SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF CHEMICAL ENGINEERING

SCH1307- PROCESS EQUIPMENT DESIGN

What is Plant Layout?

The organization of a company's physical facilities to promote the efficient use of equipment, material, people and energy.

What are the Goals of Plant Layout Design?

- Minimize unit costs
- Optimize quality
- Promote effective use of people, equipment, space and energy
- Provide for employee convenience, safety and comfort
- Control project costs
- Achieve production deadlines

What Procedure is followed in Plant Layout Design?

Plant Layout Procedure - Phase 1 Information Gathering

- Determine what will be produced
- Determine how many will be produced
- Determine what components will be made or purchased
- Determine required operations
- Determine sequence of operations
- Set time standards for each operation

Plant Layout Procedure - Phase 2 Production and Flow Analysis

- Determine the plant rate, R
- Determine the number of machines
- Balance production lines
- Study the flow requirement
- Determine activity relationships
- Layout each workstation

Plant Layout Procedure - Phase 3 Support Services

- Identify needs for personal and plant services
- Identify office needs
- Develop total space requirements
- Select material handling equipment
- Allocated area
- Develop plot plan and building shape

Plant Layout Procedure - Phase 4 Implementation and Evaluation

- Construct master plan
- Seek input and adjust
- Seek approvals
- Install
- Start up
- Follow up

What is Flow Analysis?

Considers the operations, transportations, inspections, delays, and storages required as a part moves from receiving to shipping in a plant.

What are the goals of Flow Analysis?

- to minimize distance traveled
- to minimize backtracking
- to minimize cross-traffic
- to eliminate unnecessary steps in the process
- to combine steps in the process
- to minimize production costs

What plant flow analysis techniques are used?

- Process charts
- Flow diagrams
- Operations charts
- Process Charts
  - operations
  - transportations
  - storages
  - inspections
  - delays

Process Chart Example

Analysis of Process Charts

- Can I eliminate this step?
- Can I automate this step?
- Can I combine this step with another?
- Can I change the routing to reduce distances traveled?
- Can I move workstations closer together?
- Can I justify production aids to increase effectiveness?
- How much does this part cost to produce?

Flow Diagram

Graphical diagram which shows the path traveled by each part from receiving to stores to fabrication of each part to final assembly to pack out to warehousing to shipping. Flow Diagram Example

Types of Supports for Vessels

Type of supports to be provided to a vessel depend upon its configuration, height to diameter ratio of the vessel, convenience of location, operating temperature and materials of construction

Type of supports to be provided to a vessel depends upon its configuration, height to diameter ratio of the vessel, convenience of location, operating temperature and materials.

There are four types of supports commonly used.

Skirt support

Bracket or Lug support

Saddle support

Leg support

Tall vertical columns and heat exchangers are often supported on skirts.

Medium size process vessels having height to diameter ratio 2-3 are provided with bracket or lug supports. Horizontal vessels are usually provided with saddle supports. Small vessels of capacity 1-2 m^3 are provided with leg supports.

Skirt supports

Tall columns such as distillation column, absorption column are provided with skirt support. From a designer point of view, skirt support is attractive because it produces minimum amount of local stresses caused by mechanical loads acting at its junction with the vessel. Analysis of skirt support is far easy as compared to bracket supports.

Skirt is a cylindrical shell having diameter equal to outside diameter of the vessel or more than the outer diameter of the vessel. It is welded at the bottom of the vessel and rests over a bearing plate which rests over concrete foundation.

Skirt support is designed by considering the following loads:

1. Dead weight of the vessel.

2. Operating weight of the vessel.

3. Lateral loads by restrained thermal growth of interconnecting pipes.

4. Wind load acting over the vessel.

5. Seismic load

To calculate the skirt thickness all these loads are required to be considered

Bracket or Lug Supports

Bracket supports are very common for process equipments. Vertical vessels with height to diameter ratio 2-3 are generally provided with bracket supports. These are fabricated from plates and attached to the vessel with minimum possible weld length. Brackets rests on columns or structural beams. A vessel with bracket support is shown below. There are many advantages of the bracket supports.

1. Cost is less.

2. Can be easily attached to the Vessel with minimum weld length.

3. Can be easily levelled.

4. Can absorb diametrical expansions if sliding arrangement is provided.

5. Most suitable for thick wall vessels because of their ability to absorb bending stresses eccentrically of loads.

There are some disadvantages also. These are:

Brackets are eccentric to the vessel. This results in bending moment and compressive, tensile, shear stresses are induced in the vessel wall. Therefore these are not suitable for thin wall vessels unless the vessel wall is reinforced with backing plate.

For vessel up to 0.8 m diameter two brackets are sufficient. Up to 3 m diameter, 4 brackets are used 6 brackets up to 5 m diameter and 8 brackets above 5 m diameter are used.

Saddle Supports

Horizontal vessels are generally provided saddle supports.. If the underside of the vessel is to be located only a short distance above the ground line, steel saddles resting on the top of concrete piers can be used. Horizontal vessels resting on saddle support is shown in Fig. The vessel behaves like a beam. Number of saddles is generally two. It can be more if unavoidable. Supports in the form of ring are preferred if it is required at more than two positions.
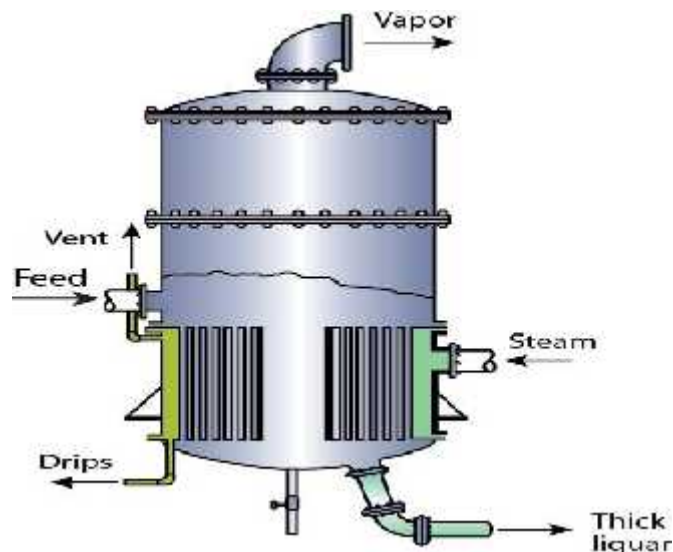
Evaporator

Evaporation is the removal of solvent as vapor from a solution. The aim is to concentrate a non-volatile solute, such as organic compounds, inorganic salts, acids or bases from a solvent. Common solutes are caustic soda, caustic potash, sodium sulfate, sodium chloride, phosphoric acid, and urea. The most common solvent in most of the evaporation systems is water. Evaporation is normally stopped before the solute starts to precipitate in the operation of an evaporator.

TYPE OF EVAPORATORS

Evaporator consists of a heat exchanger for boiling the solution with special provisions for separation of liquid and vapor phases. Most of the industrial evaporators have tubular heating surfaces. The tubes may be horizontal or vertical, long or short; the liquid may be inside or outside the tubes.

2.1. Short-Tube Vertical Evaporators

Short-tube vertical evaporators are the oldest but still widely used in sugar industry in evaporation of cane-sugar juice. These are also known as *calandria* evaporators. It became so common in process industry that this evaporator is sometimes known as *standard evaporator*. Short-tube vertical evaporators consist of a short tube bundle (about 4 to 10 ft in length) enclosed in a cylindrical shell. This is called calandria. The feed is introduced above the upper tube sheet and steam is introduced to the shell or steam chest of the calandria. The solution is heated and partly vaporized in the tubes. The central tube in a calandria is of longer diameter. Typically it's downcomer area is taken as 40 to 70% of the total cross sectional area of tubes. The circulation rate through the downcomer/downtake is many times the feed rate. The flow area of the downtake is normally approximately equal to the total tubular flow area.

