Course Code: ChBC-43

Credits: 04

Mechanical Operations

by

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Vision of NIT Srinagar

To establish a unique identity of a pioneer technical Institute by developing a high quality technical manpower and technological resources that aim at economic and social development of the nation as a whole and the region, in particular, keeping in view the global challenges.

Mission of NIT Srinagar

- To create a strong and transformative technical educational environment in which fresh ideas, moral principles, research and excellence nurture with international standards.
- To prepare technically educated and broadly talented engineers, future innovators and entrepreneurs, graduates with understanding of the needs and problems of the industry, the society, the state and the nation.
- To inculcate the highest degree of confidence, professionalism, academic excellence and engineering ethics in budding engineers.

Vision of the Chemical Engineering Department

To be one of the leading Chemical Engineering Departments in the Country engaged with teaching, research and training of students with high moral values to solve the problems of Chemical and Allied industries for meeting the aspirations of society.

Mission of the Chemical Engineering Department

- To create and sustain the strong foundations of Chemical Engineering education, research and innovation.
- To produce well qualified, innovative Chemical Engineers with entrepreneurial skills & leadership qualities to face and solve the problems of industries and the society at large.
- To make professional leaders, academicians and engineers with high moral values and ethics.

Program Educational Objectives (PEOs)

PEO1	Providing broad-based Chemical Engineering education on the solid foundations of mathematics, basic sciences, engineering and social studies by choice based credit system.
PEO2	Enable the students to become future leaders in engineering practices for the overall betterment of society and instill in them a work culture based on foundations of ethics, scientific temperament and team work.
PEO3	Equip the students with knowledge, understanding and applications of Chemical Engineering tools for enabling them to pursue innovative research.
PEO4	Attain excellence in engineering and design through education in the principles and practices of Chemical Engineering.

Program Outcomes	
PO1	**Engineering Knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
PO2	**Problem Analysis**: Identify, formulate, review research literature, and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.
PO3	**Design/Development of Solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
PO4	**Conduct Investigations of Complex Problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions for complex problems.
PO5	**Modern Tool Usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
PO6	**The Engineer and Society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
PO7	**Environment and Sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
PO8	**Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
PO9	**Individual and Team Work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
PO10	**Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
PO11	**Project Management and Finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
PO12	**Life-long Learning**: Recognize the need for, and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological change.

Course Instructor: Dr. Kurella Swamy

Program Specific Outcomes(PSOs)

PSO1	Apply the principles and practices of Chemical Engineering discipline along with the basic sciences and humanities to solve the complex engineering problems concerning the issues of environment, safety, economics, culture and society etc
PSO2	Acquire and apply the new knowledge with professional responsibility and ethics towards the advancement of academic and research pursuits in Chemical and Allied disciplines in the societal contexts.
PSO3	Design, develop and modify the Chemical Processes and to analyze these by applying the physicochemical and biological techniques.

Syllabus and References

S.No	Topics	Hours
1	**Introduction:** Properties and handling of particulate solids, characterization of solid particles, Storage and transportation of bulk solids (types of conveyers, their selection), Pneumatic and hydraulic conveying of solids, general characteristics and flow relations, mechanical conveyers.	8
2	**Crushing and Grinding:** Theory of Crushing. Laws of crushing-Rittingers" law, Kick"s law, Classification of crushing and grinding machinery, coarse crusher, jaw crusher, gravity crushers, intermediate crushers (roll, disc or cone crusher, edge runners, squired cage disintegrator, hammer mill), fine grinders-burhstones, roller mills, ball and tube mills.	8
3	**Size Separation:** Principle of screening, screen analysis, types of screening equipment (grizzlies, trommels, shaking and vibrating screens), effectiveness of a screen, air separating method (cyclone separator, bag filters, electrostatic precipitator, scrubbers).	8
4	**Settling:** Free and hindered settling, classification of classifiers (simple and mechanical), introduction to the design of continuous thickeners.	8
5	**Filtration:** Classification of filters, effect of pressure on filtration, filter aids, constant pressure and constant rate filtration theory, membrane filtration.	8
6	**Agitation and Mixing:** Theory of mixing, power consumption of mixer impellers, mixing liquids with liquids, mixing gas with liquid, mixing of viscous masses, mixing of solids with solids mixing of solid with liquid.	5

