Q: Explain about centrifugal mill.

A: Centrifugal Mill.

**Fine grinding made easy:**
No screens — cleaning made easy — controllable results

**OVERVIEW**

**Ideal for:**

- Fine grinding of friable materials
- Coarse grinding friable materials
- De-agglomerating
- Conditioning of cellulose fibers
- Tight particle size control

Finally, a mill that gives controllable particle size distribution and is easy to clean. The versatile **Centrifugal Impact Mill** provides a simple, inexpensive means of grinding, sizing, de-agglomerating and homogenizing material, and can be employed as an effective infestation destroyer. It yields particle sizes down to 325 mesh and is primarily used for friable materials. Available in #304 stainless steel, sanitary, abrasive resistant and standard carbon steel design, the Centrifugal Impact Mill operates without screens, hammers, knives or rolls.

**OPERATION**

Metered material is gravity fed through the centrally located inlet of the "stator disc". Centrifugal forces accelerate the material and launch it into the impact zone. The action created by the stationary and rotating pins creates a "treacherous path" for material to pass through. Achieving the desired tight particle size distribution is obtained by controlling the rotor speed. Varying the rotor speed between a few hundred rpm up to 5400 rpm provides the flexibility to use the machine as a coarse grinding or de-agglomerating unit as well as a fine grinding mill. Whether the machine is used for cracking wheat, grinding iron oxide powder, creating powdered sugar or as a cellulose fiber conditioner, large production throughput rates can be attained in an inexpensive, compact machine. It also fits in neatly after most flaking operations.

Vertical orientation of the Centrifugal Impact Mill housing allows the outer disc to hinge open for rapid cleaning and inspection of all product-contact surfaces.
CENTRIFUGAL MILL

The Centrifugal Mill is a high speed rotor mill with unmatched performance. It is used for the rapid size reduction of soft to medium-hard and fibrous materials. Because of the efficient size reduction technique this mill ensures the gentle preparation of analytical samples in a very short time. The comprehensive range of accessories including a large variety of ring sieves and rotors as well as collection systems makes the Centrifugal Mill a versatile instrument that can be easily adapted to varying applications. The optional Vibratory Feeder is load-controlled via an interface and ensures a uniform grind at maximum output rate. When using a cyclone, the sample material is additionally cooled by the air stream and more rapidly discharged from the grinding chamber via the cassette pan with outlet. This effect can be increased by connecting a vacuum cleaner.

APPLICATION EXAMPLES
activated charcoal, animal tissue, bentonite, bones, cereals, chemical products, coal, coffee beans, coke, collagen, corn, dried fruit and vegetables, dried larvae, drugs, electronic components, feed pellets, fertilizers, food, limestone, minerals, paper, pharmaceutical materials, plant materials, plastics, powder coatings, refuse derived fuels, rice, rubber granulate, seeds, spices, straw, ...

PRODUCT ADVANTAGES

- Powerdrive with optimally matched frequency converter and 3-phase motor
- Comfortable parameter setting via display and ergonomic 1-button operation
- Wide range of accessories including various collection and feeding systems, rotors and sieves
- Gentle and very rapid size reduction by pre- and fine grinding in one run
- Wide speed range
- Patented cassette system for maximum sample recovery and easy cleaning
- Easily exchangeable grinding and sieve inserts
- Defined final fineness due to ring sieves sieves with aperture sizes from 0.08 - 10 mm
- Comfortable safety housing with automatic cover closure
motor compartment and electronics protected against dust and material penetration

**Features**

<table>
<thead>
<tr>
<th>Applications</th>
<th>fine grinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of application</td>
<td>agriculture, biology, chemistry / plastics, construction materials, engineering / electronics, environment / recycling, food, geology / metallurgy, medicine / pharmaceuticals</td>
</tr>
<tr>
<td>Feed material</td>
<td>soft, medium-hard, brittle, fibrous</td>
</tr>
<tr>
<td>Size reduction principle</td>
<td>impact, shearing</td>
</tr>
<tr>
<td>Material feed size*</td>
<td>&lt; 10 mm</td>
</tr>
<tr>
<td>Final fineness*</td>
<td>&lt; 40 µm</td>
</tr>
<tr>
<td>Batch size / feed quantity*</td>
<td>300 ml with standard cassette, 20 ml with mini-cassette, 1000 ml with paper filter bag, 4500 ml / 2500 ml / 450 ml / 230 ml with cyclone, 6,000 - 18,000 min⁻¹, free selectable</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Speed at 50 Hz (60 Hz)</th>
<th>6,000 - 18,000 min⁻¹, free selectable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor peripheral speed</td>
<td>31 - 93 m/s</td>
</tr>
<tr>
<td>Rotor diameter</td>
<td>99 mm</td>
</tr>
<tr>
<td>Types of rotors</td>
<td>6-tooth rotor / 12-tooth rotor / 24-tooth rotor / 8-tooth mini-rotor</td>
</tr>
<tr>
<td>Material of grinding tools</td>
<td>stainless steel, titanium, steel 1.4404, stainless steel with wear-resistant coating</td>
</tr>
<tr>
<td>Sieve sizes</td>
<td>trapezoid holes 0.08 / 0.12 / 0.20 / 0.25 / 0.50 / 0.75 / 1.00 / 1.50 / 2.00 mm, round holes 3.00 / 4.00 / 5.00 / 6.00 / 10.00 mm</td>
</tr>
</tbody>
</table>

| Setting of grinding time | - |
| Collector capacity       | 900 ml with standard cassette, 50 ml with mini-cassette, 3000 ml with paper filter bag, 5000 ml / 3000 ml / 500 ml / 250 ml with cyclone |

| Drive                   | 3-phase asynchronous motor with frequency converter |
| Electrical supply data  | different voltages |
| Power connection        | 1-phase |
| Protection code         | IP 20 |
| Power consumption       | 1300 W |
| W x H x D closed        | 410 x 515 x 365 mm |
| Net weight              | ~ 38 kg |
| Documentation           | Operation & Application Video |
Standards

*depending on feed material and instrument configuration/settings

**WORKING**

In the Centrifugal size reduction takes place by **impact and shearing effects** between the rotor and the fixed ring sieve. The feed material passes through the hopper (with splash-back protection) onto the rotor. Centrifugal acceleration throws it outward with great energy and it is precrushed on impact with the wedge-shaped rotor teeth moving at a high speed. It is then finely ground between the rotor and the ring sieve. This 2-step grinding ensures particularly **gentle but fast processing**. The feed material only remains in the grinding chamber for a very short time, which means that the characteristic features of the sample to be determined are not altered. The ground sample is collected in the collecting cassette surrounding the grinding chamber or in the downstream cyclone or paper filter bag.

**Diag :- Spare parts of a Centrifugal mill.**

---

**Q2: What are azeotropic mixtures.**

**A: Azeotropic mixtures** - Many liquids cannot be separated into two pure components by simple distillation, because the volatilities of the components are equal. Such a mixture is known as an azeotrope (Greek: boil unchanged). So therefore azeotropic solution is a solution which distils unchanged at a constant temperature. Such solutions are also known as constant boiling mixtures.

Minimum boiling point azeotropic solutions-Type II solutions (non-ideal solutions): A system with maximum vapour pressure or minimum boiling point is known as azeotropic mixture. For e.g.– chloroform and acetone, pyridine and acetic acid. The azeotropic mixture has a lower boiling point than that of component with the least boiling point. At the minimum boiling point temperature, the liquid composition remains constant and is equal to the vapour composition (arising from such a liquid system).

Consider a hypothetical case in which the mixture contains more of D than C, which is represented by M. If the mixture is distilled, the vapour has a composition of x. When this vapour is condensed, the liquid composition is represented by M1, which is richer in D than C. When liquid is redistilled, the vapour has composition of x1. When this vapour is condensed, the liquid has the composition of M2. Thus on repeated distillation, the liquid D will be in pure form and remains in still. Similar arguments can be proposed for fractional distillation of component C by considering left side curves to trough.
Maximum boiling point azeotropic solutions - Type III solutions (non-ideal solutions): A system with minimum vapour pressure or maximum boiling point is known as azeotropic mixture. For e.g.- benzene and ethanol, water and ethanol. The azeotropic mixture has a higher boiling point. At the maximum boiling point temperature, the liquid composition remains constant and is equal to the vapour composition (arising from such a liquid system).

Consider a hypothetical case in which the mixture contains more of A than B, which is represented by L. if the mixture is distilled, the composition of vapour v is richer in A and poorer in B. At this state, the liquid residue in the distillation flask will be richer in B and poorer in A. the vapour at v is condensed, the liquid composition is represented by L1. If this liquid is distilled, the composition of vapour v1 is further richer in A and poorer in B. thus on repeated distillations, the liquid A in pure form can be obtained as a distillate. But the residue the remained in the still is always the mixture of A and B of constant composition. Similar arguments can be proposed for fractional distillation of component B by considering left side curves to P.

NOTE-
FOR DIAGRAMS, PLEASE REFER SUBRAMANYAM PAGE NO.313 & 315.FIRST EDITION

Q:3. EXPLAIN CORROSION AND ITS PREVENTION.

A: CORROSION AND ITS PREVENTION

Corrosion is defined as the reaction of a metallic material with its and can result in a functional failure of metallic component or of a complete system.

