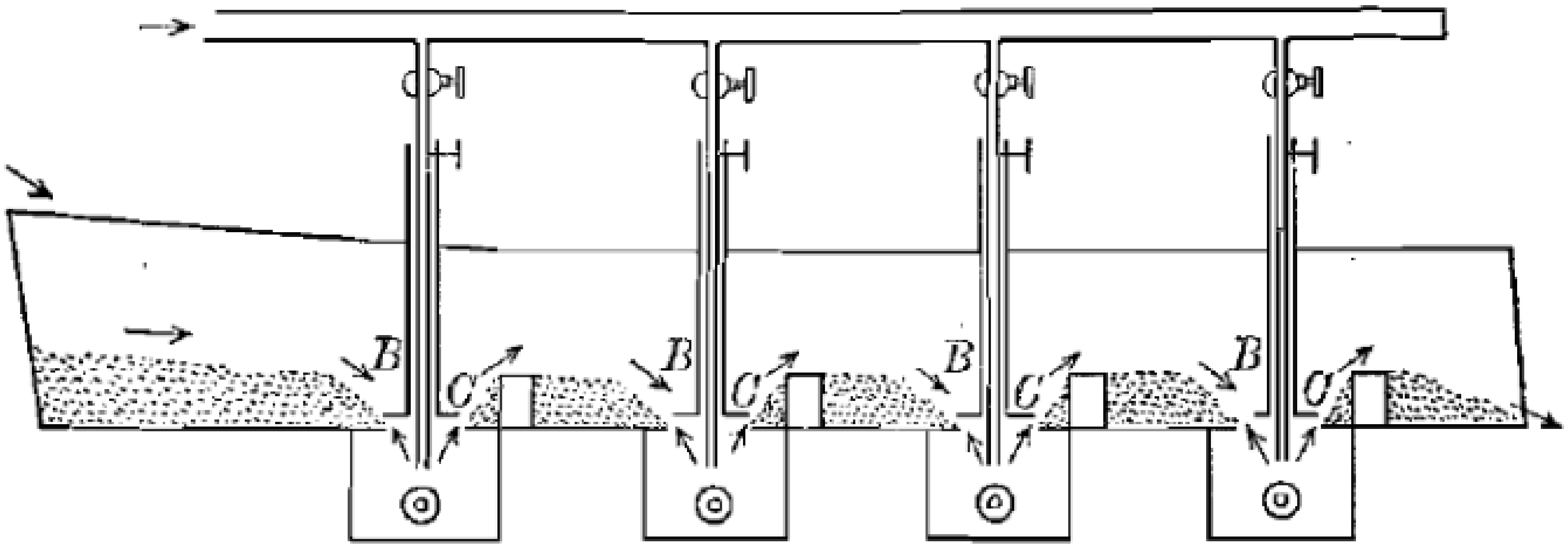
- a) Shallow pocket free settling classifiers
- b) Evans classifiers
- c) Deep pocket free settling classifiers

ii. Hindered settling classifiers

- a) Fahrenwald sizer
- b) Bunko classifier



Hindered settling classifiers



Free settling hydraulic classifier - Evans classifier