Long-Tube Vertical Evaporators

This is another most widely employed natural circulation evaporator because it is often the cheapest per unit of capacity. The long vertical tube bundle is fixed with a shell that extends into a larger diameter vapor chamber at the top (**Figure 3.2**). The long-tube vertical (LTV) evaporator consists of one pass shell and tube heat exchanger. In this type of evaporator, the liquid flows as a thin film on the walls of long (from 12 to 30 feet in length) and vertical heated tube. Both rising film and falling types are used. Tube length usually varies from 20 to 65 ft. The main advantage of this type of evaporators is higher heat transfer rate. The feed enters at the bottom and the liquid starts boiling at lower part of the tube. The LTV evaporators are commonly used in concentrating black liquors in the paper and pulp industries.
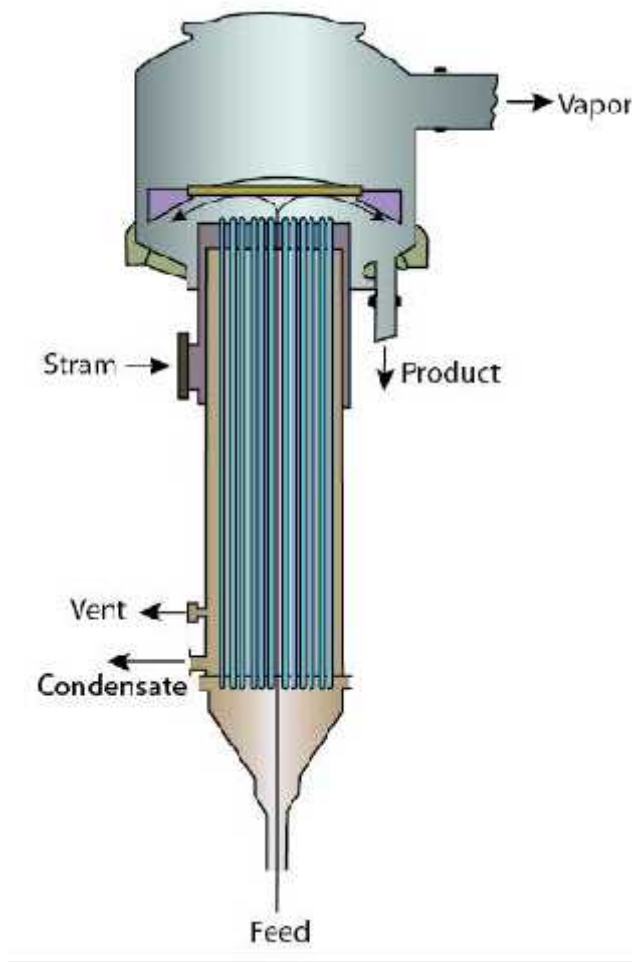
Falling Film Evaporators

In a falling film evaporator, the liquid is fed at the top of the tubes in a vertical tube bundle. The liquid is allowed to flow down through the inner wall of the tubes as a film. As the liquid travels down the tubes the solvent vaporizes and the concentration gradually increases. Vapor and liquid are usually separated at the bottom of the tubes and the thick liquor is taken out. Evaporator liquid is recirculated through the tubes by a pump below the vapor-liquid separator. The distribution of liquid in the inner wall of the tubes greatly affects the performance of this type of evaporator. The falling film evaporator is largely used for concentration of fruit juices and heat sensitive materials because of the low holdup time. The device is suitable for scale-forming solutions as boiling occur on the surface of the film.
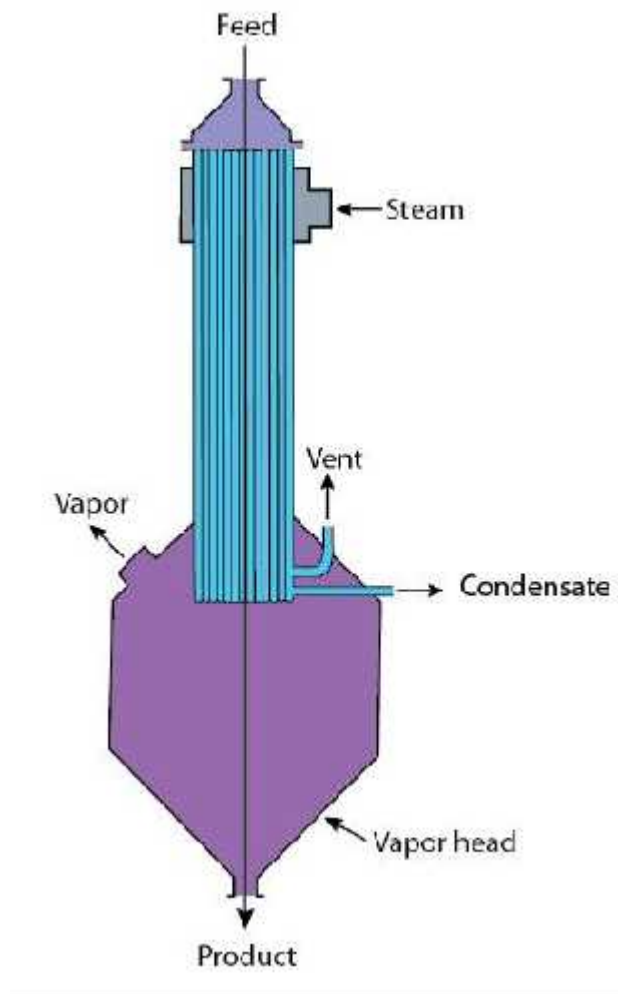

Forced Circulation Evaporators

Forced circulation evaporators are usually more costly than natural circulation evaporators. However the natural circulation evaporators are not suitable under some situations such as:

- highly viscous solutions due to low heat transfer coefficient
- solution containing suspended particles and for heat sensitive materials

All these problems may be overcome when the liquid is circulated at high velocity through the
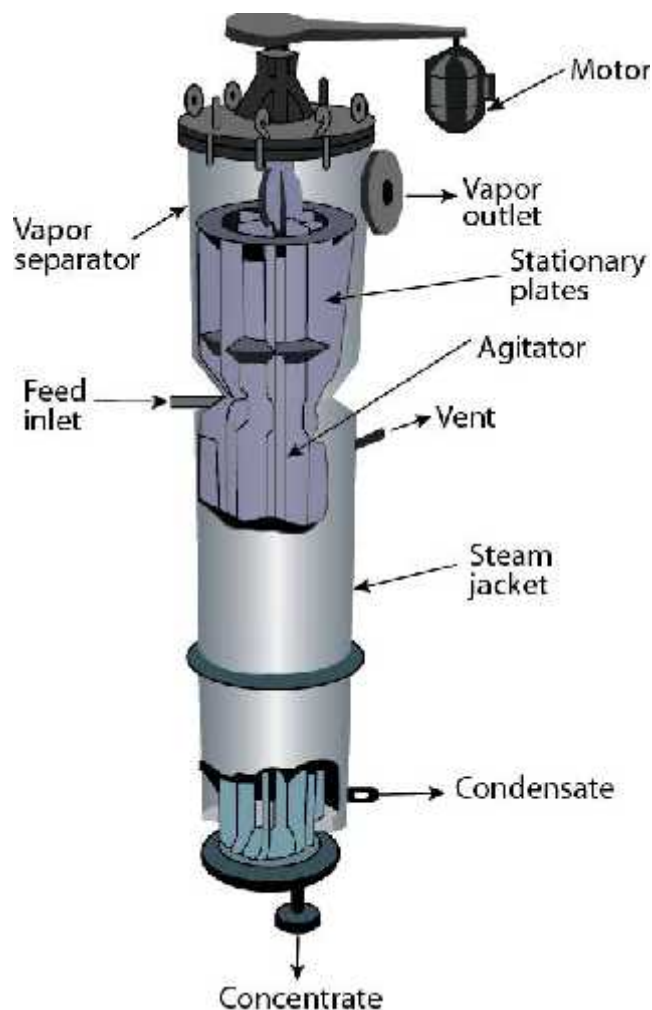
heat exchanger tubes to enhance the heat transfer rate and inhibit particle deposition. Any evaporator that uses pump to ensure higher circulation velocity is called a forced circulation evaporator. The main components of a forced circulation evaporator are a tubular shell and tube heat exchanger (either horizontal or vertical), a flash chamber (separator) mounted above the heat exchanger and a circulating pump. The solution is heated in the heat exchanger without boiling and the superheated solution flashes off (partially evaporated) at a lower pressure are reduced in the flash chamber. The pump pumps feed and liquor from the flash chamber and forces it through the heat exchanger tubes back to the flash chamber. Forced circulation evaporator is commonly used for concentration of caustic and brine solutions and also in evaporation of corrosive solution.
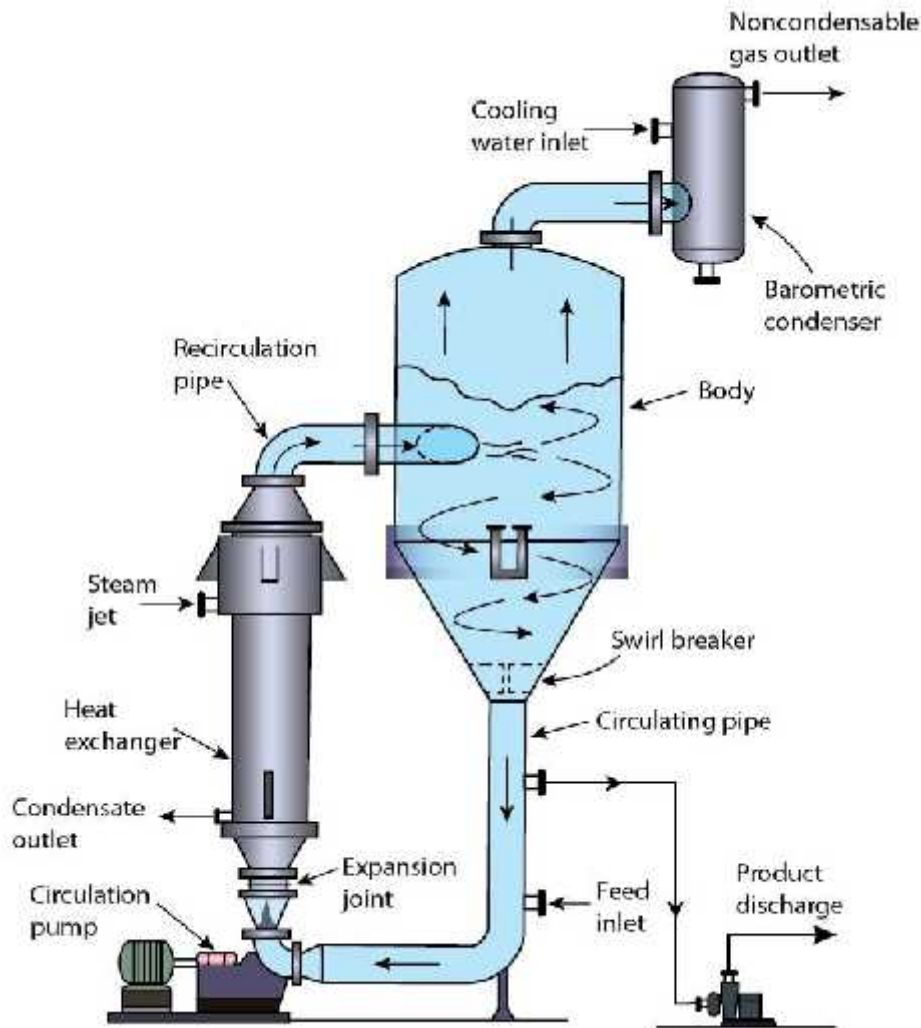
Agitated Thin Film Evaporator