Exposure of a surface to air, water and caustic chemicals are responsible for corrosion. Since metals are good conductors, they undergo electrochemical changes on their surfaces. The compound that is formed during corrosion is referred to as corrosion product and the metal is referred to as corroded. The corrosion media are generally liquid (mostly aqueous solution), but also solids and gases.

Corrosion can be either dry or wet type:

Dry corrosion: it involves the direct attack of dry gases (air and oxygen) on the metals through chemical reactions. As a result an oxide layer is formed over the surface. This type of corrosion is not common.

Wet corrosion: it involves the direct attack of aqueous media (strong or dilute, acidic or alkaline) on metal through electrochemical reactions. The moisture and oxygen are also responsible. This type of corrosion is quite common.

Application:

Knowledge of corrosion is helpful in certain areas to prevent problems.

- Dies and punches: In the compression of tablets, dies and punches should be free from rust and corrosion. Use of chromium plated dies can avoid this problem.
- Milling equipment: In these equipment, a perfect fit between the moving parts should be maintained for effective size reduction. Thus due to corrosion surface imperfections, do not facilitate proper cleaning of the equipment.
- Chemical processing reactors: Diverse nature of solutions which come in contact with the reactor surface often lead to corrosion on account of corrosive media and environment conditions.
Fermenters: During fermentation, the release of trace metals from the equipment may have deleterious effects on the enzyme system and metabolic pathways of the organisms. The possible corrosion aspects in the fermentors are pits and cervices, which make it difficult to clean and remove the contamination. Maintenance of hygiene, need for sterility and prevention of contamination are important considerations in the construction of fermenters.

Storage conditions: Prolonged storage of reactive chemicals lead to corrosion of fermenters.

THEORIES OF CORROSION

The metal surface undergoes an electrochemical reaction with moisture and moisture and in the atmosphere. This theory is known as *electrochemical theory of corrosion*. The mechanism involves the formation of a galvanic cell (anodic and cathodic areas), by different metals (for example, Fe and Cu) or in different areas on the same piece of metal (for example, iron).

1) Corrosion Reactions on Single metal

Electrochemical reactions can illustrated by considering the corrosion on a piece of iron, owing to surface imperfections (localized stresses, grain orientation, inclusions in the metals) or due to variations in the environment. Numerous tiny reactions may occur.

(For diagram refer-“Pharmaceutical Engineering” by C.V.S. Subramanyam; First edition; Published by Vallabh Prakashan; page no.-433; figure 16.1)

**Reaction at anode:** Oxidation takes place with the release of electrons. Positively charged iron atoms get dethatched from the solid surface and enter into solution (electrolyte) as positive ions.

At anode: \[ \text{Fe} \rightarrow \text{Fe}^{++} + 2\text{e}^- \] (indicated by rough surface)

The released free electrons (negative charge) pass round the external circuit

**Reaction at cathode:** reduction of constituents occurs with the taking up of electrons. The fee electrons reach the cathode and react with some positively charged species such as hydrogen ions in the electrolyte solution. In the absence of acid, water itself dissociates to generate H+ ions.

At cathode: \[ 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2 \uparrow \] (indicated by formation of bubbles at the surface)

The amount of metal (iron) which is dissolved in the electrolyte is proportional to the number of electrons flowing, which in turn is dependent upon the potential and resistance of the metal.

The overall reaction: \[ \text{Fe} + 2\text{H}_2\text{O} \rightarrow \text{Fe(OH)}_2 + \text{H}_2 \uparrow \]

*Red brown rust*

High evolution of H2 accompanies rapid corrosion such as hydrogen embrittlement. Depletion of hydrogen al enhances corrosion. In moderate concentrations of H2, corrosion slows down.

2) Corrosion Reactions between Metals

Galvanic corrosion results from the flow of current from a more active metal (anode) to less active metal (cathode). For example, Zinc dissolves and forms an anode, while Copper (Cu) forms the cathode. These two metal form two electrodes and their presence in and electrolytic solution form a Galvanic cell.

(For diagram refer-“Pharmaceutical Engineering” by C.V.S. Subramanyam; First edition; Published by Vallabh Prakashan; page no.-434; figure 16.2)
Spontaneous reaction can occur when two electrodes are connected through an external wire.

Reactions at anode and cathode are:

At anode: $\text{Zn} \rightarrow \text{Zn}^{++} + 2\text{e}^- \quad (\text{indicated by rough surface})$

(Oxidation)

At cathode: $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2 \uparrow \quad (\text{indicated by formation of bubbles at the surface})$

(Reduction)

The corrosion current flows at the expose of anode metal, which get corroded continuously, whereas the cathode metal is protected.

**FACTORS INFLUENCING CORROSION**

A number processing factors affect rate of corrosion.

- **Solution pH**

  The pH affects the rate of corrosion of metals by one of the 3 general patterns.

  1) Metals such as iron dissolve rapidly in acidic solution. In the middle pH range (4 to 10), the concentration of $\text{H}^+$ ions is low. Hence the corrosion rate is controlled by the rate of transport of oxidizer (oxygen).

  2) Certain amphoteric metals dissolve rapidly in either acidic or basic solution. Examples are aluminium and zinc. Corrosion proceeds.

  3) Noble metals are affected by pH. Examples are gold and platinum.

     The $\text{H}^+$ ions have a tendency to take up electrons to form $\text{H}_2$ gas. Therefore, $\text{H}^+$ ions capture electrons and promote anodic corrosion.

- **Oxidizing agents**

  Oxidizing agents may accelerate the corrosion of one class of materials, whereas retard another class. Oxidizing agents such as oxygen ($\text{O}_2$) react with hydrogen to form water. Once hydrogen is removed, corrosion is accelerated. For example, copper in sodium chloride solution follows this mechanism.

  Oxidizing agents retard corrosion due to formation of surface oxides films, which makes the surface more resistant to chemical attack. Therefore, adsorbed oxygen layer is essential. Thus a balance between power of oxidizing compounds to preserve the protective film and their tendency to destroy the protective film determine the corrosion of the metal.

- **Temperature**
The rate of corrosion tends to increase with rising temperature. It has a secondary effect. The influence of temperature on corrosion may follow several mechanisms.

1) Increase in temperature reduces the solubility of oxygen or air. The released oxygen enhances the corrosion.
2) Increase in temperature induces phase changes, which enhances the rate of corrosion. At high temperatures, organic chemicals are saturated with water. As the temperature decreases, water gas condensed.
3) Oxygen is needed for maintaining iron oxide film, which prevents corrosion. In the absence of oxygen (due to increase in temperature), the corrosion of stainless steel increases.
4) Copper-based alloys do not depend on the film of corrosion.

❖ Velocity

When the corrosive medium moves at a high velocity along the metallic surface, the rate of corrosion frequently increases. High velocity has the following effects.

1) Corrosion products are formed rapidly, because chemicals (including oxidizing substances) are brought to the corroding surfaces at high rate.
2) The accumulation of insoluble film on the metallic surface is prevented. Therefore, corrosion of these films decreases.
3) The corrosion products (or film) are easily stifled are carried away, thereby exposing the new surfaces for corrosion.

Thus corrosion proceeds unhindered. This factor is responsible for the corrosion of a number of equipment parts, such as condensers, evaporator pipes, propellers, agitators and centrifugal pumps.

❖ Surface films

➢ Once corrosion is started, its further progress is often controlled by the nature of surface films. A variety of surface films have been observed.

➢ Thin oxide films are formed on the surface of stainless steel (rusting). These films tend to retain or absorb moisture, which delays the time of drying. Hence, the surface exposure to atmosphere or corrosive vapour increases the extent of corrosion. The rust films formed on low alloy steels are more protective than those formed on unalloyed steel.

➢ Insoluble salts such as carbonates and sulphates may be precipitated from hot solution on the metal surfaces. These protect the metal surface.

➢ If the film is porous (example is Zinc Oxide), corrosion continues. Nonporous films (example is Chromium Oxide film on iron) prevent further corrosion.

➢ Oil and grease films may occur on the surfaces either intentionally or naturally. These films protect the surface from direct contact with corrosive substances. Examples are metals submerged in sewage or equipment used for processing oily substances.

❖ Other factors

The concentration of corrosive chemicals in the environment influences the rate of corrosion. In addition, corrosion rates are seldom linear over a wide range. Concentration is important during plant shut-down. The presence of moisture that collects during cooling can turn innocuous chemicals into dangerous corrosives.

TYPES OF CORROSION
Pure metals and their alloys tend to enter into chemical union with the components of corrosive medium to form compounds. Corrosion can be broadly classified as follows:

1. Fluid corrosion, General
2. Fluid corrosion, Localized
3. Fluid corrosion, structural
4. Fluid corrosion, biological

**Fluid corrosion: General**

When corrosion is generally confined to a metal surface, it’s known as *general corrosion*. This type occurs in a uniform fashion over the entire exposed surface area at a wide range of temperatures. General corrosion is of two types:

**Physicochemical Corrosion**: the effects of this type are swelling, cracking, crazing, softening etc. Examples are plastic and nonmetallic material.

**Electrochemical Corrosion**: this type of corrosion occurs at discrete points of metallic surfaces when electricity flows from cathodic area to anodic area. Metallic surface gets divided into anodic portion or cathodic portion.

