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PART A: NOTES

CHAPTER 1
SIZE SEPARATION

1.1 PARTICLE CHARACTERISTICS

The particle characteristics are defined by their size, shape and density.

The shape of an individual particle is expressed in terms of the sphericity ϕ_s. The equivalent diameter of a non-spherical particle is defined as the diameter of a sphere having the same volume as the particle. The sphericity ϕ_s is the ratio of the surface area of the sphere, whose diameter is equal to the equivalent diameter of the particle, to the actual surface area of particle. The sphericity ϕ_s is given by the relation

$$\phi_s = \frac{6/D_p}{S_p/V_p} \qquad \text{.................................(1)}$$

Where D_p = equivalent diameter of the particle

V_p = Volume of a particle

S_p = Surface area of a particle

Particle sizes are usually expressed in different units based on the size range involved. Coarse particles are measured in millimeters, fine particles in terms of screen size, very fine particles in micrometers or nanometers. Ultrafine particles are also described in terms of their surface area per unit mass, usually in m^2 / g.

If the total mass of uniform particles of diameter D_p, sphericity ϕ_s and density ρ_p in a sample is m, the total surface area of particles is given by

$$A = \frac{6m}{\phi_s \rho_p D_p} \qquad \text{.................................(2)}$$

1.2 MEAN PARTICLE SIZES

There are many definitions for the average particle size for a mixture of particles. These include:

- **VOLUME – SURFACE MEAN DIAMETER**

The volume – surface mean diameter defined as

$$\bar{D}_s = \frac{\sum_{i=1}^{n} N_i \bar{D}_{pi}^3}{\sum_{i=1}^{n} N_i \bar{D}_{pi}^2} \quad \text{.................................(3)}$$

If the number of particles in each fraction N_i is known, then it is given by

$$\bar{D}_s = \frac{1}{\sum_{i=1}^{n} \left(x_i / \bar{D}_{pi} \right)} \quad \text{.................................(4)}$$

- **ARITHMETIC MEAN DIAMETER**

It can be defined as

$$\bar{D}_N = \frac{\sum_{i=1}^{n} \left(N_i \bar{D}_{pi} \right)}{\sum_{i=1}^{n} N_i} = \frac{\sum_{i=1}^{n} \left(N_i \bar{D}_{pi} \right)}{N_T} \quad \text{.................................(5)}$$

Where N_T = total number of particles in entire sample

- **MASS MEAN DIAMETER**

It can be defined as

$$\bar{D}_w = \sum_{i=1}^{n} \left(x_i \bar{D}_{pi} \right) \quad \text{.................................(6)}$$

- **VOLUME MEAN DIAMETER**

It can be defined as

$$\bar{D}_V = \left[\frac{1}{\sum_{i=1}^{n} \left(x_i / \bar{D}_{pi}^3 \right)} \right]^{1/3} \quad \text{.................................(7)}$$

1.3 SCREENING

It is a method to separate the fine particles on the basis of their sizes. To perform screen analysis following steps are used:

- A set of standard screens are arranged serially in a stack with the smallest mesh at bottom and largest at top.
- The sample is placed on the top screen and then the stack is shaken mechanically for a definite time, usually 20 minutes.
- The particles retained on each screen are removed and weighted and the masses of the individual screen increments are converted to mass fractions or mass % of the total sample.
- Any particles that pass the fines screen are caught in a pan at the bottom of the stack.
- The results of a screen analysis are tabulated to show the mass fraction of each increment as a fraction of the mesh size range of the increment.

Here, the notation 14/20 mean “through 14 mesh and on 20 mesh.”

Mesh	**Screen Opening D_{pi}, mm**	**Mass Fraction Retained, x_i**	**Average Particle Diameter in Increment, $\bar{D}_{pi}$, mm**	**Cumulative Fraction Smaller Than D_{pi}**
4	4.699	0.0000	-	1.0000
14	1.168	0.25701	1.409	0.2722
48	0.295	0.0102	0.356	0.0282
Pan	-	0.0075	0.037	0.0000