Agitated thin film evaporator consists of a vertical steam-jacketed cylinder and the feed solution flows down as a film along the inner surface of large diameter jacket. Liquid is distributed on the tube wall by a rotating assembly of blades mounted on shaft placed coaxially with the inner tube. The blades maintain a close clearance of around 1.5 mm or less from the inner tube wall.

The main advantage is that rotating blades permits handling of extremely viscous solutions. The device is suitable to concentrate solutions having viscosity as high as up to 100 P.

Motor
Vapor outlet
Vapor separator
Stationary plates
Agitator
Feed inlet
Vent
Steam jacket
Condensate
Concentrate

MULTIPLE EFFECT EVAPORATORS

Evaporators are classified by the number of *effects*. In case of a *single-effect* evaporator, the vapor from the boiling liquor is condensed and the concentrated product is withdrawn from the bottom of the evaporator. Although the operation is simple, the device does not use steam efficiently. Typically 1.1 to 1.3 kg of steam is required to evaporate 1 kg of water.

The steam consumption per unit mass of water evaporated can be increased by putting more than one evaporator in series such that the vapor from one evaporator is used in the second evaporator for heating. The vapor from the second evaporator is condensed and the arrangement is called *double-effect* evaporators. The heat from the vapor generated in the first evaporator is used in the second evaporator. Evaporation of water is nearly doubled in double effect evaporation system compared to single effect per unit mass of steam used. Additional effects can be added in series in the same way to get a *triple-effect* evaporator, *quadruple-effect* evaporator and so on. There are several configurations based on feeding arrangement.
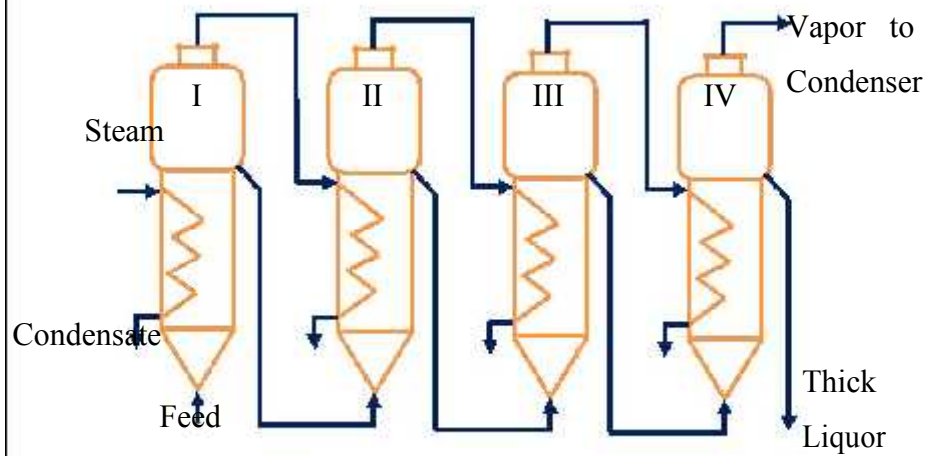
3.7a. Forward feed.
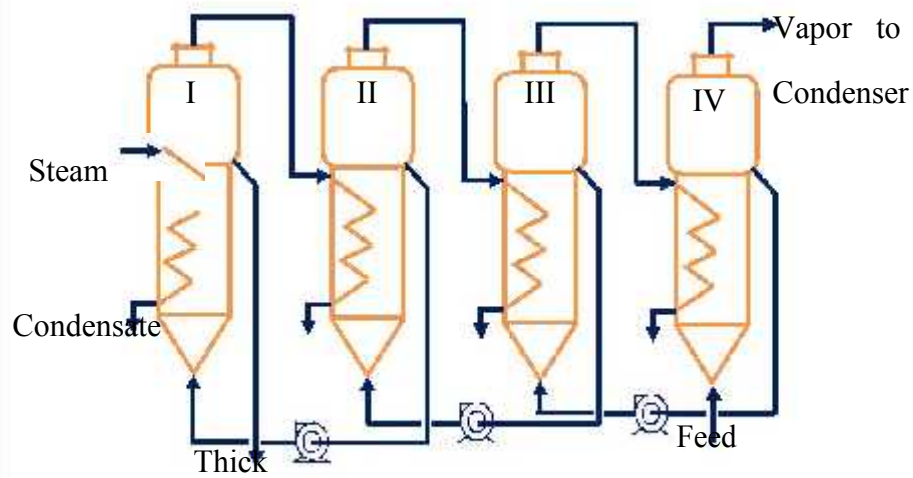
3.7b. Backward feed.
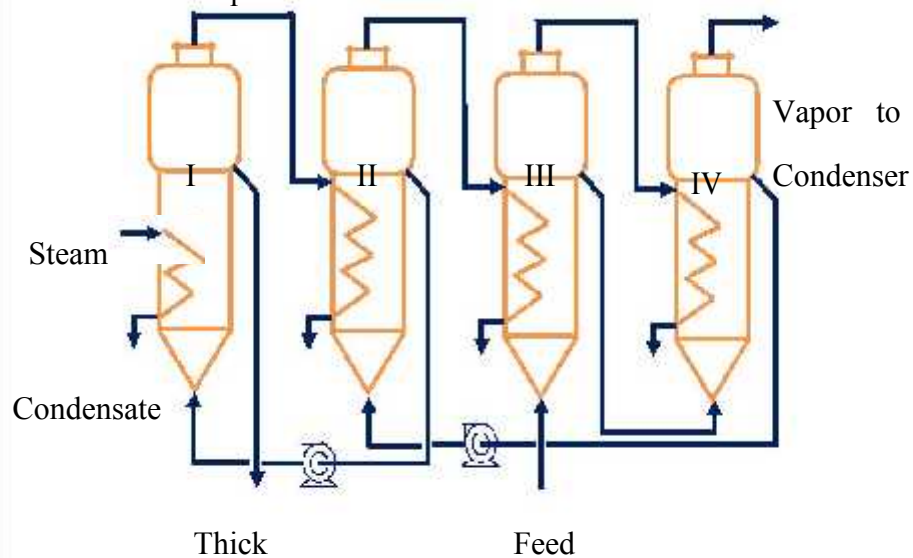
3.7c. Mixed feed.