**Fluid corrosion: Localized**

Fluid corrosion is most frequently observed on different locations in a material. It occurs in numerous ways. It can be further classified as:

- **Specific site corrosion**: Mechanically weak spots or dead spots in a reaction vessel cause specific site corrosion. It can be further classified as-
  - *Inter-granular corrosion*: Selective corrosion that occurs in grain boundaries in a metal/alloy is called intergranular corrosion.
  - *Pitting corrosion*: This type of corrosion results in development of pits and cavities. They range from deep cavities to shallow depression.
  - *Cervice corrosion*: In this type, corrosion occurs in cervices because solutions are retained at such places, which takes longer time to dry out.

- **Stress induced corrosion**: Residual internal stress in the metal or external applied stress accelerates the corrosion. It can be further classified as-
  - *Stress corrosion cracking*: At the surface, if the tensile strength is equal to or more than the yield stress, the surface develops cracks. This is known as stress corrosion cracking.
  - *Corrosion fatigue*: Corrosion fatigue is the ability of the metal surface to withstand repeated cycles of corrosion. As this process continues, the surface loses its fatigue resistance and ultimate failure of equipment.
  - *Fretting corrosion*: It occurs when metal slide over each other and cause mechanical damage to one or both.

- **Flow related corrosion**: Liquid metals can cause corrosion. Usually the driving force is the tendency of the liquid to dissolve solids or penetrating the metal along the grain boundaries at places of wetting. It can be further classified as-
  - *Impingement corrosion*: It is also known as erosion-corrosion or velocity accelerated corrosion. It is accelerated by removal of corrosive products (such as oxide films), which would otherwise tend to stifle the corrosion reaction.
  - *Erosion*: Erosion is the destruction caused by the flow of liquid/gas (with or without suspende solids).
  - *Cavitation erosion*: Formation of transient voids or vacuums bubbles in a liquid stream passing over a surface is known as cavitation.
Chemical reaction related corrosion: Corrosion involves chemical reaction such as oxidation and reduction at anode and cathode, respectively. It can be further classified as:

- **Galvanic corrosion:** It is associated with the flow of a less-active metal (copper cathode) from a more reactive metal (zinc anode) in the same environment.
- **Oxygen concentration cell:** This type of corrosion is due to the presence of oxygen electrolytic cell, i.e., a difference in amount of oxygen in solution at one point exist when compared to another.
- **Hydrogen embrittlement:** hydrogen can penetrate carbon steel and reacts with carbon to form methane. The removal of carbon results in decreased strength.

Fluid corrosion: Structural

In the structural fluid corrosion type, the structural (mechanical) strength is reduced on account of corrosion. This may occur when one component of alloy is removed or released into the solution. Some examples are:

- **Graphite corrosion:** Graphite is an allotropy of carbon and occurs in gray cast iron. The metallic iron is converted into corrosive products leaving a residue of intact graphite mixed with iron corrosive products an other insoluble constituens of cast iron.

- **Dezincification:** This type of corrosion is seen in brass that contains more than 15% zinc. In brass, the principal product of corrosion is metallic copper, which may redeposit on the plant. Another mechanism involves the formation of zinc corrosion products leaving the copper residue.

Fluid corrosion: Biological

The metabolic action of microorganism can either directly or indirectly cause deterioration of a metal. Such a process is called *biological corrosion*. Microorganisms associated with corrosion are either aerobic or anaerobic. The causes of biological corrosion are:

1. Producing corrosive environment or altering enviromental composition.
2. Creatin electrolyte-concentration cells on the metal surface.
3. Altering resistance to surface films.
4. Influencing the rate of anodic/cathodic reaction.

The role of biological may be explained using anaerobic sulphate using bacteria in slightly acidic or alkaline soils. As these bacteria thrive under these conditions, they will continue to promote this reaction until failure of the pipe occurs.

\[
\text{Sulphates} \rightarrow \text{hydrogen sulphite} + \text{calcium sulphite} \\
\text{On iron in soil} \\
\text{Iron sulphide} \\
\text{(Corrosive product)}
\]
PREVENTION AND CONTROL OF CORROSION

❖ Selection of proper material

➢ Corrosion should not be permitted in fine mesh wire-screens, orifices and other items in which dimensions are critical and changes are not permitted.
➢ Non-metallic materials are useful and attractive from the point of view of economics and performance. These should be considered if their strength temperature design specifications are satisfactory.
➢ Permissible corrosion rates are important factors and differ with equipment. Appreciable corrosion can be permitted for tanks and lines, if anticipated and allowed for thickness in its design.
➢ The corrosion characteristics of chemicals and limitations of construction materials must be considered from the literature before selecting the equipment.
➢ In addition, processing conditions to which the material is exposed should be considered.

❖ Proper design of equipment

➢ In designing of equipment, a number of fittings such as baffles, stiffeners, drain nozzles, location of valves and pumps should be considered.
➢ Corrosion can be minimized, if equipment designed facilitates:
  ▪ Elimination of crevices
  ▪ Complete drainage of liquids
  ▪ Ease of cleaning
  ▪ Ease of inspection and maintenance

➢ A direct contact between two metals should be avoided, if they are separated widely in the electrochemical series. Otherwise they should be insulated.

❖ Coating and linings

➢ Non-metallic coatings and linings can be applied on steel and other material of construction in order to combat corrosion.
➢ Appropriate methods such as electropainting cladding, organic coatings should be considered.
➢ Effective lining can be obtained by bonding directly to substrate metal or building multiple layers or lamination.
➢ Organic coatings are used as linings in equipment such as tanks piping, pumping lines and shipping containers. Some examples of linings are:
  ▪ Ceramic
  ▪ Carbon brick
  ▪ Plastic
  ▪ Elastic
  ▪ Glass coated
  ▪ Organic
Some examples of lining are:

<table>
<thead>
<tr>
<th>Lining</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tin coated steel (tin plate)</td>
<td>food containers</td>
</tr>
<tr>
<td>Lead (Pb) coating (Terne plate)</td>
<td>roofings</td>
</tr>
<tr>
<td>Aluminium (Al) coated steel</td>
<td>high temperature conditions</td>
</tr>
<tr>
<td>Zinc (Zn) coated steel</td>
<td>many atmospheric conditions</td>
</tr>
</tbody>
</table>

Altering environment

- Corrosion can be combated or reduced by employing the following environmental conditions.
  - Removing air from boiler feed water prevents the influence of water on steel.
  - Reducing aeration prevents the formation of passive oxide film in stainless steel.
  - Pumping of inert gas into solutions prevents the contact of air or oxygen as in case of nickel based alloys.
  - Reducing the temperature.
  - Eliminating the moisture.
  - Reducing the velocity or turbulence.
  - Shortening the time of exposure.

Addition of acid media should be done as the last step, so that maximum dilution can be obtained.

Inhibitors

- The corrosion inhibitors are added to the environment to decrease the corrosion of metals. These forms protective films.
  - Adsorption type, for example, adsorbed on the metal.
  - Scavenger type, for example, remove corrosion agents.
  - Vapour phase type, for example, sublime or condense on metal surface.

Examples of inhibitors:

<table>
<thead>
<tr>
<th>Inhibitors</th>
<th>Material protected in medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromates, phosphates, silicates</td>
<td>iron and steel in aqueous solution</td>
</tr>
<tr>
<td>Organic sulphides, amines</td>
<td>iron and steel in acidic medium</td>
</tr>
<tr>
<td>Copper sulphate</td>
<td>stainless steel in hot dil. solutions of H₂SO₄</td>
</tr>
</tbody>
</table>

Cathodic protection
The cathodic protection is based on the galvanic action between the metals of the plant and anode suspended in the solution. The metal to be protected is made a cathode, i.e., electrons are supplied, thereby dissolution of metal is suppressed.

This is achieved by 2 methods:
- Sacrificial anode method
- Impressed emf method

**Sacrificial anode method:** In this method anode are kept in electrical contact with the metal to be protected (cathode). The anodes are sacrificed since it goes into the solution.

(For diagram refer—“Pharmaceutical Engineering” by C.V.S. Subramanyam; First edition; Published by Vallabh Prakashan; page no.-446; figure 16.4)

For example, for the protection of iron and steel tanks, the metal such as zinc, aluminium, magnesium and their alloys are used as sacrificial anodes. These are used in limited pH range when high soluble rate is acceptable, since these are amphoteric. Anode metal is selected from the electrochemical series amongst the metal present below the tank metal.

**Impressed emf Method:** This is also known as applied current system, i.e., external voltage is impressed between tank and electrodes. The negative terminal of power supply is connected to the material to be protected. Therefore, the natural galvanic effect is avoided and the anode is maintained positive.

(For diagram refer—“Pharmaceutical Engineering” by C.V.S. Subramanyam; First edition; Published by Vallabh Prakashan; page no.-434; figure 16.2).

Since electrode is not consumed, any conducting material, metal or non-corrodible alloys can be used. For example in case of sulphuric acid and deionised water, graphite and high silicon steel are compressed. The anodes can be buried in the ground or suspended in the aqueous solution of electrolyte.

**Advantages:**
- This method is used for large tank to store mild corrosive liquors. In these cases, mild steel is used with negligible corrosion.
- Cathodic protection method is simple and most effective.
- It is inexpensive. It enables the use of cheaper material for plant construction.

**Disadvantage:**
- Corrosion can not be reduced to zero.

**Anodic protection:**
In the method a predetermined potential is applied to the metal specimen and the corresponding current changes are observed. During the initial stage, the current increases indicating the dissolution (corrosion) of the metal. When the current reaches a critical point, passivisation occurs, i.e., the oxide layer sets in a suitable oxidizing environment. The potential at critical point is called *passivating potential*. Above this passivating potential, the current flow decreases to a very small value called passivating current.
The *passivating current* is defined as the minimum protective current density required to maintain passivisation. At this stage, an increase in potential will not corrode the metal since the latter is in a highly passive state. For example, in case of stainless steel, titanium becomes easily passive and cannot offer cathodic protection. In such cases, the corrosion rate may be slowed down by the use of anodic current.