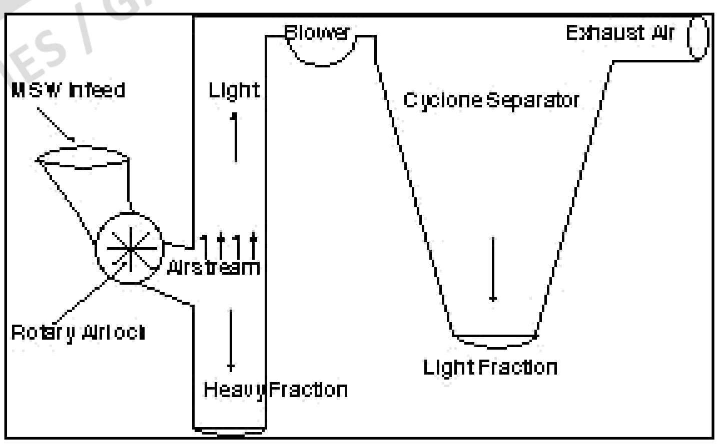
It is one method to classify the particles by their sizes.

1.4 ELUTRIATION

Elutriation, also known as *air classification*, is a process for separating lighter particles from heavier ones using a vertically-directed stream of gas or liquid (usually upwards). This method is predominately used for particles with size (>1μm). The smaller or lighter particles rise to the top (overflow) because their terminal velocities are lower than the velocity of the rising fluid. The terminal velocities of any particle in any media can be calculated using Stokes' Law if the particle Reynolds number is below 2.

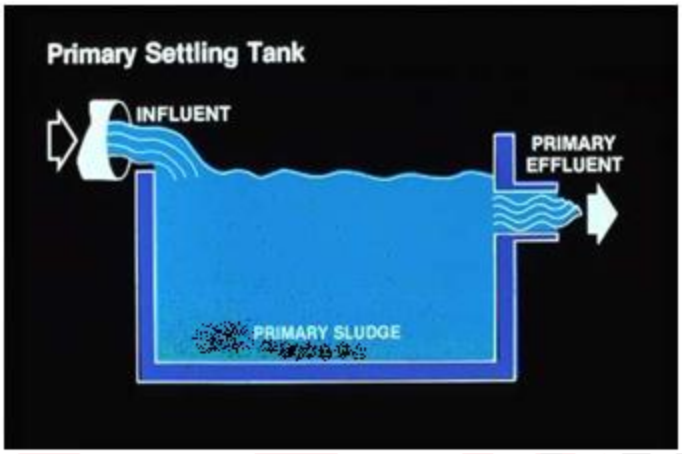
Elutriation is a materials separation method where smaller and larger materials are forced apart with the use of a column of liquid or gas. It can be used on the macro and micro level, from preparation of cell samples for analysis to separation of single stream recycling. Equipment for use in elutriation is available from a number of manufacturers and people can order custom equipment for unique applications. Such equipment tends to be more expensive than offerings on the conventional product lineup.

In elutriation, materials are fed into a rising column of separation medium. This can be something like a buffer solution or a jet of air. Small, light particles drift up in the column, while large, heavy particles sink down. This creates a series of layers of different materials of different sizes. In something like single stream recycling, large air jets are used for quick and basic separation, allowing plastic containers to go to one side of a processing facility, while glass lands on the other, for example, with metals being separated earlier in the process with the use of magnets.



1.5 SETTLING

Settling is the process by which particulates settle to the bottom of a liquid and form a sediment. Particles that experience a force, either due to gravity or due to centrifugal motion will tend to move in a uniform manner in the direction exerted by that force. For gravity settling, this means that the particles will tend to fall to the bottom of the vessel, forming a slurry at the vessel base.



1.6 CLASSIFICATION

Classification is defined as the separation of a mixture of solid particles into various fractions according to their size or density, which are allowed or caused to settle through a fluid either in motion or at rest. The fluid in question is generally water but it can also be air.

When the materials of the same density are separated according to their sizes, the operation is known as *sizing.*

When the materials of the same equivalent size are separated according to their densities, the operation is known as *sorting.*

1.6.1 PRINCIPLES OF CLASSIFICATION

When a solid particle falls through a vacuum under the influence of gravity alone, its velocity increases continuously due to acceleration. But when the same solid particle falls through a fluid such as air or water, its velocity increases at a lower rate due to friction caused by the movement of the particle in the fluid which cancels a part of the gravitational force. This frictional force increases with the increase in the velocity of the particle. And when the frictional force becomes equal to the gravitational force, the velocity of a particle reaches a constant value, known as the *terminal settling velocity.*

This velocity depends on the parameters such as the shape, size and density of the solid particle and the density and viscosity of the fluid.