4. PERFORMANCE OF EVAPORATORS (CAPACITY AND ECONOMY)

The performance of a steam-heated evaporator is measured in terms of its capacity and economy. Capacity is defined as the number of kilogram of water vaporized per hour. Economy (or steam economy) is the number kilogram of water vaporized from all the effects per kilogram of steam used. For single effect evaporator, the steam economy is about 0.8 (<1). The capacity is about n-times that of a single effect evaporator and the economy is about $0.8n$ for a n-effect evaporators. However, pumps, interconnecting pipes and valves are required for transfer of liquid from one effect to another effect that increases both equipment and operating costs.

Boiling point elevation (BPE)

Most evaporators produce concentrated liquor having a boiling point considerably higher than that of pure solvent (or water). This phenomenon is called boiling point elevation (BPE). BPE occurs as the vapor pressure of a solution (usually aqueous solution) is less than that of pure solvent at the same temperature. Boiling point of a solution is a colligative property. It depends on the concentration of solute in the solution for a pair of solute and solvent.

BPE of the concentrated liquor reduces the effective temperature driving force compared to the boiling of pure solvent. Equilibrium vapor generated from a solution exhibiting boiling point elevation is superheated with respect to vapor generated during boiling of pure solvent. The vapor is generated at the solution boiling point, which is higher than the pure component boiling point. The vapor, however, is solute free, so it won't condense until the extra heat corresponding to the elevation is removed, thus it is superheated. Therefore the BPE of the concentrated solution must be known for evaporator design.

Design problem

A 5% aqueous solution of a high molecular weight solute has to be concentrated to 40% in a forward-feed double effect evaporator at the rate of 8000 $kg.h^{-1}$. The feed temperature is 40°C. Saturated steam at 3.5 $kg.cm^{-2}$ is available for heating. A vacuum of 600 mm Hg is maintained. Calculate the area requirements, The overall heat transfer coefficients are 550 $kcal.h^{-1} m^{-2} °C^{-1}$ in the first and the last effect respectively. The specific heat of the concentrated liquor is 0.87 $kcal.kg^{-1}°C^{-1}$.
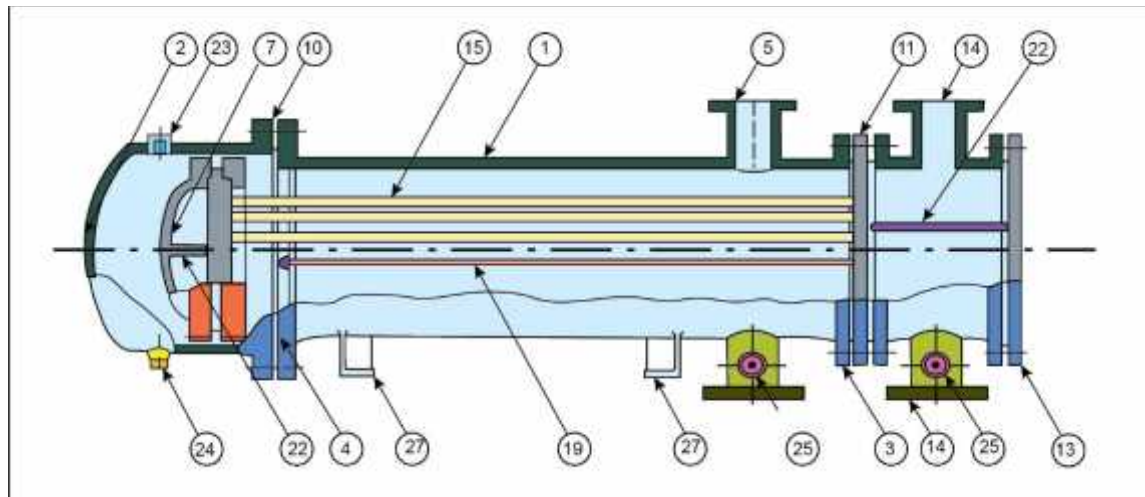
Heat Exchangers
Classification of heat exchangers

Transfer of heat from one fluid to another is an important operation for most of the chemical industries. The most common application of heat transfer is in designing of heat transfer equipment for exchanging heat from one fluid to another fluid. Such devices for efficient transfer of heat are generally called Heat Exchanger.

Fixed tube-sheet exchanger: The simplest and cheapest type of shell and tube exchanger is with fixed tube sheet design. In this type of exchangers the tube sheet is welded to the shell and no relative movement between the shell and tube bundle is possible (**Figure 1.2**).
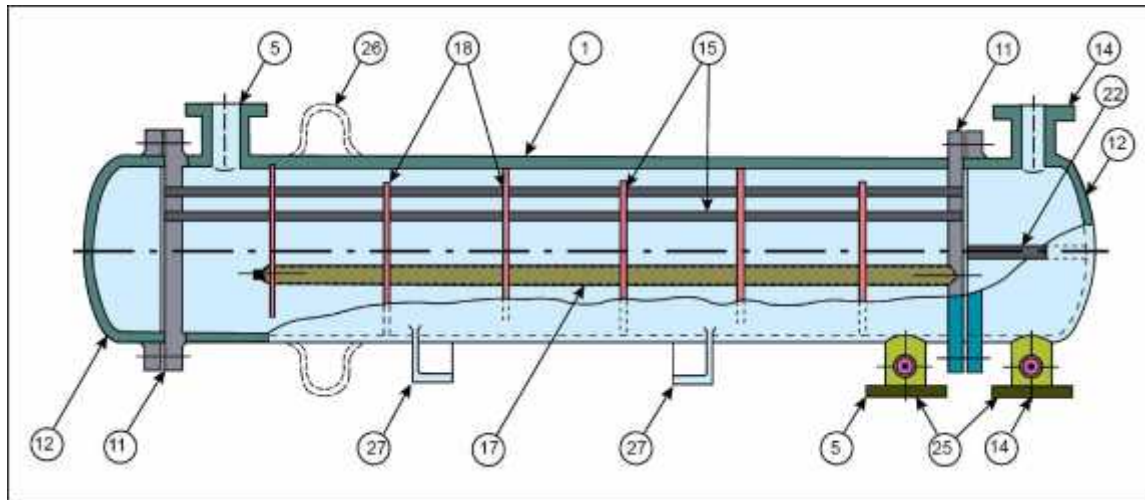
Removable tube bundle: Tube bundle may be removed for ease of cleaning and replacement. Removable tube bundle exchangers further can be categorized in floating-head and U-tube exchanger.

Fouling Considerations

The most of the process fluids in the exchanger foul the heat transfer surface. The material deposited reduces the effective heat transfer rate due to relatively low thermal conductivity. Therefore, net heat transfer with clean surface should be higher to compensate the reduction in performance during operation. Fouling of exchanger increases the cost of (i) construction due to oversizing, (ii) additional energy due to poor exchanger performance and (iii) cleaning to remove deposited materials. A spare exchanger may be considered in design for uninterrupted services to allow cleaning of exchanger. The effect of fouling is considered in heat exchanger design by including the tube side and shell side fouling resistances.

Selection of fluids for tube and the shell side

Tube-side fluid	Shell-side fluid
Corrosive fluid Cooling water, Fouling fluid Less viscous fluid High-pressure steam Hotter fluid	Condensing vapour (unless corrosive) Fluid with large temperature difference (>40°C)

Process Design Procedure

Step #1. Obtain the required thermophysical properties of hot and cold fluids at the **caloric temperature or arithmetic mean temperature**.

Step #2. Perform energy balance and find out the heat duty (Q) of the exchanger.

Step #3. Assume a reasonable value of overall heat transfer coefficient ($U_{o,assm}$). The value of $U_{o,assm}$ with respect to the process hot and cold fluids

Step #4. Decide tentative number of shell and tube passes (n_p). Determine the LMTD and the correction factor F_T (F_T normally should be greater than 0.75 for the steady operation of the exchangers. Otherwise it is required to increase the number of passes to obtain higher F_T values.

Step #5. Calculate heat transfer area (A) required:

Step #6. Select tube material, decide the tube diameter (ID= d_i , OD = d_o), its wall thickness (in terms of BWG or SWG) and tube length (L). Calculate the number of tubes (n) required to provide the heat transfer area (A): $n_t = \dfrac{A}{\pi d_o L}$

Calculate tube side fluid velocity, $u = \dfrac{4\dot{m}\,(n_p/n_t)}{\pi \rho d_i^{\,2}}$

If u <1 m/s, fix n_p so that, Re $= \dfrac{4\dot{m}\,(n_p/n_t)}{\pi d_i \mu} \geq 10^4$

Where, m, ρ and μ are mass flow rate, density and viscosity of tube side fluid. However, this is subject to allowable pressure drop in the tube side of the heat exchanger.

Step #7. Decide type of shell and tube exchanger (fixed tubesheet, U-tube etc.). Select the tube pitch (P_T), determine inside shell diameter (D_s)

Step #9. Assign fluid to shell side or tube side (a general guideline for placing the fluids is summarized in **Table 1.4**). Select the type of baffle (segmental, doughnut etc.), its size (i.e. percentage cut, 25% baffles are widely used), spacing (B) and number. The baffle spacing is usually chosen to be within 0.2 D_s to D_s .