- **Advantage:**
  - Anodic protection requires a small current. The anodic protection method is utilized in the transportation of concentrated sulphuric acid.

- **Disadvantages:**
  - Corrosion cannot be reduced to zero.
  - This method cannot be applied for metals, which do not passivate.

A proper material should be selected for a specific process based on the literature and by personal experience. The factors influencing corrosion will not only help in selecting the right kind of the material, but also suggest the processing conditions. It is equally essential to identify the type of corrosion, if it occurs. Since the theories are known. It is possible to adopt appropriate preventive measures.

**Q4: Discuss in detail the various types of rectifying columns?**

**A:** Distillation is defined as the separation of the components of the liquid mixture by the process involving vaporization and subsequent condensation at another place.

Fractional distillation can be defined as the process in which vaporization of a liquid mixture gives rise to a mixture of constituents from which the desired one is separated in pure form. It is also known as **RECTIFICATION** because a part of the vapor is condensed and returned as liquid. This method is very useful for separating miscible volatile liquid.

In this type of distillation, special types of still-heads are required so that the re vaporization and condensation can take place at one time only. These are called **RECTIFYING COLUMNS**. These are normally a long vertical tube in which the vapour the passes upwards and get condensed and return to the flask. These are constructed to give following advantage:

- It offers a cooling surface for vapour to get condensed.
- It gives downward flow for the liquid which has high melting point.
- It allows easy condensation.

**RECTIFYING COLUMNS** are mainly of two types:

- Packed columns
- Plate columns
Packed columns: In this type, columns are packed in such a form so as to effect the necessary liquid/vapour contact. The packing can have one single turn of wire or glass, glass rings.

It can be of three types: a. pear shape, b. rod shape, c. disc shape.

Diagram on page no. 320 in Shubarmanyam

Construction: It consist of a tower containing a packing that becomes wetted with a film of liquid, which is brought into contact with vapour in the intervening spaces.

APPLICATION: Packing must be uniform so as to obtained the good column. If it is irregular then mass transfer becomes less effective. Mainly used in laboratories. Example of such a column used in laboratories is widmer column.

Plate columns: Many forms of plates are used in the fractionating columns. These can be divided into two main categories:

Bubble cap plates

Turbo grid plates.

[A] Bubble cap plates: this type of plates are used in distillation which are carried out at large scale.

Construction: in this type of column various plates are used which are mounted one above the other and these plates lead to the downcomer. Caps are placed on each plate which allows the vapour to escape by bubbling through the liquid.

Note: diagram on page no. 321 of Subramanyam

Working: Ascending vapour from the still passes through the bubble –caps on the plate A and the rising vapour will be richer in the more volatile component. And this liquid passes through the second plate and the liquid gets vapourised because the heat of condensation vapourises the liquid. Same work is done with liquid when it gets on the Third plate and so on all the way up to the column. each bubble-cap plate has the same effect.

Advantage: it is effective over a wide range of vapour-liquid proportions and velocities because it is excellent contact as the vapour bubbles through the liquid.

Disadvantage: 1. The layer on each plate result in considerable hold-up of the liquid over the entire length. 2. the column does not drain even after the completion of distillation.

Q5: Discuss the material and energy balance aspect of a crystallizer. Give working of a agitated batch crystallizer?

Answer:
Crystallization of a substance, is very important pharmaceutical operation, either inorganic or organic, whether on the small scale in a research laboratory or on the commercial bulk drug manufacture. During the manufacture of the drug, after the reaction is completed in solution resulting in the formation of a drug or its intermediate, it must be crystallize out of the solution. This is necessary because crystallization if properly carried out results in the separation of a pure form of the material.

On a smaller scale purity and yield are the main criteria, however in commercial practice additional requirements such as size, range of sizes and shape are also significant.

Classification of crystallizer:-

These are classified on the basis of the method by which supersaturation is brought about:-

Crystallizers:-

**Method 1: Supersaturation by cooling alone**, it can be further classified by two methods (i) Batch crystallizers (ii) Continuous crystallizers.

(i) Batch crystallizers- It can be further classified by two methods (i) Tank crystallizer (ii) **Agitated batch crystallizer**.

(ii) Continuous crystallizer- It also can be further classified in two methods (i) Swenson-Walker crystallizer (ii) Others.

Method 2: Supersaturation by evaporation of the solvent(krystal crystallizer).

Method 3: Supersaturation by adiabatic evaporation, i.e. cooling+evaporation.

Method 4: Supersaturation by salting out.

**AGITATED BATCH CRYSTALLIZE**

**Principle:** It is applicable for those substances that have a steep solubility curve where the solubility of the substances rapidly decreases with reduction in temperature. The solution is generally concentrated in a separate evaporator and then fed to the crystallizer.

**Working:** In this crystallizer, water is circulated through the cooling coils of the solution is agitated by the propellers on the central shaft.

Agitation increases the rate of cooling and keeps the solution at a more uniform temperature. It also keeps the fine crystals in suspension which can then grow uniformly without forming too large crystals or aggregates. Thus the product is more uniform in size and is finer than in the older tank method.

**Limitation:** It is a batch process & the capacity is low. Further, the solubility of the material is least at the surface of the cooling coils and this results in rapid build up of crystals on the coil surface resulting in a decrease in heat transfer.

**Diagram:-** It can be noted by C.V.S. SAMBAMURTHY on page no. 236.
Q6: Discuss the material and energy balance aspect of a crystallizer. Give working of a agitated batch crystallizer?

Answer:

Crystallization of a substance, is very important pharmaceutical operation, either inorganic or organic, whether on the small scale in a research laboratory or on the commercial bulk drug manufacture. During the manufacture of the drug, after the reaction is completed in solution resulting in the formation of a drug or its intermediate, it must be crystallize out of the solution. This is necessary because crystallization if properly carried out results in the separation of a pure form of the material.

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Limitation: It is a batch process & the capacity is low. Further, the solubility of the material is least at the surface of the cooling coils and this results in rapid build up of crystals on the coil surface resulting in a decrease in heat transfer.
Q7: Discuss the material and energy balance aspect of a crystallizer. Give working of a agitated batch crystallizer?

Answer:

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On a smaller scale purity and yield are the main criteria, however in commercial practice additional requirements such as size, range of sizes and shape are also significant.

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Diagram: It can be noted by C.V.S. SAMBAMURTHY on page no. 236.

Q: Miers super saturation theory of crystallization and vacuum crystallizer.

Ans: Miers super saturation theory postulate a definite relationship between concentration and temperature at which crystals will spontaneously form in an initially unseeded solution.

According to it the super solubility curve represents the limit at which nucleus formation begins spontaneously where crystallization can start in the absence of any solid particle.

A plot of temperature v/s concentration of solute

(Note) Refer page no 370 from pharmaceutical engineering C.V.S Subrahmanyam

The curves A B represent the normal solubility any point on the curve represent the solute in equilibrium with the solvent. This is the maximum limit for the solubility of substance. The curve F G represents the super solubility which is roughly parallel to the normal solubility curve. It represent the limit at which nucleus formation begin spontaneously.

According to mires theory, crystallization do not start at p but it take place somewhere in the neighborhood of the point D, when certain condition are specified.

Mier states that under ideal conditions of crystallization of nucleus formation starts at F G and crystal growth begins.

Then concentration of substance roughly follows the curve D E.

Limitation:

1) According to Miers theory, crystallization starts at super solubility curve but generally tendency is that crystallization takes place in a area rather than a line.

2) Miers theory is applicable when pure solute and pure solvent are used, in practice it is impossible to get them in pure state.

3) If the solution is kept for longer period, nucleation starts well below the super solubility curve.
4) For crystallization, the solution must be stored for a longer periods. during storage millions of dust particle can enter.

**Condition for obeying Mier’s theory:-**
1) The solution must be free from foreign solid particles.
2) The solute and the solvent must be pure.
3) The solution must be protected from entry of any particle.
4) The solution must be free from solid solute particle.

**VACUUM CRYSTALLIZER.**

**PRINCIPLE:**
In vacuum crystallizer, supersaturation is obtained by adiabatic evaporative cooling. When warm saturated solution is introduced into the crystallizer, due to high vacuum the solution undergoes flashing.

**CONSTRUCTION:**
Vacuum crystallizer is a cylindrical body with conical shape. A condense is attached to the crystallizer with a vacuum pump in between. The bottom of crystallizer is attached to a discharge pipe. The internal body of crystallizes can be lined with acid resistant material such as lead or rubber. Two propellers are placed above discharge pipe to prevent short-circuit of the feed.

*(NOTE) Refer page no 378 from pharmaceutical engineering  C.V.S Subrahmanyam*

**WORKING :-**
High vacuum is created using a vacuum pump. the vacuum so created must correspond to a boiling point of the solution. hot saturated solution is fed into the crystallizer at a convenient point. solution undergoes flashing which results in evaporation of solvent. this process is allowed adiabatically. the resultant cooling causes supersaturation and crystallization. flashing of the solution in the crystallizer leads to ebullition, which keep the crystals in the suspension. the propellers mix the content thoroughly and prevent the contents reaching the discharge pipe without flashing. With the help of pump, the product is collected and subjected to filtration to obtain crystals. the filtrate return to the feed.