1. McCabe, W.I., Smith, J.C., "*Unit Operations in Chemical Engineering", 7th Edn.,McGraw-Hill (2011).
2. Badger, L.W., Banchero, T.J., "*Introduction to Chemical Engineering",* 3rd Edn., McGraw-Hill (1997).
3. Coulson, J.M., Richardson, J.F., "*Chem. Engineering, 2nd Vol.*", Butterworth-Heinemann.
4. Foust, A. S., Wenzel, L. A., Clump, C. W., Maus, L., Andersen, L. B., "*Principles of Unit Operations*", 2nd Ed., Wiley-India (2008).
5. Perry, R.H., Green, D.W., "*Perry's Chemical Engineers' Handbook",* 7th Edn.", McGraw-Hill Book Company (2008).

Course Outcomes

1	Understand the characterization, classification, conveying and storage of solids
2	Calculate the power requirements and crushing efficiencies of size reduction equipment using laws of communition and understand the working of different size reduction equipment
3	Analyze the screening results to estimate the screen effectiveness and acquire knowledge of screening mechanism and separation of solids from solids and gases
4	Apply the knowledge of filtration theory to estimate the filtration time, specific cake and medium resistance of filtration processes and understand the settling characteristics
5	Acquire the knowledge of agitation and different types of agitated vessels

CO-PO & CO-PSO Mapping

COs	POs												PSOs		
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	3	2	2	1		1	2					1	3	3	3
2	3	3	2	2		2	3					2	3	3	3
3	3	3	3	3		2	2					1	3	3	3
4	3	3	3	3		3	3					2	3	3	3
5	3	1	1	2									2	1	1

3: Excellent (highly correlated)

2: Good (moderate)

1: Satisfied (Low)