Step #10. Determine the tube side film heat transfer coefficient (h_i) using the suitable form of Sieder-Tate equation in laminar and turbulent flow regimes. Estimate the shell-side film heat transfer coefficient (h_o) from: Select the outside tube (shell side) dirt factor (R_{do}) and inside tube (tube side) dirt factor. Calculate overall heat transfer coefficient (U) based on the outside tube area

Design Problem

150000 lb per hour of kerosene will be heated from 75 to 120°F by cooling a gasoline stream from 160 to 120°F. Inlet pressure will be 50 psia for each stream and the maximum pressure drop of 7 psi for gasoline and 10 psi for kerosene are permissible. Published fouling factors for oil refinery streams should be used for this application. Design a shell and tube heat exchanger for this service.

VAPOR PRESSURE AND BOILING

The vapour pressure of a liquid at a particular temperature is the equilibrium pressure exerted by molecules leaving and entering the liquid surface. Liquids with high vapor pressures (volatile liquids) will boil at lower temperatures The vapor pressure and hence the boiling point of a liquid mixture depends on the relative amounts of the components in the mixture Distillation occurs because of the differences in the volatility of the components in the liquid mixture. For example, when a subcooled liquid with mole fraction of A=0.4 (point A) is heated, its concentration remains constant until it reaches the bubble-point (point B), when it starts to boil. The vapors evolved during the boiling has the equilibrium composition given by point C, approximately 0.8 mole fraction A. This is approximately 50% richer in A than the original liquid.

Relative Volatility

Relative volatility: is a measure of the differences in volatility between 2 components, and hence their boiling points. It indicates how easy or difficult a particular separation will be. Thus if the relative volatility between 2 components is very close to one, it is an indication that they have very similar vapor pressure characteristics. This means that they have very similar boiling points and therefore, it will be difficult to separate the two components via distillation.
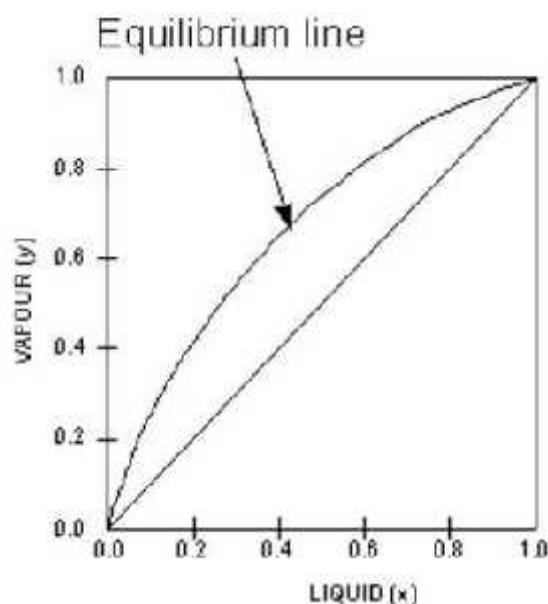
Raoult's law

It states that the partial vapor pressure of each component of an ideal mixture of liquids is equal to the vapor pressure of the pure component multiplied by its mole fraction in the mixture.

Ideal solution: An ideal solution will obey Raoult's Law,

Real solutions: Solutions which deviate from Raoults law are called as 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 deviate from the Raoult's law.
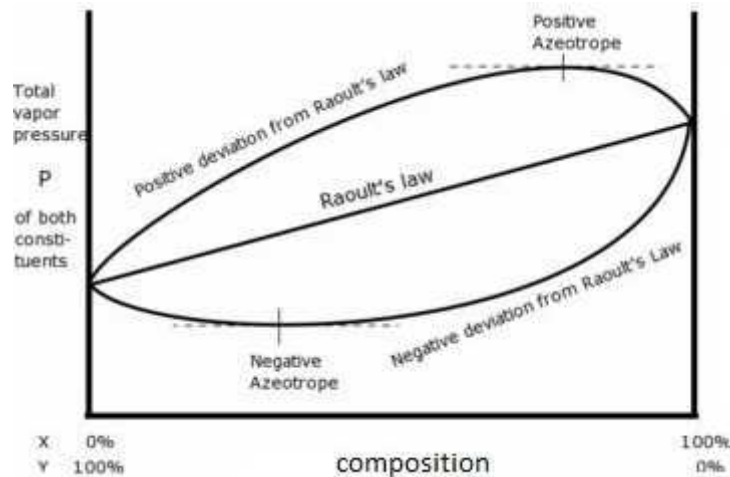
TYPES OF DISTILLATION COLUMNS

There are many types of distillation columns, each designed to perform specific types of separations, and each design differs in terms of complexity.

Batch and Continuous Columns

One way of classifying distillation column type is to look at how they are operated. Thus we have: batch and continuous columns.

Batch Columns In batch operation, the feed to the column is introduced batch-wise. That is, the column is charged with a 'batch' and then the distillation process is carried out. When the desired task is achieved, a next batch of feed is introduced.

Continuous columns

They process a continuous feed stream. No interruptions occur unless there is a problem with the column or surrounding process units. They are capable of handling high throughputs and they are most common of the two types.

Types of Continuous Columns

Continuous columns can be further classified according to:

The nature of the feed that they are processing,

- □ binary column - feed contains only two components

- □ multi-component column - feed contains more than two components

The number of product streams they have

- □ Multi-product column - column has more than two product streams
- □ Extractive distillation - where the extra feed appears in the bottom product stream
- □ azeotropic distillation - where the extra feed appears at the top product stream

The type of column internals

- □ tray column - where trays of various designs are used to hold up the liquid to provide better contact between vapor and liquid, hence better separation

- □ packed column - where instead of trays, 'packings' are used to enhance contact between vapor and liquid

DISTILLATION COLUMN DESIGN

Distillation columns are designed using VLE data for the mixtures to be separated. The vapor-liquid equilibrium characteristics (indicated by the shape of the equilibrium curve) of the mixture will determine the number of stages, and hence the number of trays, required for the separation. This is illustrated clearly by applying the McCabe-Thiele method to design a binary column.

McCABE-THIELE DESIGN METHOD

The McCabe-Thiele approach is a graphical one, and uses the VLE plot to determine the theoretical number of stages required to effect the separation of a binary mixture. It assumes constant molar overflow and this implies that:

Molal heats of vaporization of the components are roughly the same

Heat effects (heats of solution, heat losses to and from column, etc.) are negligible

for every mole of vapour condensed, 1 mole of liquid is vaporised

The design procedure is simple. Given the VLE diagram of the binary mixture, operating lines are drawn first.

- Operating lines define the mass balance relationships between the liquid and vapor phases in the column.

- There is one operating line for the bottom (stripping) section of the column, and on for the top (rectification or enriching) section of the column.

- Use of the constant molar overflow assumption also ensures the operating lines are straight lines.