**ADVANTAGES:-**
1) It can be operated either batch wise or continuously.
2) It can be constructed as large size as desired.
3) It is very simple without any moving parts.
USES:-

Due to low temperature conditions, it is suitable for thermolabile substance.

RAOULT'S LAW - This law states that partial vapour pressure of each volatile constituent is equal to the vapour pressure of each volatile constituent multiplied by its mole fraction in the solution at a given temperature. Since the solution is homogeneous by definition, the relative numbers of components on the surface reflect the number of these components in the whole solution. These numbers can be expressed on the mole fraction scale. Thus Raoult’s law is appropriately suited to describe an ideal solution.

Consider a mixture of miscible liquids A and B. In this mixture:
Let partial vapour pressure exerted by A = \( P_A \) kPa
Let partial vapour pressure exerted by B = \( P_B \) kPa
Let partial vapour pressure exerted by the pure component of A = \( p_A^{0} \) kPa
Let partial vapour pressure exerted by the pure component of B = \( p_B^{0} \) kPa
Let mole fraction concentration of liquid A = \( X_A \)
Let mole fraction concentration of liquid B = \( X_B \)
Mathematically, raoult’s law can be expressed as:
\[
\begin{align*}
\text{Partial vapour pressure of a liquid} &= \text{vapour pressure of pure liquid multiplied by mole fraction of the liquid.} \\
\text{For liquid A:} &\quad \text{Let partial vapour pressure} \quad \text{exerted by A} = P_A \\
\text{and mole fraction of liquid A} &\quad \text{is} \quad X_A \text{, then its contribution \(\) } \quad P_A = p_A^{0}X_A \\
\text{For liquid B:} &\quad \text{Let partial vapour pressure} \quad \text{exerted by B} = P_B \\
\text{and mole fraction of liquid B} &\quad \text{is} \quad X_B \text{, then its contribution \(\) } \quad P_B = p_B^{0}X_B \\
\end{align*}
\]

IDEAL MIXING - An ideal solution can be said to follow Raoult’s Law but it must be kept in mind that in the strict sense ideal solutions do not exist. For a solution to be ideal we must assume that it does not matter whether a molecule A has another A as neighbor or a B molecule. This is only approximately true if the two species are almost identical chemically.

Real solutions
Many pairs of liquids are present in which there is no uniformity of attractive forces i.e. the adhesive and cohesive forces of attraction are not uniform between the two liquids, so that they show deviation from the Raoult's law which is applied only to ideal solutions.

Negative deviation

When adhesive forces between molecules of A and B are greater than the cohesive force between A and A, or B and B, then the vapor pressure of the solution is less than the expected vapor pressure from Raoult's law. This is called a negative deviation from Raoult's law. These cohesive forces are lessened not only by dilution but also attraction between two molecules through formation of hydrogen bonds. This will further reduce the tendency of A and B to escape.
For example, chloroform and acetone show such an attraction through a strong dipole-dipole interaction.

Positive deviation
When the cohesive forces between like molecules are greater than the adhesive forces, the dissimilarities of polarity or internal pressure will lead both components to escape solution more easily. Therefore, the vapor pressure will be greater than the expected from the Raoult's law, showing positive deviation. If the deviation is large, then the vapor pressure curve will show a maximum at a particular composition, e.g. benzene and ethyl alcohol, carbon disulfide and acetone, chloroform and ethanol.

NOTE-
FOR DIAGRAMS,,PLEASE REFER SUBRAMANYAM PAGE NO.-297,FIRST EDITION….

VOLATILITY- Volatility of a substance in a solution may be defined as the equilibrium partial pressure of the substance in the vapour phase divided by the mole fraction of the substance in the solution.

For example, a substance A in liquid mixture has partial pressure Pa and its concentration in the mixture is Xa on mole fraction scale. Then volatility of A may be mathematically expressed as:

\[ \text{Volatility of component } A = \frac{\text{Partial vapour pressure of } A}{\text{mole fraction of } A \text{ in solution}} \]

Thus volatility of a material in the pure state is equal to the vapour pressure of the material.

RELATIVE VOLATILITY- Consider a liquid mixture containing two components A and B. In such a case, the volatility of one component is expressed in terms of the second. RELATIVE VOLATILITY may be defined as:

\[ \text{Relative volatility, } R = \frac{\text{Volatility of component } A}{\text{Volatility of component } B} \]

Relative volatility is commonly expressed with the higher of the two volatilities in the numerator. This means that the relative volatility should never have a numerical value less than 1.

Q: Discuss in detail about heat and material balance.
Distillation

Support of packing material:

The packing must be supported by suitable means at the base of the column.

- A cone shaped support of heavy rods is quite satisfactory.

Advantages:

1. Lower pressure drop
2. Cheaper
3. Suitable for corrosive material (operation)
4. Low amount of liquid is held up in column
5. Minimum exposure of temperature sensitive liquids, therefore use for thermosensitive material for rectification
6. For small diameter column, packed column is more suitable than Bubble Cap

Disadvantages:

1. Inflexible
2. Not operable over wide range of vapor or liquid load
3. Distribution of liquid is difficult

Liquid distributor at wall and center remain unwetted, so redistributing partitions are required.

Since the packed column has no actual plate, it is necessary to speak of the height of equivalent theoretical plate (HETP) for a given type of packing in a specified diameter column.

\[
\text{HETP} = \frac{\text{Actual height of column in ft}}{\text{No. of theoretical plates}}
\]

Example: 1.4-inch diameter column packed with 1/4-inch diameter packing rings to a height of 6 ft is found to perform the fractionation of a mixture of benzene and toluene as completely as calculated for 12 theoretical plates.

\[
\text{HETP} = \frac{6 \times 12}{12} = 6 - \text{inch}
\]

(B) Reflux Ratio:

The reflux ratio is calculated as the mole of liquid returned to the top of the distillation column per unit time divided by the moles of distillate withdrawn as product per unit time.

\[
\text{Reflux Ratio} = \frac{L}{D} = 3.25
\]

When no product is withdrawn and all the top condenser is returned to the column, reflux ratio is infinite. The operation is known as TOTAL REFLUX.

3.6 METHOD OF CALCULATION

(A) Heat and Material Balance

Around Rectifying Column

Consider the system shown diagrammatically in Fig. 3.13(A) suppose that a feed F, of a mixture of components A and B contains X_A mole fraction of A to be separated continuously in a fractionating column operating at constant pressure P. The overhead (distillate) product is to contain X_D mole fraction of component A.

The temperature of the feed, overhead, and bottom products are specified as t_f, t_d, and t_b respectively.

The corresponding enthalpies of these streams are h_f, h_d, and h_b respectively.

![Diagram of distillation column](image)

Fig. 3.13(A) Material and Energy Balance around Rectifying Column under Steady State Condition
Q: Explain theories of size reduction.
1.1.5 THEORY OF SIZE-REDUCTION (ENERGY - LAWS)

(I) MECHANISM OF SIZE REDUCTION

If a single lump of material is subjected to a sudden impact, it will generally break so as to yield a few relatively large particles and a number of fine particles, with relatively few particles of intermediate size. If the energy in the blow is increased, the larger particles will be of a rather smaller size and more numerous and whereas the number of fine particles will be appreciably increased, their size will not be much altered. It therefore appears that the size of the fine particles is closely connected with the internal structure of the material, and the size of the larger particles is more closely connected with the process by which the size reduction is effected.

In general, solid particles may be crushed when a load or energy applied is greater than the breaking strength of the material. Size reduction consists of two parts:

(i) First opening up any small fissures (cracks) which are already present.

(ii) Secondary formation of new surfaces.

Hence, large particles with several cracks fracture much more rapidly than small particles with a fewer number of cracks. A material such as coal contains number of small cracks, so large pieces are broken more rapidly than the small ones. Fine grinding needs more energy to initiate cracks. From the point of view of energy utilization (use), size reduction is a very inefficient process and only between 0.1 and 2.0% of the energy supplied to the machine appears as increased surface energy in the solids. The efficiency of the process is very much influenced by the manner in which the load is applied, and its magnitude, but in addition the nature of the force exerted is also very important, e.g., whether it is predominantly a compressive, an impact or a shearing force. If the applied force is insufficient for the elastic limit to be exceeded, the material is compressed (compression force is used) and energy is stored in the particles. When the load is removed, the particle expand again to its original condition without doing useful work, the energy appears as heat and no size reduction is effected.

(II) ENERGY LAWS:

The two earliest empirical laws applicable to predict the energy requirements for comminution have been proposed. These are commonly known as:

(i) Rittinger’s law

(ii) Kick’s law.

Neither of these laws exactly express the performance of any grinding or crushing machine. In 1951, the third law:

(iii) Bond Law

Proposed by Bond.

The above mentioned laws can be derived from the basic differential equation.

\[
\frac{dE}{dt} = -Cf^n \quad 1.1
\]

This equation states that the energy \( dE \) required to effect a small change \( dt \) in the size of unit mass of material is a simple power function of the size.