1.6.2 LAWS OF CLASSIFICATION

Some of the general laws of classification are the following:

(i) The coarse particles have a relatively faster settling velocity than the fine particles of the same specific gravity and the same shape.

(ii) The heavy gravity particles have a relatively faster settling velocity than light gravity particles of the same size and the same shape.

(iii) The regular particles like the spherical ones have a relatively faster settling velocity than irregular particles of the same weight.

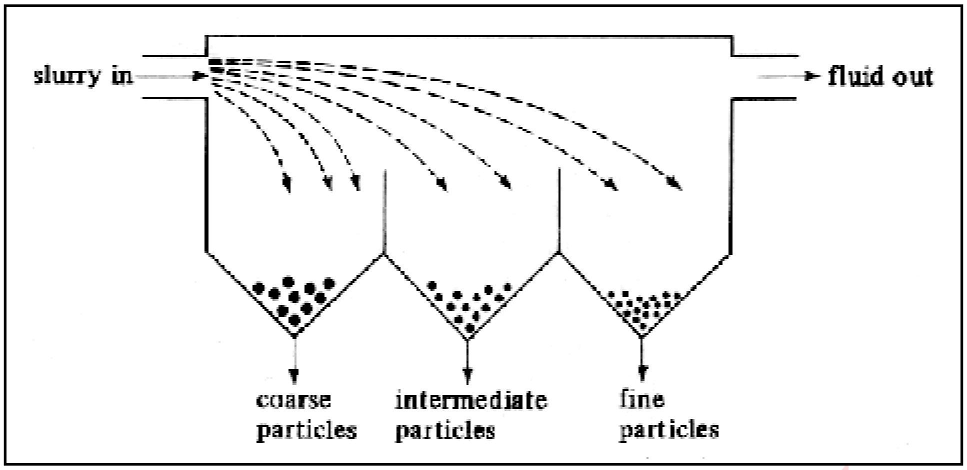
(iv) The settling velocity of solid particles decreases with the increase in fluid density and viscosity.

1.6.3 CLASSIFICATION EQUIPMENTS

There are basically two major type of classifying equipments:

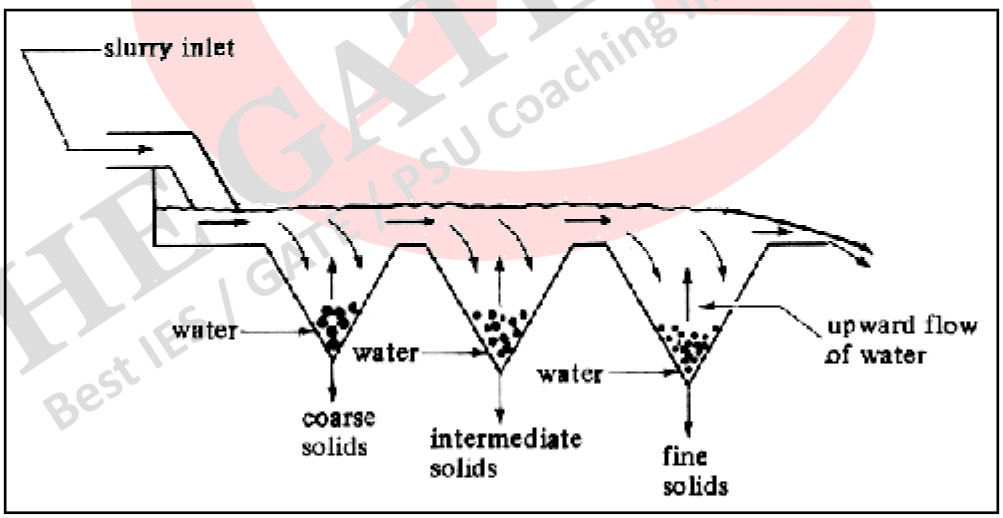
1.6.3.1 SIMPLE CLASSIFIER

In the simple classifier, the design is similar to that of the straight gravity settling tank, except that the bottom half is divided into several equal partitions. What happens is that instead of just falling into a big mess on the bottom of the tank, the coarse particles get trapped in the first chamber, the intermediates get trapped in the middle partitions, and the fine particles, the dust, gets captured in the last section. Then, you can drain the sections from the bottom and have segregated sediment.