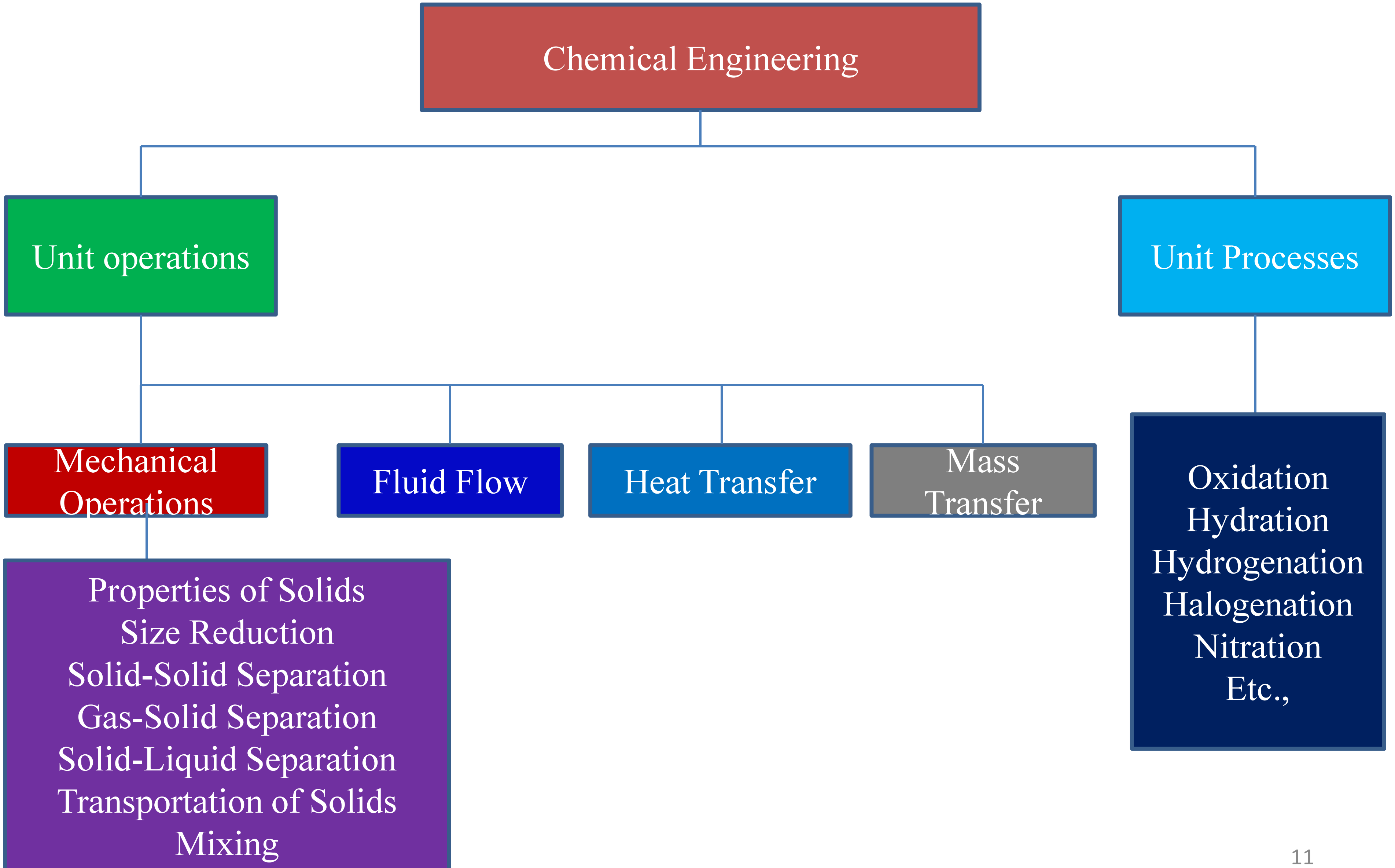
Blank: Not correlated

Evaluation Scheme

Component	Duration (Hours)	Weightage (Marks)	Date & Time
Midterm Exam	1.5	30	According to Academic Calendar
End Semester Exam	3.0	60	According to Academic Calendar
Assignments/Surprise Tests/Quizs	--	10	Class Timings

Grading: Absolute Grading

Introduction



CHARACTERISATION, STORAGE & TRANSPORTATION OF SOLIDS

Characterization of Solid Particles

- Solid particles characterized by ***Size, Shape*** and ***Density***
- Homogeneous solids have the ***same density*** as the bulk material
- Particles obtained by breaking up a composite solid , such as metal ore, have various densities, usually different from the density of bulk material
- Size and shape are easily specified for regular particles, such as spheres and cubes
- For irregular particles (sand and mica flakes) the terms size and shape are not so clear must be arbitrarily defined.

Shape

- The simplest of three dimensional shapes is the Sphere.
- The dimensionless term ***Sphericity*** , Φ, is in common use to compare particles of irregular shapes with that of spherical one.
- ***Sphericity:*** *The surface area of a sphere of the same volume as the particle divided by the actual surface area of the particle.*

  The ratio of the surface-volume ratio for a sphere of diameter D_p and the surface-volume ratio for the irregular particle whose nominal size D_p.

- *For a non spherical particle, the sphericity is*

$$\Phi = \frac{Surface\ to\ volume\ ratio\ of\ sphere\ of\ diameter\ Dp}{Surface\ to\ volume\ ratio\ of\ particle\ whose\ nominal\ size\ is\ Dp}$$

$$\Phi = \frac{(\frac{S_P}{V_P})_{Sphere\ of\ particle\ volume}}{(\frac{S_P}{V_P})_{particle}}$$

$$(\frac{S_P}{V_P})_{Sphere\ of\ particle\ volume} = \frac{\pi {D_P}^2}{\frac{1}{6}\pi {D_P}^3} = \frac{6}{D_P}$$

Shape

- The shape of the particle deviates from that of a spherical, the sphericity goes on decreasing towards zero.
- *Sphericity sometimes defined as how close the irregular particle is to a spherical particle.*
- ***Sphericity is independent of particle size.***
- ***The reciprocal of sphericity is known as the surface shape factor*** $(\Phi_s = \frac{1}{\Phi})$
- **The volume of a spherical particle is proportional to the cube of its diameter.**
- ***If we assume same for the irregular particles:***