(1) Rittinger’s Law:

If \( p \) is put equal to \( -2 \), integration gives

\[
E = C \left( \frac{1}{L_2} - \frac{1}{L_1} \right) \quad 1.2
\]

Writing \( C = K_R f_c \), where

\( f_c = \) crushing strength of the material

\( K_R = \) Rittinger’s constant

\( E = \) Net energy required per unit weight in a given process.

\[
L_2 = \text{size of discharged product (final size)}
\]

\( L_1 = \text{size of the feed (initial size)} \)

Rittinger’s law is based on the assumption that the energy required (consumed) is proportional to the fresh surface produced (sheared). This is more applicable to fine powders and leads to the conclusion that ‘Expenditure of energy increases very rapidly with diminishing particle size.’

To apply above mentioned assumption, consider the cube of material represented in Fig. 1.2. Each edge of this cube has a length \( D \). Suppose that this cube is to be crushed into smaller cubes each of whose edges has a dimension of \( d \). In Fig 1.2, the ratio of \( D \) to \( d \) has been taken as 4:1. This ratio \( D/d \) may be represented by \( n \). From Fig. 1.2 it will be seen that there are \( (n - 1) \) planes of fracture in each of three directions. In other words, to crush this cube into smaller cubes these must be sheared a surface amounting to \( 3(n - 1) D^2 \) square units. Suppose it takes ‘B’ ft-lb of work to produce 1 sq in. of new surface. The work necessary to crush a cube whose dimension
is 'D' in. to cube of a dimension 'd' ln. is therefore,

\[ \text{Work} = 3BD^2(n - 1) \]

In 1 cu.in. of material to be crushed there are \( \frac{1}{D^3} \) of the larger units.
It may be assumed that if the units,

Fig. 1.2 Development of Rittinger's Law

are not perfect cubes the ratio of the area of an actual unit to the area of a cube of the same major dimension will be the same for all sizes. This ratio will be represented by 'K'. Inserting this values in equation (1.4), and remembering that \( n = D/d \), equation 1.5 results:

\[ \text{Work per Cu.in.} = \frac{1}{D} \left( 3BD^2K \right) (n - 1) \]
\[ = 3BK \left( \frac{1}{d} - \frac{1}{D} \right) \]
\[ = 3BK \left( \frac{1}{L_2} - \frac{1}{L_1} \right) \] ........................ 1.5

By bringing into equation (1.5) a factor involving specific gravity(s), it is very simple to convert equation (1.5) from work per cubic inch to horse power per ton

hp per ton ........................ 1.6
\[ = C \left( \frac{1}{L_2} - \frac{1}{L_1} \right) \]

or
\[ C = \text{constant} = 0.0838 \frac{R_f}{s} \]

(2) Kick's Law:
If 'p' is equal to (-1), we obtain
\[ E = C \cdot \ln \frac{1}{L_2} \]
\[ E = \text{Work input} \]
and Writing \( C = k \cdot f_c \)

\[ E = k \cdot f_c \cdot \ln \frac{1}{L_2} \] ........................ 1.7

This supposes that the energy required is directly related to the reduction ratio \(-L_1/L_2\). Kick's law assumes that the energy necessary for crushing material is proportional to the logarithm of the ratio between the initial and final diameters. This means that the energy required to crush a given amount of material from 1 to 1/2 inch cubes, the same amount of energy will reduce to the 1/2 to 1/4 inch cubes, or 1/4 to 1/8 inch cubes, and so on. According to the law, it should require twice as much energy to affect a nine fold as it would a three fold reduction.

Kick's law, more closely relates to the energy required to effect elastic deformation before fracture occurs, and is more accurate than Rittinger's Law for coarse crushing where the amount of surface produced is considerably less.

(3) Bond's Law:
Bond (1951) has suggested a law intermediate between Rittinger's and Kick's Laws

Putting \( p = (-2/2) \) in Equation 1.1

\[ E = 2C \left( \frac{1}{L_1} - \frac{1}{L_2} \right) \]
\[ = 2C \left( \frac{1}{L_2} \right) \left( \frac{1}{L_1} \right) \]

Where \( s = \frac{L_1}{L_2} \) - the reduction ratio

Writing \( C = 3F_k \)
Q: Give methods of size separation.
### Size Reduction - Size Separation

#### Table 1.4: Range of particle size separation by different Methods

<table>
<thead>
<tr>
<th>Size separation Methods</th>
<th>Particle Diameter (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) By Sieving</td>
<td>5 - 10,000</td>
</tr>
<tr>
<td>(2) By sedimentation</td>
<td></td>
</tr>
<tr>
<td>(A) Gravitational</td>
<td>5 - 1000</td>
</tr>
<tr>
<td>(B) Centrifugal</td>
<td>0.1 - 5</td>
</tr>
<tr>
<td>(3) By Elutriation</td>
<td></td>
</tr>
<tr>
<td>(A) Water and air gravitational Elutriators</td>
<td>10 - 500</td>
</tr>
<tr>
<td>(B) Centrifugal Elutriators</td>
<td>0.5 - 50</td>
</tr>
<tr>
<td>(4) By Cyclone separation</td>
<td>2 - 50</td>
</tr>
</tbody>
</table>

### STANDARD FOR POWDERS

According to pharmacopoeia (L.P./B.P.) powders can be graded into seven classes. Degree of coarseness or fineness of a powder is differentiated and expressed by the size of the mesh of the sieve through which the powder is able to pass.

- **Coarse Powder (10/44):** A powder of which all the particles pass through a No. 10 sieve and not more than 40% through a No. 44 sieve.
- **Moderately coarse Powder (22/60):** A powder of which all the particles pass through a No. 22 sieve but not more than 40% through a No. 60 sieve.
- **Moderately fine Powder (44/85):** A powder of which all the particles pass through a No. 44 sieve, but not more than 40% through a No. 85 sieve.
- **Fine Powder (85):** A powder of which all the particles pass through a No. 85 sieve.
- **Very fine Powder (120):** A powder of which all the particles pass through a No. 120 sieve, (125 μm).
- **Microfine Powder:** A powder of which not less than 90% of the particles pass through a sieve No. 350 (45 μm).
- **Superfine Powder:** A powder of which not less than 90% of the particles are less than 10 μm.

### Table 1.5: Standards of Powder

<table>
<thead>
<tr>
<th>Grade of powder</th>
<th>Sieve through which all particles must pass</th>
<th>Sieve through which not more than 40% of particles pass</th>
<th>Relative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>10</td>
<td>44</td>
<td>01</td>
</tr>
<tr>
<td>Moderately coarse</td>
<td>22</td>
<td>60</td>
<td>1/6</td>
</tr>
<tr>
<td>Moderately fine</td>
<td>44</td>
<td>85</td>
<td>1/24</td>
</tr>
<tr>
<td>Fine</td>
<td>85</td>
<td>120</td>
<td>1/90</td>
</tr>
<tr>
<td>Very fine</td>
<td>120</td>
<td>-</td>
<td>1/120</td>
</tr>
<tr>
<td>Microfine</td>
<td>90% pass through 350 μm</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Superfine</td>
<td>90% pass through 10 μm</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

In addition to B.P., the B.P.C. details a further grade known as Ultra-fine powder. In this case, it is required that the maximum dimension of at least 90% of the particle must be not greater than 5 μm and none must be greater than 50 μm. Determination of particle size for this grade is carried out by a microscopic method.

#### 1.1.3 METHODS OF SIZE SEPARATION

1. **BY SIEVING (SIFTING).**
   1. **HAND SIEVING.**

   Size classification of powder may be done by passing the powdered material through openings in a sieve. In use, the powder is placed on one side of the sieve and gently tapped and shaken but not forced. Sieve separate coarse from finer particles. Material passing through the sieve is the product while that remaining on the sieve is either rejected or re-processed.

   **Perforated plate sieves:**

   Sieves may also be made by drilling holes in a metal plate so that this type will have circular apertures as against the square of wire mesh sieves these sieves are used in the larger size. It have greater accuracy than wire mesh sieves and less distortion.
### MATERIALS FOR SIEVE

<table>
<thead>
<tr>
<th>Metallics</th>
<th>Non-metallics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>Natural</td>
</tr>
<tr>
<td>- cheap</td>
<td>- Rusting problems</td>
</tr>
<tr>
<td>- No corrosion</td>
<td>- Diameter of aperture varies</td>
</tr>
<tr>
<td>- Coated Iron</td>
<td>- Nylon</td>
</tr>
<tr>
<td>- Copper</td>
<td>- Terylene</td>
</tr>
<tr>
<td>- No corrosion</td>
<td>- Silk</td>
</tr>
<tr>
<td>- Soft metal</td>
<td>- So more distortion</td>
</tr>
<tr>
<td>- Copper Alloys</td>
<td></td>
</tr>
<tr>
<td>(Brass, Phosphor - Bronze)</td>
<td>THE SIFTING CLOTH</td>
</tr>
<tr>
<td>No corrosion</td>
<td></td>
</tr>
<tr>
<td>No contamination</td>
<td></td>
</tr>
<tr>
<td>Stainless steel</td>
<td>THE COARSER BALL SUPPORT SCREEN</td>
</tr>
<tr>
<td>No corrosion</td>
<td></td>
</tr>
<tr>
<td>No distortion</td>
<td></td>
</tr>
</tbody>
</table>

#### (B) Mechanical

<table>
<thead>
<tr>
<th>AGITATION METHOD</th>
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<tr>
<td>Brushes may be agitated in a number of different ways, for example.</td>
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</table>

#### (i) Brushing method:

A single brush across the diameter of an ordinary circular sieve, rotating about the mid point. Brush is rotated by turning the handle.

Brush keep the mesh clear.