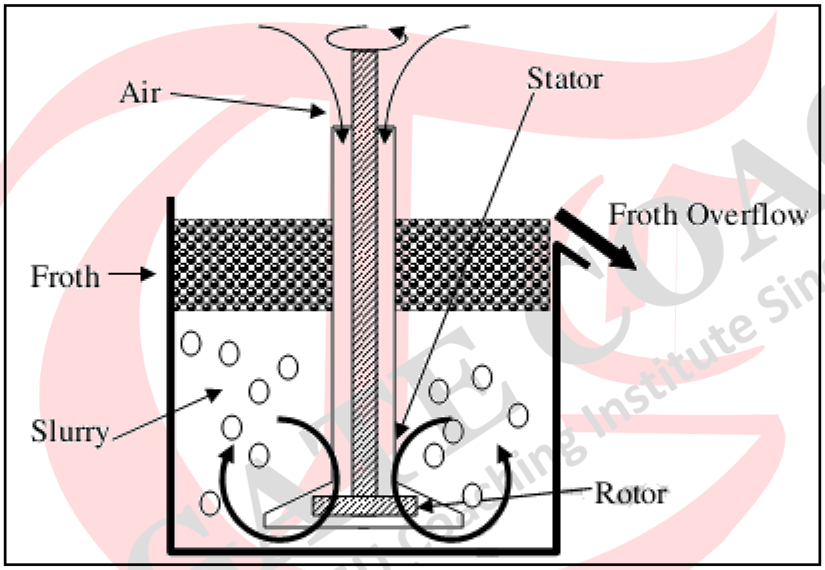
1.6.3.2 SPITZKASTEN CHAMBER

The Spitzkasten chamber runs like this. A series of conical vessels of increasing size is set up in the direction of flow. As the slurry enters the first vessel, the coarse particles get trapped, and the overflow continues on to the next, where more separation takes place. This particular settling chamber is unique because you can adjust the flow rates in between each vessel in order to provide the necessary degree of separation.



1.7 FROTH FLOATATION

Froth flotation is a highly versatile method for physically separating particles based on differences in the ability of air bubbles to selectively adhere to specific mineral surfaces in a mineral / water slurry. The particles with attached air bubbles are then carried to the surface and removed, while the particles that remain completely wetted stay in the liquid phase. Froth flotation can be adapted to a broad range of mineral separations, as it is possible to use chemical treatments to selectively alter mineral surfaces so that they have the necessary properties for the separation. It is currently in use for many diverse applications, with a few examples being: separating sulfide minerals from silica gangue (and from other sulfide minerals); separating potassium chloride (sylvite) from sodium chloride (halite); separating coal from ash-forming minerals; removing silicate minerals from iron ores; separating phosphate minerals from silicates; and even non-mineral applications such as de-inking recycled newsprint. It is particularly useful for processing fine-grained ores that are not amenable to conventional gravity concentration



1.7.1 REAGENTS

The properties of raw mineral mixtures suspended in plain water are rarely suitable for froth flotation. Chemicals are needed both to control the relative hydrophobic ties of the particles, and to maintain the proper froth characteristics. There are therefore many different reagents involved in the froth flotation process, with the selection of reagents depending on the specific mineral mixtures being treated.

1.7.1.1 COLLECTORS

Collectors are reagents that are used to selectively adsorb onto the surfaces of particles. They form a monolayer on the particle surface that essentially makes a thin film of non-polar hydrophobic hydrocarbons. The collectors greatly increase the contact angle so that bubbles will adhere to the surface. Selection of the correct collector is critical for an effective separation by froth flotation. Collectors can be generally classed depending on their ionic charge: they can be nonionic, anionic, or cationic. The nonionic collectors are simple hydrocarbon oils, while the anionic and cationic collectors consist of a polar part that selectively attaches to the mineral surfaces, and a non-polar part that projects out into the solution and makes the surface hydrophobic. Collectors can either chemically bond to the mineral surface (chemisorption), or be held on the surface by physical forces (physical adsorption).