$$V_P \ \alpha \ {D_P}^3$$

$$V_P = a\, {D_P}^3$$

a is volume shape factor and for spherical particles, $a = \frac{\pi}{6}$

Problem: Find the sphericity of a cube of dimension a×a×a

Size

- Size is the linear dimension of the particle.
- Sphere is ideal example whose size is defined by its diameter.
- *For irregular particles , the size may be found as the average of the shortest and longest dimension of the particle or, as the second largest dimension.*
- *Equivalent Diameter: The size of spherical particle having the same controlling characteristics as the particle under consideration.*
- *The controlling characteristics like volume, surface area, surface area per unit volume, settling velocity, etc., depend upon the system and the process in which the particle is involved.*
- **Equivalent Diameter:** *The size of spherical particle having the same controlling characteristics [Surface area, surface area per unit volume, settling velocity, etc] as the particle under consideration.*
- *Different ways to express the particle size depending on the various controlling characteristics are mass mean diameter, surface mean diameter, volume mean diameter and volume surface mean diamter.*

Mixed Particles

- **Specific Surface** : $A_w = \frac{6x_1}{\Phi\rho_p D_{p1}} + \frac{6x_2}{\Phi\rho_p D_{p2}} + \frac{6x_3}{\Phi\rho_p D_{p3}} + \cdots + \frac{6x_n}{\Phi\rho_p D_{pn}}$; $A_w = \frac{6}{\Phi\rho_p}\sum\frac{x_i}{D_{pi}}$

x_i = Mass fraction in a given increment ; m = Total mass

n = Number of increments

D_{pi} = Average particle diameter[average of smallest and largest particle diameter in increment]

ρ_p = Density of particle

Specific Surface Ratio: *The ratio of specific surface of the particle to the specific surface of a spherical particle of the same diameter.* $N_{WR} = A_w / \left[\frac{6}{\rho_p D_{pi}}\right]$

i) Volume Surface Mean Diameter: $D_{VS} = \frac{1}{\sum\frac{x_i}{D_{pi}}} = \frac{6}{\Phi\, A_w\, \rho_p}$

ii) Volume Mean Diameter: $D_V = [\frac{1}{\sum\frac{x_i}{D_{pi}^3}}]^{1/3}$

iii) Mass Mean Diameter: $D_m = \sum x_i D_{pi}$

Number of Particles: $N_w = \frac{1}{a\rho_p {D_V}^3}$

$$V_s = \frac{m}{\rho_p}$$

$$N_s = \frac{V_s}{v_p} = \frac{m}{v_p\rho_p}$$

$$A_s = N_s \, X \, S_p = \frac{mS_p}{v_p\rho_p}$$

$$\Phi = \frac{6}{D_P}\left(\frac{V_P}{S_P}\right)_{particle}$$

$$A_s = \frac{6m}{\Phi\rho_p D_{pi}}$$

Classification and Properties of Particles

- Classification based on Particle Size
  1. Coarse Particles: Inches/ Millimeters
  2. Fine Particles : Screen Size
  3. Very Fine Particles: Micrometers/ Nanometers
  4. Ultrafine Particles: Surface area/ Unit mass (m^2/g)
- Properties of Solids
  1. Hardness
  2. Toughness
  3. Structure
  4. Friability
  5. Moisture Content
  6. Explosive Nature
  7. Soapiness
  8. Crystallinity
  9. Temperature Sensitivity

Solids in Bulk

- The properties of solids in bulk are dependent on the properties of the individual particles including their shape, size and the way they interact with each other.
- For homogeneous solid particles, the ratio of the normal pressure P_N to the applied pressure P_A is constant.

$$K = \frac{P_N}{P_A}$$

(K is characteristic of the material and it is nearly independent of particle size)

K is Coefficient of Flowability

K depends on:

i) **Shape and interlocking tendencies of particles**

ii) **Degree of packing**

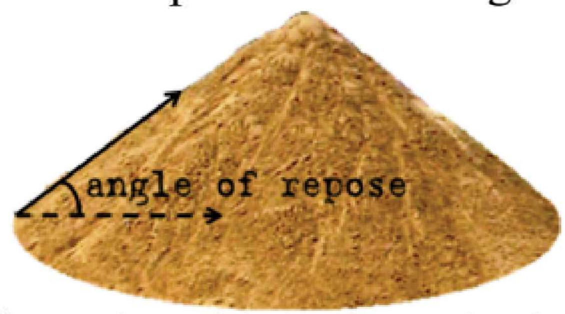
iii) **Stickiness of the particles**

K is nearly zero for cohesive solids

K varies between 0.3 to 0.6 for free flowing grannular materials

Solids in Bulk

- **Angle of internal friction (α_i):** The frictional force within the particles is measured by using the angle of internal friction , α_i .
- The tangent of α_i is coefficient of friction between two layers of particles.
- It determines the flowing characteristics of particles and it is important for design of storage vessels like bins , silos and hoppers.
- α_i is 15˚-30˚ for grannular solids and 90˚ for cohesive solids