#### (ii) Oscillation (shaking screen):

The sieve is mounted in a frame that oscillates back and forth. It is a simple method. Material may roll on the surface of the sieve.

#### (iii) Vibration:

Here mesh is vibrated at high speed by electrical means or mechanical means.

#### (1) Rotex Screen:

![Fig. 1.16 Mechanism of Rotex Screen.](image)

It consists of two screens. The upper fine sizing screen. The second is coarse sieve. In between two screens there are number of wooden blocks with sloping slides and rubber balls. The shaking motion of screen causes the rubber balls to fly, they strike the side of wooden block, the inclined side deflect the balls upward, which give vibration to the sizing screen.

#### (iv) Gyratory method:

#### (1) Rotap sieve shaker:

The sieves are arranged in sets with the coarsest on top and the finest at the bottom. The material is placed on the top sieve. Machine produces circular and tapping motion, with a uniform mechanical action. Bottom sieve is attached to a receiving pan. The weight of each fraction is determined and percentage can be calculated. It is used for continuous operation.
(I) WET SIEVING

(A) BY SEDIMENTATION

When size separations are to be carried out on particles too small to screen effectively, or where very large tonnages (heavy) are to be handled, method involving differences in the rates of settling (sedimentation) of particles of different size are used.

Suppose, for example, that two particles of different settling rates in water are placed in an upward-flowing water stream. If the velocity of the water is adjusted so that it lies between the settling rate of the two particles the slower (fine) particles will be carried upward, the faster (heavy) particles will move downward against the water stream, and separation is attained. This termed as - Elutriation.

![Comparison of Sedimentation and Elutriation](image)

(B) ELUTRIATION METHODS:

(i) Elutriation tank:

Size separation depending upon the low density of the fine particles and the high density of the coarse particles. It is also known as water sifting. It is used to separate the coarse and fine particles of non-hydrating insoluble inorganic powders after levigation process.

(a) Elutriation tank:

Elutriation depends on the movement of a fluid against the direction of sedimentation of the particles.

For gravitational system, the apparatus consists simply of a vertical column with an inlet near the bottom for the suspension, an outlet at the base for coarse particles, and an overflow near the top for fluid and fine particles. One column will give a single separation into two fractions.

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**Fig. 1.19 Continuous Sedimentation Tank**

The material is introduced in suspension into a tank containing a relatively large volume of water at a low velocity. The particles slowly settle at a lower rate, they are carried further forward before they reach the bottom of the tank, the very fine particles are carried away in the liquid overflow. Receiver at various distances from the inlet collect different grades of particles according to their settling velocity. Particles of high settling velocity collecting near the inlet.

**Fig. 1.20 Gravity Settling Tank**
Advantages of Elutriation:

1. The process is continuous.
2. As many stage can be used as necessary.
3. The separation is quicker than with sedimentation.

(d) The double Cone Classifier:

This classifier consists of a conical vessel, with a second hollow cone of greater angle arranged apex downwards inside it so that there is an annular space between the two cones. The bottom portion of the inner cone is cut away and its position relative to the outer cone can be regulated by screw adjustment. Water is passed in an upward direction, and overflows into a launder arranged round the whole of the periphery of the outer cone. The material is fed in suspension to the center of the inner one, and the liquid level is maintained slightly higher than the overflow level, so that there is continuous flow of liquid downwards in the centre cone. The particles are therefore brought into the annular space where they are classified. The smaller particles are carried away in the overflow and large particles settle against the liquid stream and are taken off at the bottom.

(3) BY CENTRIFUGAL FORCE.

(A) CYCLONE SEPARATOR:

Principle:
The cyclone separator works on the combined principles of Centrifugation and sedimentation for effecting the process of size separation.

The rate of settling of particles in a fluids (gas) stream can be greatly increased if centrifugal rather than gravitational forces are employed.

Cyclones are used primarily for the separation of solids from fluids and use centrifugal force to effect the separation.

Separation depends not only on particle size but also on particle density, so that cyclones may be used to effect a separation on the basis of particle size or particle density or both.

Construction:
The apparatus consists of a cylindrical vessel with a conical base.
**Fig. 1.25 Cyclone - Separator.**

The air with its load of solid is introduced tangentially at the top of the cylindrical portion at fairly high velocity. So that rotary (vortex) movement take place. The rotary flow within the cyclone imparts centrifugal force on particles. Centrifugal force throws particles out to the walls, hence falling to the conical base and out through the bottom.

The clean gas (Air) is taken off through a central outlet at the top. A dust bag is provided at the outlet, to collect the fine particles. Outlet provided with a nipple that extends inwardly into the separator to prevent the air short-circuiting directly from the inlet to the outlet.

**Advantages:**
1. The process is fast and efficient.
2. Used for separation of very fine particles.

**Disadvantages:**
1. Special equipment required.
2. Fluid and energy requirement is high.

**(B) AIR-SEPARATOR**

**Principle:**

It works as the principle of cyclone separator. Here current of air combined with centrifugal force is used.

**Construction:**

Feed enters on the rotating plate at (B). From the hopper (A). To the same shaft, rotating fan blade (C) are attached, which produce a current of air as shown by the arrows. Fine particles are picked up by the draft and carried into space (D), where air velocity is sufficiently reduced so that they are dropped and collected at outlet (E). Heavy particles which fall downward are removed at outlet (F).

---

**Fig. 1.26 Air Separator**

**I-II-4 NUMERICAL EXAMPLES**

**NOMENCLATURE**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Area, $\text{ft}^2$</td>
</tr>
<tr>
<td>B</td>
<td>Constant</td>
</tr>
<tr>
<td>M</td>
<td>Mass of underflow (undersize) - $\text{lb/hr}$</td>
</tr>
<tr>
<td>F</td>
<td>Force</td>
</tr>
<tr>
<td>f</td>
<td>Resisting force</td>
</tr>
<tr>
<td>F</td>
<td>Mass of feed - $\text{lb/hr}$</td>
</tr>
<tr>
<td>D</td>
<td>Length or Diameter</td>
</tr>
<tr>
<td>D</td>
<td>Mass of overflow $\text{lb/hr}$ (oversized)</td>
</tr>
<tr>
<td>DA, DB</td>
<td>Equivalent spherical diameter of particle A and B - $\text{L}$</td>
</tr>
<tr>
<td>K</td>
<td>Constant for given size / shape of particle and given screen - $\text{T}^{-1}$</td>
</tr>
<tr>
<td>g</td>
<td>Acceleration due to gravity - $\text{ft/s}^2$</td>
</tr>
<tr>
<td>(g)</td>
<td>density of fluid - $\text{M} \cdot \text{L}^{-3}$</td>
</tr>
</tbody>
</table>
SUMMARY OF THE MCCABE – THIELE METHOD:

1. The equilibrium curve and the diagonal \( X = Y \) are plotted (Fig. 3.21).
2. The value of \( q \) is calculated from the enthalpy of the feed and the enthalpies of the saturated liquid and vapor (eq. 3.56). The \( q \) line is plotted by passing a straight line of slope \( \frac{q}{(q-1)} \) through the intersection of the vertical line \( X = X_F \) with the diagonal - point \( g \).

![Diagram of McCabe-Thiele Solution of Rectifying Column Problem](image)

Fig. 3.21 McCabe Thiele Solution of Rectifying Column Problem.

3. The slope \( \frac{R}{(R+1)} \) is calculated and a line having this slope and passing through point \( a \) \( (X_D, Y_L) \) is constructed. Its intercept, where \( X = 0 \) (point \( f \)), should be \( \frac{X_D}{(R+1)} \). This is the upper operating line. The intersection of this line with the \( q \) line determine the point \( h \).

4. A line is passed through point \( f \) on the diagonal where \( X = X_W \), and point \( h \). This is the lower operating line.

(5) Beginning at point \( a \), rectangular steps (horizontal and vertical) are drawn between the upper operating line and the equilibrium curve until the \( q \) line is passed, and then between the lower operating line and the equilibrium curve until the line \( X = X_W \) is passed.

The total number of steps is the number of the theoretical plates required for the separation. The step straddling the \( q \) line is the correct feed plate location. The transfer from one operating line to the other may be made at any point between \( k \) and \( j \) Fig. 3.21 indicates seven and eight theoretical plates in the column, and feed will be on \( 4 \), plate from the top.

3.7 IMPORTANCE OF THE REFUX RATIO

(1) Influence on the Number of Plates

The ratio \( \frac{D}{R} \) of the top overflow to the quantity of the product is denoted by \( R \) and this enables the equation (3.41) of the operating lines to be expressed as (3.42), this is more convenient:

\[
Y_{(n+1)} = \frac{R}{(R+1)} X_n + \frac{X_D}{R+1}
\]

Any change in \( R \) will therefore modify the slope of operating lines and will alter the number of plates required for a given separation (Fig. 3.22). If \( R \) is known, the top line is most easily drawn by joining point \( (X_D, Y_{(0)}) \) to \( B \) \( \left( 0, \frac{X_D}{R+1} \right) \).

![Diagram of McCabe-Thiele for minimum reflux](image)

Fig. 3.22 Influence of Reflux Ratio on the Number of Plates Required for a given Separation.
(I) **Supersaturation Created by Cooling Alone**:

(A) **TANK CRYSTALLIZER**:

(Static Tank Crystallizer)

**PRINCIPLE**: Simple Cooling.

This is the oldest method.