Operating Line for the Rectification Section

The operating line for the rectification section is constructed as follows: ™First the desired top product composition is located on the VLE diagram, and a vertical line produced until it intersects the diagonal line that splits the VLE plot in half. A line with slope R/(R+1) is then drawn from this instersection point as shown in the diagram below. R is the ratio of reflux flow
(L) to distillate flow (D) and is called the reflux ratio and is a measure of how much of the material going up the top of the column is returned back to the column as reflux.
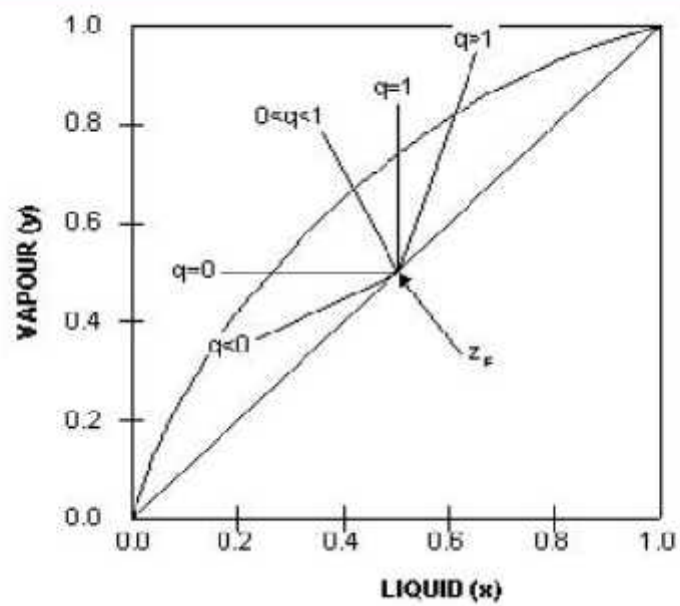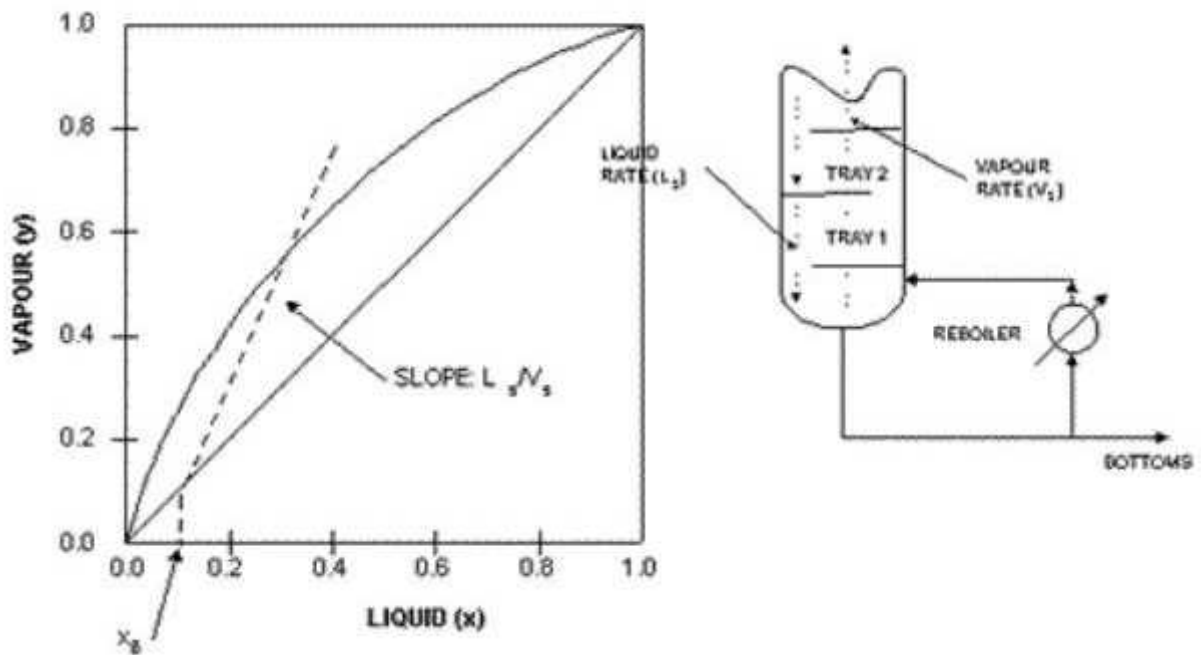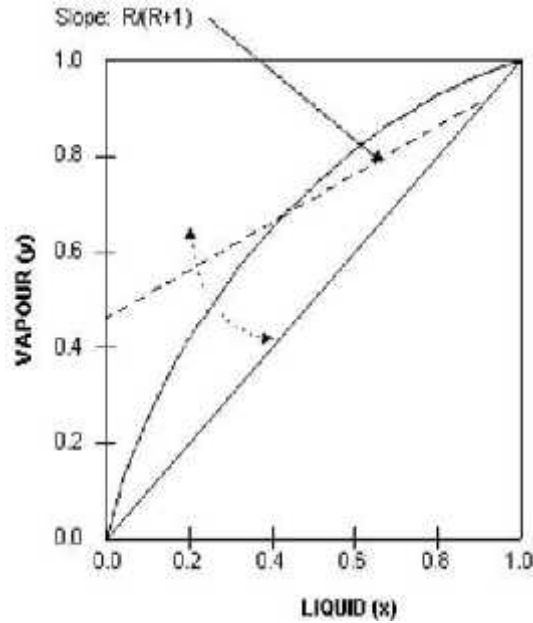
Weeping/Dumping

This phenomenon is caused by low vapor flow. The pressure exerted by the vapour is insufficient to hold up the liquid on the tray. Therefore, liquid starts to leak through perforations. Excessive weeping will lead to dumping. That is the liquid on all trays will crash (dump) through to the base of the column (via a domino effect) and the column will have to be re-started. Weeping is indicated by a sharp pressure drop in the column and reduced separation efficiency.

Flooding:

Flooding is brought about by excessive vapor flow, causing liquid to be entrained in the vapor up the column. The increased pressure from excessive vapor also backs up the liquid in the downcomer, causing an increase in liquid holdup on the plate above. Depending on the degree of flooding, the maximum capacity of the column may be severely reduced. Flooding is detected by sharp increases in column differential pressure and significant decrease in separation efficiency.
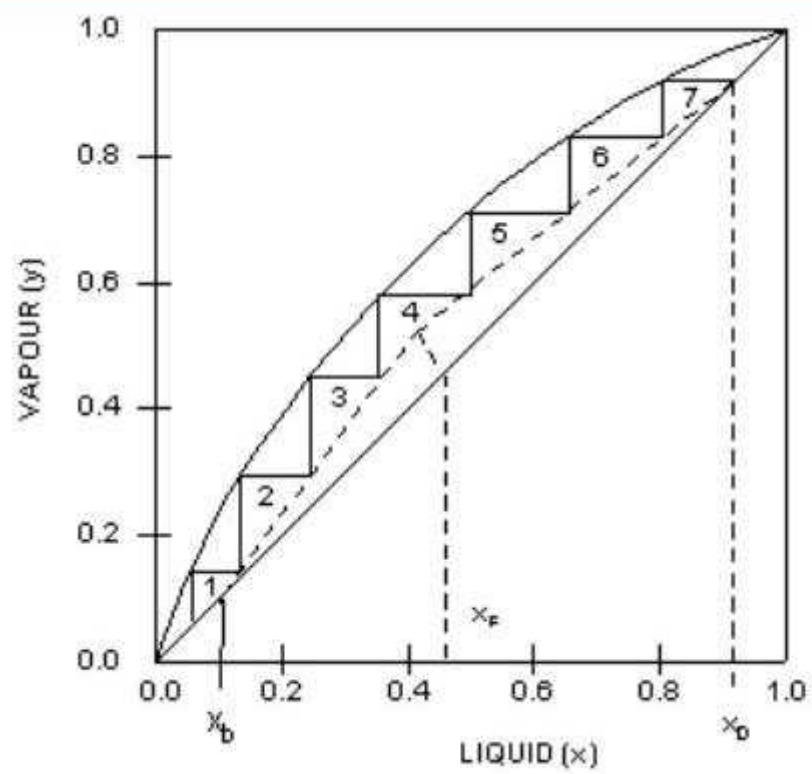
ABSORPTION

Absorption refers to an operation in which the transfer of material is from a gas phase to a liquid phase. A gas is absorbed by means of liquid in which the solute gas is more or less soluble from its mixture with an inert gas as well as more or less insoluble gas. The liquid is essentially immiscible in the gas phase.
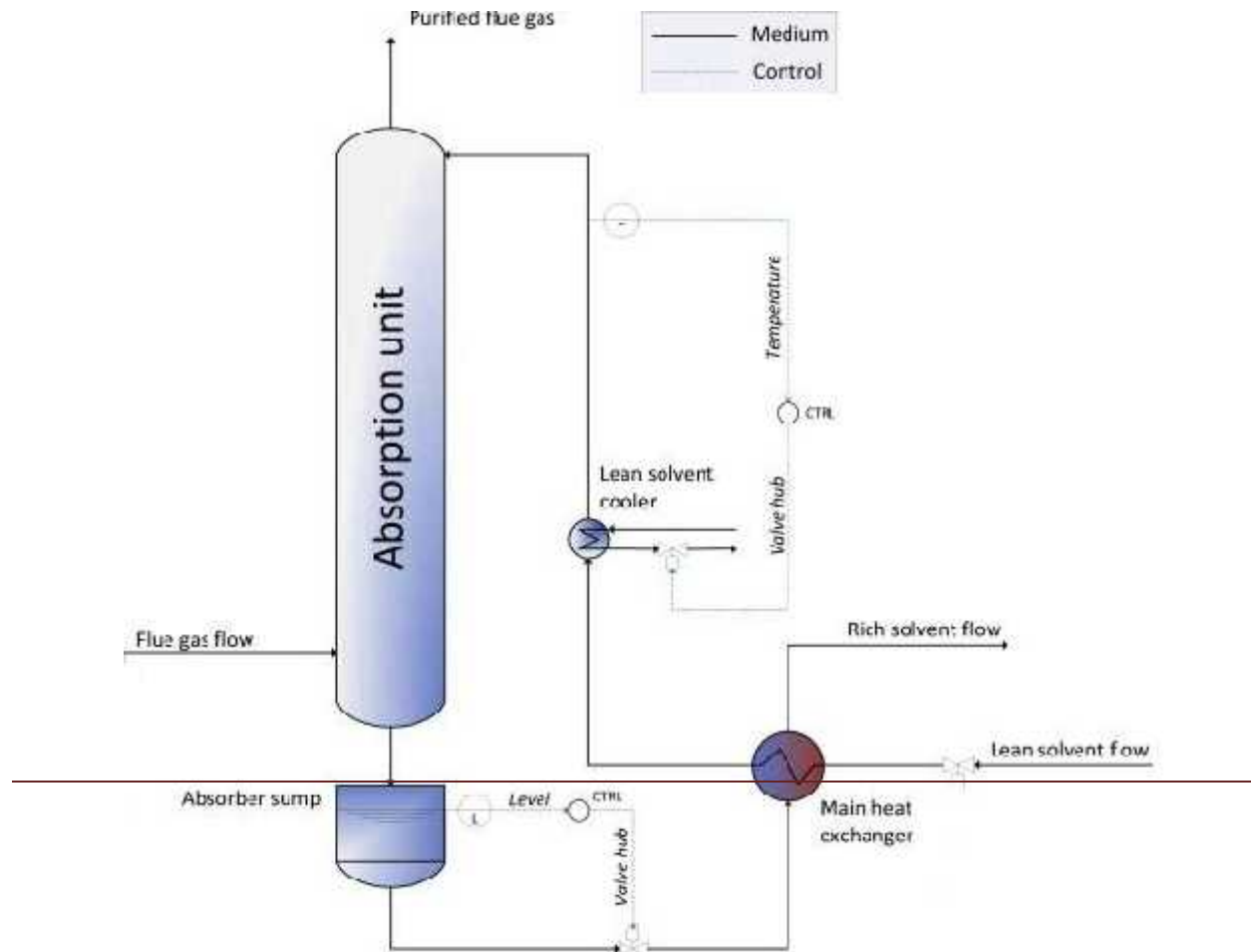
Selection of solvent for absorption and stripping