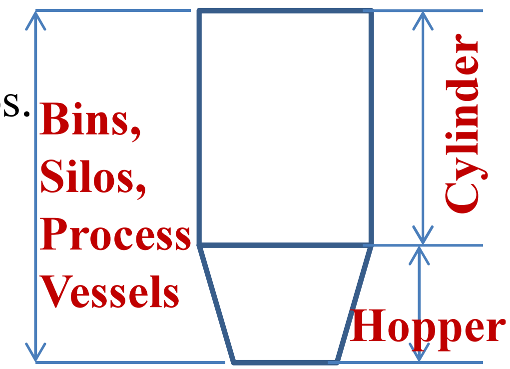


$$K = \frac{1 - Sin\alpha_i}{1 + Sin\alpha_i}$$

- **Angle of Repose (α_r):** The angle at which the sides of pile make with horizontal when solids are piled up on a plane surface.
- It is useful for determining the capacity of a bin or a pile and it is also useful in during transport.
- Low for smooth and rounded particles and higher for sticky and angular particles.
- *For homogeneous solids these two angles are nearly same but in practice $\alpha_r < \alpha_i$ due to the solid particles at the exposed surface are more loosely packed than the materials inside the file and are dried and less sticky.*

Storage of bulk solids

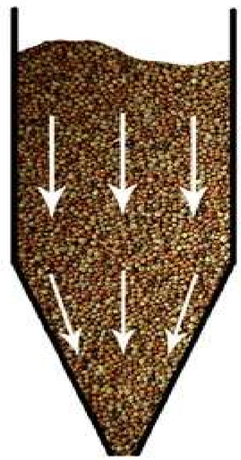
- Generally, the bulk solid is defined as numerous dry or wet solid particles ranging from fine powder to coarse solid particles that being handled in bulk form.
- Vessels : Bins, Silos, Elevators or Process Vessels
- Coarse Solids: Coal, gravel, sand and water insoluble materials are stored in open and large piles usually unprotected from weather.
- Rock salt , gun powder, solid chemicals are stored in bins and silos.
- Bins: Abrasive materials , wider and short in height
- Silos: Tall, smaller in diameter



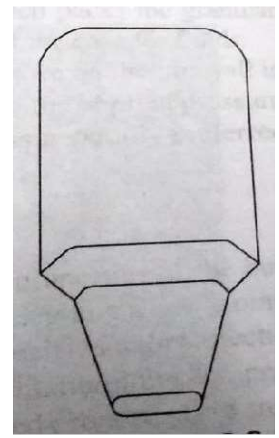
- All these containers are charged through the open top and are usually discharged through openings at the bottom.
- At the same cross section inside a bin or a silo , the lateral pressure on the bin wall is less than the vertical pressure , as the ratio of normal pressure to applied pressure K is less than the unity.
- Therefore the bottom discharge of solids is generally proffered over the side discharge.