1.7.1.2 CHEMISORPTION

In chemisorption, ions or molecules from solution undergo a chemical reaction with the surface, becoming irreversibly bonded. This permanently changes the nature of the surface. Chemisorption of collectors is highly selective, as the chemical bonds are specific to particular atoms

1.7.1.3 PHYSISORPTION

In physisorption, ions or molecules from solution become reversibly associated with the surface, attaching due to electrostatic attraction or van der Waals bonding. The physisorbed substances can be desorbed from the surface if conditions such as pH or composition of the solution changes. Physisorption is much less selective than chemisorption, as collectors will adsorb on any surface that has the correct electrical charge or degree of natural hydrophobicity.

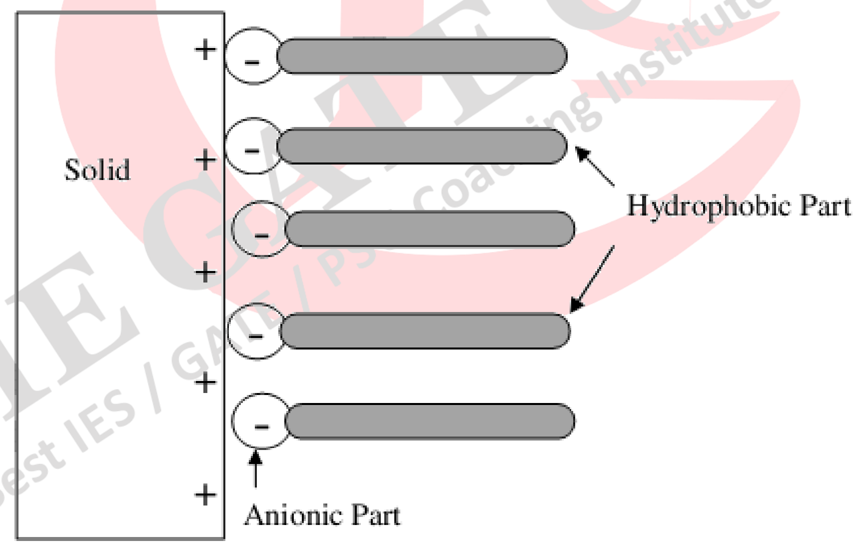
1.7.1.4 NONIONIC COLLECTORS

Hydrocarbon oils, and similar compounds, have an affinity for surfaces that are already partially hydrophobic. They selectively adsorb on these surfaces, and increase their hydrophobicity. The most commonly-floated naturally-hydrophobic material is coal. Addition of collectors such as #2 fuel oil and kerosene significantly enhances thehydrophobicity of the coal particles without affecting the surfaces of the associated ash-forming minerals. This improves the recovery of the coal, and increases the selectivity between coal particles and mineral matter. Fuel oil and kerosene have the following advantages over specialized collectors for froth flotation: 1) they have low enough viscosity to disperse in the slurry and spread over the coal particles easily, and 2) they are very low-cost compared to other compounds which can be used as coal collectors.

In addition to coal, it is also possible to float naturally-hydrophobic minerals such as molybdenite, elemental sulfur, and talc with nonionic collectors. Nonionic collectors can also be used as "extenders" for other collectors. If another, more-expensive collector makes a surface partially hydrophobic, adding non-polar oil will often increase the hydrophobicity further at low cost.

1.7.1.5 ANIONIC COLLECTORS

Anionic collectors are weak acids or acid salts that ionize in water, producing a collector that has a negatively-charged end that will attach to the mineral surfaces, and a hydrocarbon chain that extends out into the liquid, as shown in below figure.

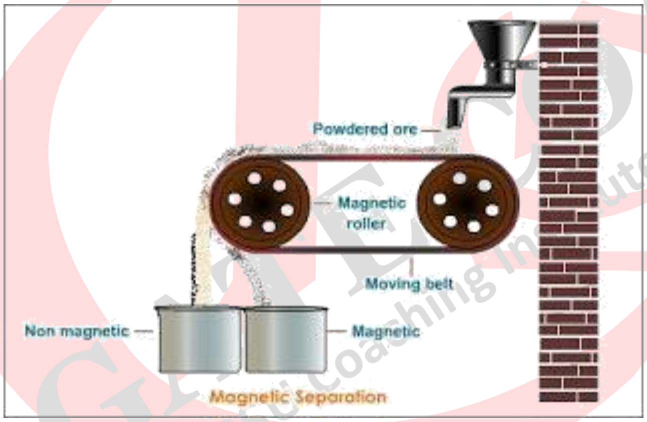


Adsorption of anionic collector onto a solid surface. The anionic portion is responsible for the attachment of the collector molecule to the surface, while the hydrophobic part alters the surface hydrophobicity.