Gas Solubility: High solubility of a gas in the solvent is preferred, utilizing low quantity of solvent. Absorbent should not dissolve carrier gas. Similar chemical nature of solute and absorbent (solvent) gives a good solubility. If chemical reaction takes place between solute and solvent, rate of absorption is extremely high. But the reaction should be reversible to recover solvent during desorption.

Volatility: Low volatility or low vapor pressure of the solvent enhances the adsorption operation as solvent loss with carrier gas is very small. Sometimes, a second less volatile solvent is used to recover the first solvent.

Viscosity: For better absorption, a solvent of low viscosity is required. In mechanically agitated absorber, greater amount of power is required for high viscous solvent and flooding is also caused at lower liquid and gas flow rates.

Corrosiveness: Non-corrosive or less corrosive solvent reduces equipment construction cost as well as maintenance cost.

Cost: The solvent should be cheap so that losses will be insignificant and should be easily available.

Toxicity and Hazard: The solvent should be non-toxic, non-flammable, non-hazardous and should be chemically stable.

Types of Absorbers

Tray column

Packed column

Packing Materials

Packing materials are utilized to provide large interfacial area of contact between two phases. These are made from either of ceramics, metals or plastics. A number of packing materials with various size, shape and performance are available. These are classified into three types, namely, **dumped or random**, **structured** and **grid**.

The packing materials have following characteristics:

Cost: The cost of the packing materials should be very low.

Surface area: A large interfacial area of contact is always recommended. In that case, pressure drop will be more.

Void volume: A high void volume is needed to maintain low pressure drop.

Fouling resistance: Packing materials should not trap suspended solids present in liquid. Bigger packing materials generally give low fouling resistance.

Mechanical strength: Good mechanical strength is desired for choosing packing materials as this will not break or deform during filling or operation.

Uniform flow of streams: Stack of packing materials should have uniform void spaces through which both the streams (gas and liquid) can flow uniformly. Nonuniform flow of streams leads to stagnant liquid pool which in turn gives low mass transfer.

(a) Raschig rings;   (b) Lessing rings and modified Raschig rings (Cross-partition rings)   (c) Berl saddle

(a) Intalox saddle and modification   (b) Pall ring and modification

(a) Intalox Metal Tower Packing (IMTP)

(b) Nutter ring

(c) Cascade Mini-Ring (CMR)

(d) Jaeger Tripac

(e) Koch Flexisaddle   (f) Nor-Pac   (g) Hiflow ring

Structured Packing's

These materials are used widely as packing materials in packed tower due to low gas pressure drop and improved efficiency. Corrugated metal sheet structured packing and Wire mesh structured packing materials are widely used in the industries.

Mellapak

Flexipak

Montez Corrugated metal sheet

Wire mesh packing

Design of packed tower based on overall mass transfer Coefficient

From overall mass transfer equation, $N_A = K_y(y_{AG} - y_A^*)$ one can write for packed tower as

$N_A = K_y(y-y^*)$

Then,

$$dh = -\frac{G'dy}{K_y \bar{a}(1-y)(y-y^*)}$$

where, y^* is solute concentration in gas phase that is capable of remaining in equilibrium with a liquid having a bulk concentration of x.

Therefore,

where, y^* is solute concentration in gas phase that is capable of remaining in equilibrium with a liquid having a bulk concentration of x.

Therefore,

$$h_T = \int_0^{h_T} dh = \int_{y_2}^{y_1} \frac{G' dy}{K_y \bar{a}(1-y)(y-y^*)}$$

$$= \int_{y_2}^{y_1} \frac{G' dy}{k_G \bar{a} P (1-y)(y-y_i)}$$

$$= \int_{x_2}^{x_1} \frac{L' dx}{k_L \bar{a}(C_{av})(1-x)(x_i-x)}$$

Graphical integration of right hand side of Equation (4.11):

Operating line AB is drawn in xy plane. Any point (x,y) is taken in operating line. A vertical line is drawn upto equilibrium line to get y^*.

$$h_T = \int_{x_2}^{x_1} \frac{L' dx}{K_x \bar{a}(1-x)(x^*-x)} = \int_{y_2}^{y_1} \frac{G' dy}{K_G \bar{a} P (1-y)(y-y^*)} = \int_{x_2}^{x_1} \frac{L' dx}{k_L \bar{a}(C_{av})(1-x)(x^*-x)}$$

Equation 4.7 can be written as

$$h_T = \int_0^{h_T} dh = \int_{y_2}^{y_1} \frac{G' y_{iBM} \, dy}{k_y \bar{a} \, y_{iBM} (1-y)(y-y_i)} = \int_{y_2}^{y_1} \frac{G' (1-y)_{iM} \, dy}{k_y \bar{a} (1-y)_{iM} (1-y)(y-y_i)}$$

where, $y_{iBM} = (1-y)_{iM} = \dfrac{(1-y_i)-(1-y)}{\ln \frac{(1-y_i)}{(1-y)}}$

$$h_T = \frac{G'}{k_y \bar{a}(1-y)_{iM}} \int_{y_2}^{y_1} \frac{(1-y)_{iM} \, dy}{(1-y)(y-y_i)}$$

As, $\dfrac{G'}{k_y \bar{a}(1-y)_{iM}}$ remains constant at the packing section though G' varies. This quantity is called 'height if transfer units' (HTU) and designated as H_{tG}. It is important to measure the separation effectiveness of the particular packings for a particular separation process. It also describes the mass transfer coefficient. Larger mass transfer coefficient leads to the smaller value of HTU.

Hence,

$$H_{tG} = \frac{G^{/}}{k_y\bar{a}\,(1-y)_{iM}} = \frac{G^{/}}{k_y^{/}\bar{a}}$$

The integral part of Equation (4.14) is called number of gas phase transfer units as N_{tG}.

$$h_T = H_{tG} \times N_{tG}$$

When overall gas phase mass transfer coefficients are used, the height of the packing is as follows:

$$h_T = \int_{y2}^{y1}\frac{G^{/}\,dy}{K_y\bar{a}\,y_{BM}^{*}(1-y)(y-y^{*})} = \frac{G^{/}}{K_y\bar{a}\,y_{BM}^{*}}\int_{y2}^{y1}\frac{dy}{(1-y)(y-y^{*})} = H_{toG} \times N_{toG}$$

where, $H_{toG} = \dfrac{G^{/}}{K_y\bar{a}\,y_{BM}^{*}}$, $N_{toG} = \displaystyle\int_{y2}^{y1}\frac{dy}{(1-y)(y-y^{*})}$ and $y_{BM}^{*} = (1-y)_{BM}^{*} = \dfrac{(1-y^{*})-(1-y)}{ln\frac{(1-y^{*})}{(1-y)}}$.