Flow of bulk solids

Funnel



Mass-flow Pattern



Expanded flow bin

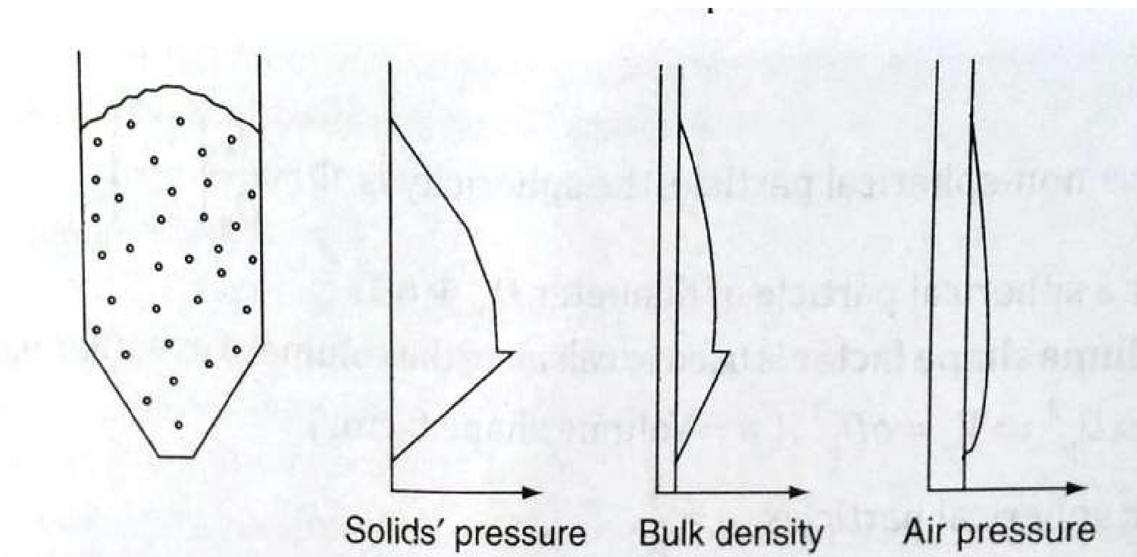
Problems Associated:

No flow

Erratic flow

Flushing

Segregation



Pressure and Density Analysis during flow of bulk solids

Transportation of Solids

- Hands, electric trucks, trolleys, or carts for short distances
- Rail, road, or ships for long distance (Uneconomical and disadvantageous)
- Conveyors and Elevators.
- **Conveyors:** Either carry the solids on them or drag them through a channel (short and long distances), operated either intermittently or continuously.
- **Elevators:** The conveyors that lift the solids vertically
- Pneumatic, Hydraulic and Mechanical Conveying
- Belt conveyors, screw conveyors and bucket elevators
- The selection of equipment depends on:
  1. Capacity requirements
  2. Distance of travel
  3. Shape and size of materials
  4. Material characteristics (Chemical and Physical)
  5. Whether the solids are to be transported horizontally , vertically or on an incline.

Pneumatic Conveying

- Suspending fluid is gas , usually air, flowing at velocities between 15-30 m/s in pipes ranging 50-400 mm in diameter.

Principal Types of Systems:

- **Negative Pressure (Vacuum) Systems:** Useful in transferring solids from multiple intake points to a single delivery point
- **Positive Pressure Systems:** Best for one intake point and multiple delivery points
- **Vacuum Pressure Systems:** Combines the advantages of above two
- **Prefluidized Systems:** require less air , and consequently less power than any other methods.
- **Materials Handled:** Fine powders to 6.5 mm pellets, bulk density 16 to 3200 kg/m3
- Vacuum systems are typically limited to solids flow rates less than 6800 kg/h and equivalent conveyor lengths less than 300 m.
- Pressure systems operate at 1 to 5 atm gauge and are used to for free flowing solid sof particles less than 6.5 mm in size , where flow rates greater than 9000 kg/h are needed. The pressure loss through the system is about 0.5 atm.

Hydraulic Conveying

- Particles smaller than about 50 μm in diameter settle very slowly and are readily suspended in a moving liquid.
- Larger particles are harder to suspend , and when the diameter is 0.25 mm or greater , a fairly large liquid velocity is needed to keep the particles moving , especially in horizontal pipes.
- The critical velocity **(V_C)** below which particles will settle out is typically between 1-5 m/s, depending on the density difference between solids and liquid, the particle diameter, the slurry concentration, and the size of the pipe.
- Critical velocities are larger in big pipe than in small pipe.
- The pressure drop in slurries of nonsettling particles may be found from the equations for a homogeneous liquid with appropriate allowance for the increased density and apparent viscosity.
- For settling slurries there is no single satisfactory correlation; the pressure drop in a horizontal pipe is greater than that in a single phase fluid of the same density viscosity as the slurry, especially near the **V_C**, but approaches that in the single phase liquid as the velocity increases.
- When the velocity is **$3V_C$** or greater , the pressure drop in the slurry and that in the equivalent single phase liquid are equal.
- The velocity in along slurry pipeline is typically 1.5 – 2.0 times **V_C.**