**CONSTRUCTION**: Big rectangular uncovered metal tank.

**OPERATION**: Hot saturated solution is poured in tank. Solution is allowed to cool by natural convection. Cooling rate dependent on humidity and air velocity.

No attempt is made to seed or agitation. Crystallization is neither accelerate nor control. Sometimes rods or strings are hung in the tank to give the crystals additional surface on which crystal grow and prevent sediment of crystals. When tank have cooled sufficiently, remaining mother liquor drained and crystals removed by hand.

**ADVANTAGES**:

1. Simple operation.
2. Cheap (inexpensive)
3. No special or complicated equipments are required.

**DISADVANTAGES**:

1. Nucleation is not control. So crystals size varies from small to very large.
2. As crystals removed by hand, require much labour.
3. As tank require to cool several days it is time consuming process.
4. Floor space and inventory in process are large.
5. Crystals produced are aggregated and occludes impurities from mother liquor.
6. Low capacity.
7. Batch operation.

**APPLICATION**:

1. For noncritical users for demand of large crystals.
2. For glaubers salt.
3. For synthetic sponge.
II. AGITATED BATCH CRYSTALLIZERS

PRINCIPLES:
Artificial cooling with agitation.

CONSTRUCTION:
A modified tank crystallizer. It consists of a jacketed and agitated tank. Cooling jackets fitted around the walls. Cooling rate is controlled by cold water or ice-water refrigerant.

Solution is agitated by slow speed propeller at the central shaft. Agitation performs two functions:
(i) Increases rate of heat transfer.
(ii) Keeps crystals in suspension, giving opportunity to grow uniformly and no aggregates or large crystals form.

OPERATION:
Saturated solution is pumped into tank. Solution is agitated by propeller and cold water is circulated in jacket.

ADVANTAGES:
1. More efficient than tank crystallizer.
2. Uniform and more fine product.

DISADVANTAGES:
1. Low capacity.
2. Large floor space.
3. Cooling surface in tank must be shut down and washed out as it decreases the rate of heat transfer.
4. Batch operation.

APPLICATIONS:
1. For substances whose solubility is dependent on temperature.
2. For small scale production.

1. SWENSON-WALKER CRYSTALLIZER:
(Scraped Surface Crystallizer)

PRINCIPLES:
Super saturation by cooling.

CONSTRUCTION:
It consists of a U-shaped pan (A) with a semi-cylindrical bottom.
mixing may be considered to be complete. Based on these concepts, a statistical procedure for measuring mixing is as follows:

Consider one type of material tracer material is added for easy analysis.

Let over all fraction (proportion) of tracer material in the mix be \( \tau \). OR

\( P \)

Take a number of small samples at random from various locations in the mixed mix and determine the fraction of tracer - \( X_1 \) (OR say \( X_1, X_2, X_3, \ldots, X_N \)) in each. Let \( N \) samples are tested and the average value of the measured concentrations be \( \bar{X} \).

When \( N \) is very large \( \sigma \) approach \( \tau \), OR \( P \)

When \( N \) is small \( \sigma \) and \( \bar{X} \) appreciably differ.

If mixture is perfectly mixed and perfectly analyzed then \( \sigma = \tau \)

(No deviation form Mean value)

If mixing is not complete:

\[ \sigma \neq \tau \]

Then standard deviation about average value \( \tau \) is a measure of quality of mixing.

\[ \sigma = \sqrt{\frac{\sum (n - \bar{x})^2}{N - 1}} \]

(Std. deviation)

The value of \( S' \) (Std. deviation) is a relative measure of mixing, valid for set of tests.

A more general measure is the ratio of \( S' \) to the standard deviation at zero mixing - \( \sigma_0 \).

Before mixing material exists as two layers, one contains no tracer material and one which is tracer only.

Therefore:

\[
\begin{align*}
X_1 \text{ (first layer)} &= 0 \\
X_2 \text{ (other layer)} &= 1 \\
\sigma_0 &= \sqrt{\mu(1 - \mu)} \\
\text{OR} \\
\sigma_1 &= \mu(1 - \mu) = P(1 - P)
\end{align*}
\]
POR, μ = over all fraction of tracer in the mixture
Mixing Index, $I_m$, is (Per Pettie)

$$I_m = \frac{S}{\sigma_0} = \frac{\sum (t_i - \bar{x})^2}{N(N-1)\mu (1-\mu)}$$

In any batch mixing $I_m$ is unity (0) before mixing and becomes smaller as mixing proceeds. Theoretically $I_m$ would approach zero at long mixing times, in reality it does not. The reasons are:
1. Mixing is never quite complete.
2. Analytical method is not extra ordinarily precise.

The measured values $X_1, X_2, X_3, \ldots X_N$ never agree with each other or with $\bar{x}$ (mean), and $I_m$ is not found zero even with perfectly mixed material.

The minimum limiting value of $I_m$ for completely mixed materials varies with the consistency of the material processed, effectiveness of mixer and precision of the analytical method. Typically it falls in the range between 0.1 and 0.01.

Mixing Index for Granular Solids:

It is not based on conditions at zero mixing, but on the standard deviation that would be observed with a completely random, fully blended mixture. With highly consistent (pencils/similars) this value ($\sigma_0$) will be zero. With granular solids ($\sigma_0^2$) it is not zero.

Consider mixture of salt and sand. 'N' samples are withdrawn, each sample contain 'n' particles.

Let over all fraction by number of particles, of sand in total mix $μ_p$.

$$μ_p = \frac{μ}{n} \text{ (if small sample)}$$

For granular solids the mixing index $I_m$ is defined as $σ_0/σ_0^2$

$$I_m = \frac{σ_0}{σ_0^2} = \frac{μ(μ_0 - μ)^2}{n^2 \sum (x_i - \bar{x})^2}$$

N = Number of particles in a sample
n = Number of particles in a sample
σ_0 = Standard deviation at zero time (Ref std. for paste)
σ_0^2 = Equilibrium standard deviation for complete mixing (Ref. std. for solids)

If 'n' is 1 in equation 6.4, the two equations - 6.2 and 6.4 become identical. If samples of one particle each are taken from any mixture, the analysis will be either $X_i = 1$ OR $X_i = 0$. Equation 6.2 may be applied to solids before mixing begins, and mixing index at zero mixing becomes

$$I_m = \frac{σ_0^2}{σ_0^2}$$

at zero mixing

Rate of Mixing:

As other rate processes, the rate is proportional to driving force. The mixing index $I_m$ is a measure of how far mixing has proceeded toward equilibrium.

For short mixing period the rate of change of mixing index $I_m$ is directly proportional to $(1 - I_m)$

OR

$$\frac{dt}{d(t)} = k (1 - I_m)$$

K = constant.

Equilibrium value for $I_m$ is 1:

$$(1 - I_m) = \frac{1}{k} \Rightarrow \frac{d}{d(t)} \Rightarrow \frac{1}{k} (1 - I_m)$$

Also:

$$\frac{1}{k} \Rightarrow \frac{1}{k} (1 - I_m)$$

Then:

$$t = \frac{1}{k} \left( 1 - e^{-k} \right)$$

$$t = \frac{1}{k} \left( 1 - \frac{1}{2} \right)$$

$k$ = constant.
In estimating the degree of Mixing as the time progresses, samples are taken at various spots in the mixer, assayed, and the standard deviation (σ) of the assays is a measure of the degree of mixing (M).

![Graph showing standard deviation vs. time or number of rotations]

If the final standard deviation (σ_f) is subtracted from the found standard deviation (σ), the logarithm of the difference is linear in time. It is customary to divide difference (σ_f - σ_i) by the initial difference (σ_i - σ_f), so that the ratios go from 1.0 to 0.0, in other words:

\[ \frac{σ_f - σ_i}{σ_i - σ_f} = -Kt \]

A graph of Y OR Rotation Plotted versus \( \frac{σ_f - σ_i}{σ_i - σ_f} \) OR Log

- A straight line, having slope - 'K' Mixing rate constant

\[ \log \left( \frac{σ_f - σ_i}{σ_i - σ_f} \right) \]

Time of Mixing OR Nos of Rotations

\[ \log \left( \frac{σ_f - σ_i}{σ_i - σ_f} \right) \]

Degree of Mixingness = (1 - M)

M is the degree of Mixing.

### Power Requirements:

Large amounts of mechanical energy are needed to mix heavy plastic masses. The material must be sheared into elements which are moved relative to one another, folded over, remonolled, and divided. Only part of the energy supplied to the mixer is directly useful for mixing; and it is very small. Probably means which work intensively on small quantities of material, dividing it into very small elements, makes more effective use of energy than those which work more slowly on large quantities. Regardless of the design of the machine, however, the power needed to drive a mixer for pastes and deformable solids is many times greater than that needed by a mixer for liquids. The energy supplied appears as heat, which must be removed to avoid damaging the machine or the material.

The power consumption of a wide variety of impellers working in liquids of differing densities and viscosities, have been plotted in the form of a curve, which give valuable information.

![Graph showing power consumption vs. Reynolds number]

In the turbulent range, it is found that power is proportional to the cube of the speed, fifth power of the diameter, and the first power of the sp. gravity and that viscosity has no effect.

The equation for horizontal part is:

\[ P = N^3 \cdot \frac{D_p^5}{\mu} \]

Where:
- \( P \) = Impeller-propeller diameter
- \( N \) = Horse power turning the impeller shaft
- \( D_p \) = Speed of rotation - R.P.M
- \( \mu \) = sp. gravity