1.8 MAGNETIC SEPARATION

It is the method to separate the solid – solid mixture with the help of their magnetic properties. For this we use magnetic separator.

A magnetic separator is a device used to separate mixture of fine, dry materials based upon their magnetic properties. The principles governing this process are magnetism and the interaction between magnetic, gravitational and centripetal forces. Magnetic properties of a material are based upon atomic structure and magnetic field intensity. The principles involved in a separation apparatus include: feed rate, velocity of the particles and magnetic field strength. Magnetic separation has two general applications, purification of feeds, and the magnetic removal impurities or the collection of the magnetic components from the mixture.

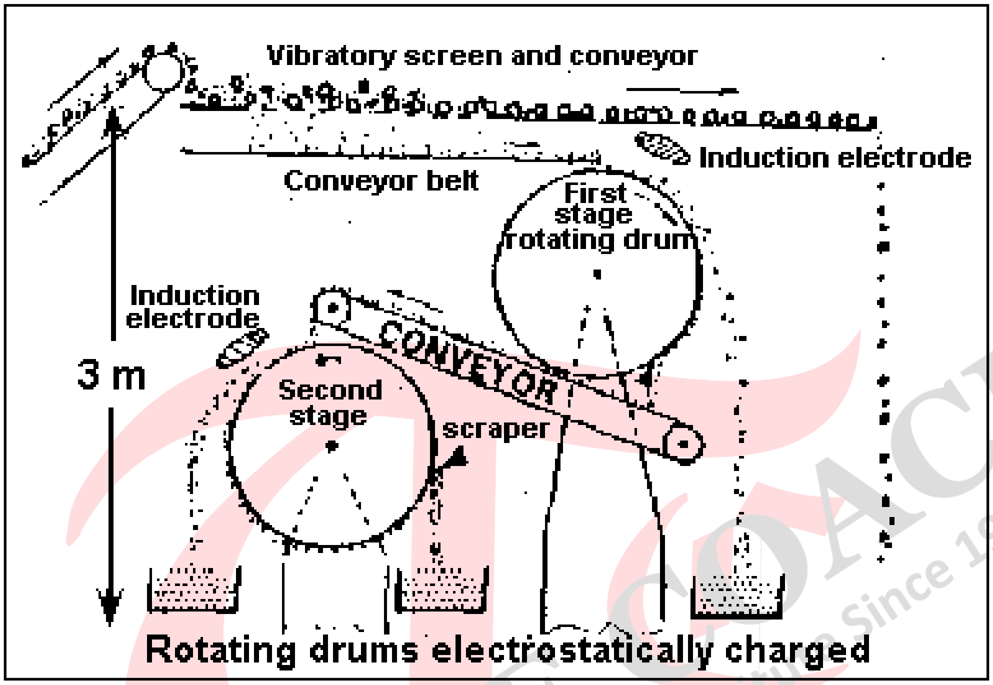


1.9 ELECTROSTATIC SEPARATION

Electrostatic separation is a process that uses electrostatic charges to separate crushed particles of material. An industrial process used to separate large amounts of material particles, electrostatic separating is most often used in the process of sorting mineral ore. This process can help remove valuable material from ore, or it can help remove foreign material to purify a substance. In mining, the process of crushing mining ore into particles for the purpose of separating minerals is called *beneficiation.*

An electrostatic separator is a device for separating particles by mass in a low energy charged beam. It works on the principle of corona discharge, where two plates are placed close together and high voltage is applied. this high voltage is used to separate the ionized particles.

Usually these are used in power plants where the harmful gases coming out of the chimneys are first treated using electrostatic separator. here the two electrodes are oppositely charged, with a negative electrode the positive ions gets attracted and thus results in a reddish flame whereas the positive electrode is used to treat the negatively charged ions resulting in a bluish white flame that is visible at nights.