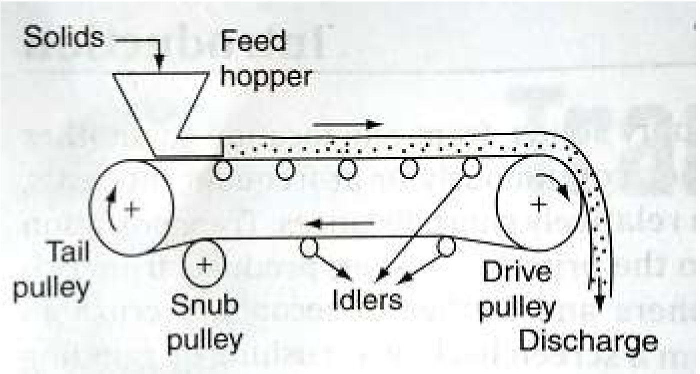
Belt Conveyors

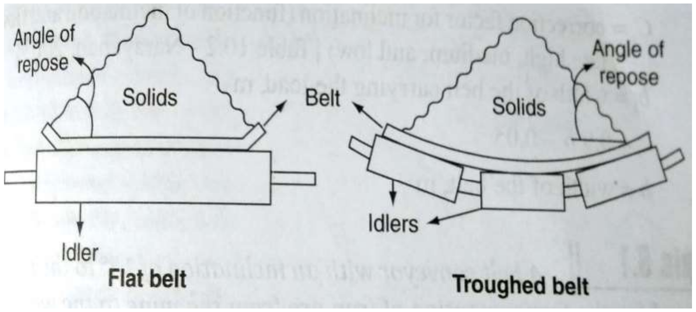
- Consists of a continuous belt passing around two large pulleys at the two ends

  (drive pulley and tail pulley)
- Solids loaded on the upper surface of the belt near the tail pulley through a feed hopper and are carried to the other end of the belt and are discharged over the drive pulley.
- The loaded belt is supported during its carrying run by closely spaced rollers (idlers), while during the returning run the belt is supported by widely spaced idlers.
- The idlers so spaced to prevent the sagging of the belt during its operation.
- The length of belt may change due to the load of solids or seasonal changes in temperature and humidity. For this reason, a snub pulley is provided to the returning part of the belt.
- Flat belts – boxes, solid units, solid particles with a high α_r
- The angle of inclination of the belt is less than the αr solid particles to be transported and between 10˚-20˚ .
- Canvas or rubber and are reinforced with steel wire to impart strength.
- Neoprene, vulcanized rubber and other special types are available for handling high and moist materials.

Belt Conveyors

- The capacity depends upon
  1. Width and speed of the belt
  2. Friction between the belt surface and the solids
  3. Angle of repose of solid particles
  4. Angle of inclination of the belt
  5. Stickiness of the solid particles
  6. Degree of toughing
  7. Shape, size and specific gravity of solids





- Maximum capacity of belt conveyors:

$$Q_b = A_b\ V\ \rho_b$$

Q_b = maximum capacity of the belt conveyor(kg/s); A_b = cross sectional area of load on the conveyor belt(m^2) ; V = linear speed of the belt(m/s); ρ_b = bulk density of the solids(kg/m^3)

$$A_b = K_a\ C_i\ b^2$$

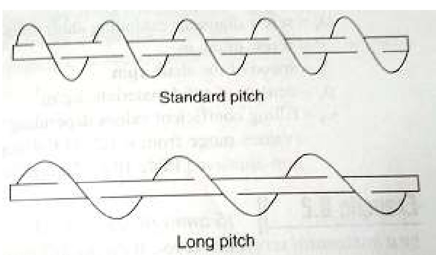
K_a =A constant whose value depends on the flowability of the material and the angle of inclination of side rollers

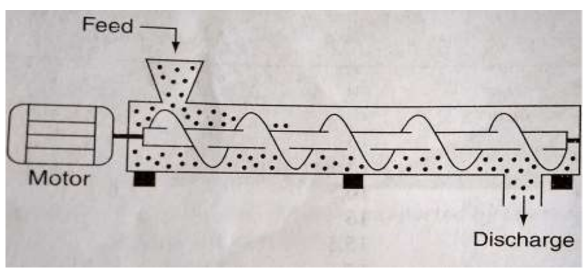
C_i = Correction factor for inclination (function of inclination and flowability)

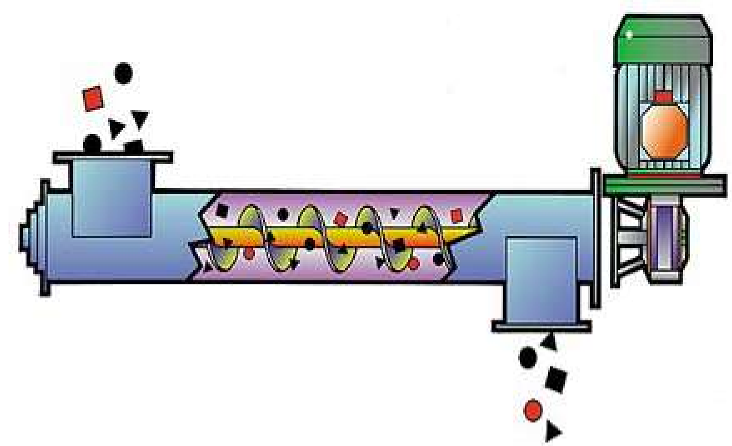
b = width of the belt carrying the load, m = 0.9 x- 0.05 ; x = width of the belt, m

Screw Conveyors

- Operated horizontally or at a slight incline (upto 20˚) and are extensively used for transporting finely divided solids; sticky materials ; and semisolid materials including food waste , municipal solid wastes and boiler ash.
- Short distances, 40 m horizontal, 30m vertical direction.
- Consists U-shaped trough inside which a screw or spiral flight mounted on a shaft is placed parallel to the trough bottom.
- The shaft is supported on a bearing at each end and is generally driven at feed/one end.
- The solid particles to be conveyed are fed to the trough a feed hopper and as the shaft along with the screw rotates, the solid particles are rushed forward towards the discharge end along the front face of the spiral.







Screw Conveyors

- **Advantages:** simple design, ease of maintenance , slurry or sticky materials can be transported, with increasing pitch spacing , capacity can be increased without increasing the speed, heating, drying , cooling can be done.
- **Disadvantages:** high wear of screw and trough materials , size reduction of materials, higher power consumption, capacity decreases with increase in inclination, conveyor length is restricted.
- **Capacity:** Depends on screw diameter, screw pitch and speed of rotation

$$Q_S = C_i \left[\frac{\Pi}{4} D_s^{\,2}\right] P \left[\frac{N}{60}\right] \rho_s C_f$$

- C_i = correction factor for inclination which varies from 1.0 for horizontal conveyor to 0.6 for inclination of 20˚. Other values are 0.9, 0.8 and 0.7 for inclinations of 5, 10 and 15 degrees respectively.
- D_s = Screw diameter excluding shaft diameter, m
- P = Screw pitch, m; N = Speed of shaft, rpm; ρ_s = Density of solid materials , kg/m^3
- C_f = Filling coefficient values depending primarily on the type of materials (values range from 0.125 to 0.4 depending on heavy/light, abrasive/non –abrasive)

Bucket Elevators

- Used only for vertical transport of bulk solids
- Consists of a number of buckets attached to a continuous double strand chain or belt which passes over two sprockets or pulleys located at different elevations inside a casing.
- Solid materials are directly fed into the buckets partly and are scooped up from the boot partly , which are carried up vertically and are discharged into a hopper as the buckets turn over the upper sprocket.
- The emptied buckets faced downward travel vertically downward and again scoop up materials as they pass the lower sprocket.

Types :

Centrifugal discharge type – buckets are spaced (used to handle free flowing materials or small lump materials)

Continuous type – buckets are very closely spaced (used for large lump materials)

Positive discharge type - buckets are spaced and the return belts are snubbed back beneath the upper sprocket to invert them for positive discharge (used to lift sticky materials or cohesive solids and are slow speed equipment).