1.10 CENTRIFUGAL SEPARATION

A centrifugal separator is a machine that uses centrifugal, gravitational, and inertial forces to divide two or more substances. This device can be used to separate solutions, gas mixtures, or other matter that can be physically parted. Centrifugal separation occurs when a mixture in the machine's chamber is spun very quickly, and heavy materials typically settle differently than lighter ones. Centrifugal separators have a wide variety of applications, in many industries.

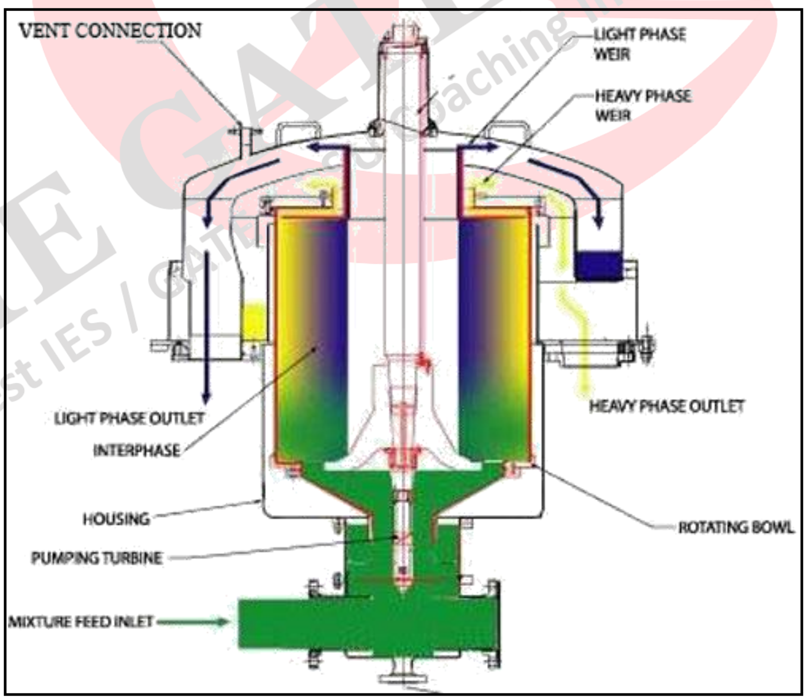
When a mixture enters the spinning chamber of a centrifugal separator, distinct substances within it are affected differently by the force created by the spinning. For example, gravitational force generally pulls heavier particles down more quickly than lighter ones, and the force of inertia affects the mixture as it spins. As the substances separate, they can be collected in various ways. Sometimes, they are collected mechanically, but, other times, they are physically separated. One method of this can be by screening

Heavier solid particles are often allowed to settle as they slide down the walls of the separator. They are then typically collected from the bottom. Generally, a gas can be purified by spinning any particulate matter and moisture out of it. The gas can then be collected, as it rises to the top and through an exit opening in the centrifugal separator. Liquids of different weights and viscosities may be divided into differing chambers of a separator as it moves.

Some of the applications in which a centrifugal separator can be used include dividing cream from milk, sand from gravel, and oil from water. The food and beverage industries often use these machines in the making of syrups, sugars, and malt liquors. Manufacturers of paints and varnish also use these machines, as do pharmaceutical manufacturers, animal feed makers, and the ceramics and abrasives industries.

A particular kind of machine, known as a *centrifugal water separator*, is often used to remove water from compressed air. This is important because water in the air can cause rust to occur in the metal components of a compressor, and in any attached machines or tools that utilize the compressed air. Typically, any condensate is spun out of the air by the separator, and collected in bowls where it is then pumped out of the compressor.

As the technology of the centrifugal separator has progressed, new applications have been found for its use. There are devices known as *ultracentrifuges* that are being used to separate larger molecules into their components. This advancing technology is particularly useful in the pharmaceutical industry.



1.11 SIZE ENLARGEMENT

In a size – enlargement operation, small particles are brought together purposely to form larger ones, generally by some mechanical means. The size – enlargement operations are many, namely, agglomeration, granulation, compaction, encapsulation, pelletizing, sintering, etc. and the agglomeration method is discussed here in brief.

Size – enlargement operations are followed in the process industries with a wide variety of objectives, such as

- To improve storage and handling characteristics of materials
- To improve flowability and disability
- To minimize dusting or material losses
- To create a safe working environment
- To enhance appearance
- To control solubility and dispersibility