Define NTU

Height of Packing (Z) = NTU x HTU

Where,

NTU = number of transfer units – dimensionless

HTU = height of transfer units - dimension of length

The number of transfer units (NTU) required is a measure of the difficulty of the separation. A single transfer unit gives the change of composition of one of the phases equal to the average driving force producing the change. The NTU is similar to the number of theoretical trays required for tray column. Hence, a larger number of transfer units will be required for a very high purity product.

Height Equivalent to Theoretical Plate (HETP)

For a specified separation job, in packed tower, the height of packing is to be determined and in tray tower, numbers of ideal trays are determined. The ratio between packing height to number of trays required for the same separation is called height equivalent to theoretical plate (HETP).

$$HETP = \frac{h_T}{N_T} = \frac{Height\ of\ packing}{Number\ of\ ideal\ trays}$$

Height of packing (Z) = HETP x Number of trays

HETP varies with size and type of packing, flow rate of gas and liquid, concentration of solute, physical and transport properties as well as equilibrium relationship and uniformity of liquid and gas distribution. HETP is used to characterize the packing. A good packing has small HETP.

Absorption Factor

Where A is absorption factor and is defined as $A = L/(mG)$.

Henry's Law

A law stating that the mass of a dissolved gas in a given volume of solvent at equilibrium is proportional to the partial pressure of the gas

Stripping or Desorption

Mass transfer occurs from liquid to gas phase.

The solute is removed from the liquid solution by contacting with gas.

Single stage counter current Unit

G_1, G_2 : molar flow rates of entering and leaving gas

G_S: molar flow rate of inert gas

L_1, L_2 are the molar flow rates of leaving and entering liquid

L_S is the molar flow rate of pure solvent
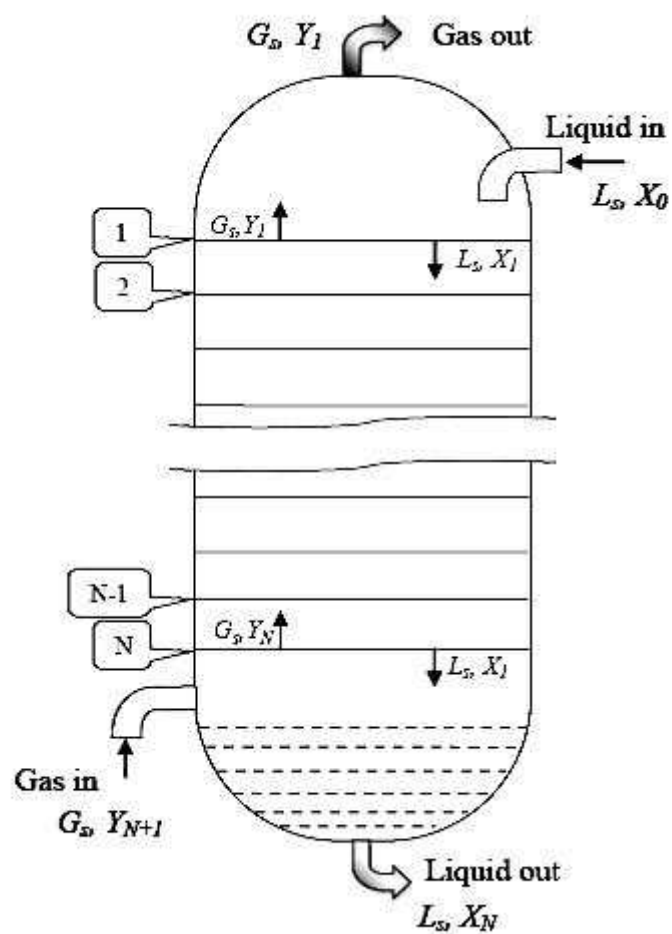
X,Y are the mole ratios of solute to **inert component** in liquid and gas phase respectively x,y are the mole ratio of solute in liquid and gas phases

Making Material Balance

STEP-BY-STEP PROCEDURE

(1) For a particular gas-liquid system, draw equilibrium curve on X-Y plane.

(2) Draw operating line in X-Y plane (PQ) using material balance Equation. Lower terminal Q (X2, Y2) and upper terminal P (X1, Y1) are placed in x-y plane.

Making Material Balance

If liquid mass flow rate, Ls is not known, minimum liquid mass flow rate (Ls)min is to be determined. Ls is generally 1.2 to 2 times the (Ls)min.
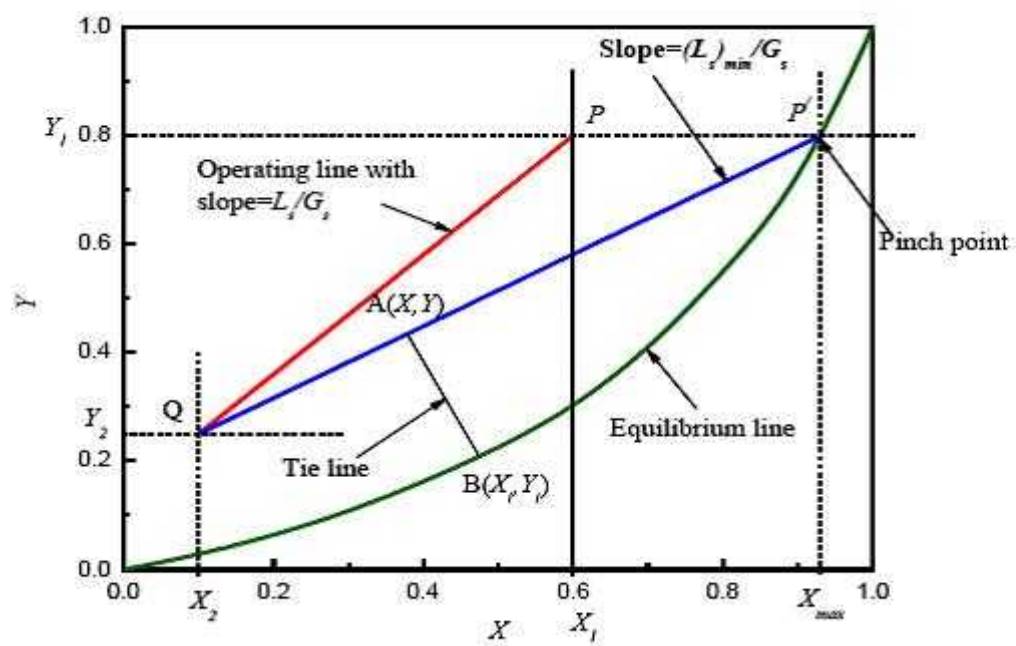
The following parameters should be known for the determination of "number of stages" (1) Gas feed rate, (2) Concentration of gas at inlet and outlet of the tower, (3) Minimum liquid rate; actual liquid rate is 1.2 to 2 times the minimum liquid rate, (4) Equilibrium data for construction of equilibrium curve now,
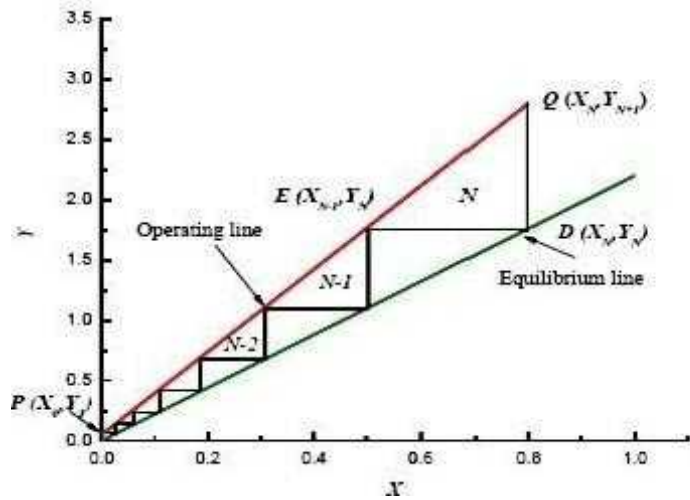

$$Z = \text{No of trays} \times \text{HETP}$$

Example

A gas stream containing 90 mol% N_2 and 10% CO_2 is passed through an absorber, in which pure and cool water at 5°C is used as a solvent The operation is assumed to be isothermal at 5 o C and isobaric at 10 atm The liquid flow rate is 1.5 times the minimum liquid flow rate Determine the number of equilibrium stages required to absorb 92 mol% of CO_2 Given Henry's constant of CO_2 in water at 5°C of 876 atm/mole fraction.

=

the equilibrium or the y-x data can be computed

X   0 0.0001 0.0004 0.0006 0.0008 0.0010 0.0012

Y   0 0.00884 0.0363 0.0555 0.0754 0.0960 0.1175
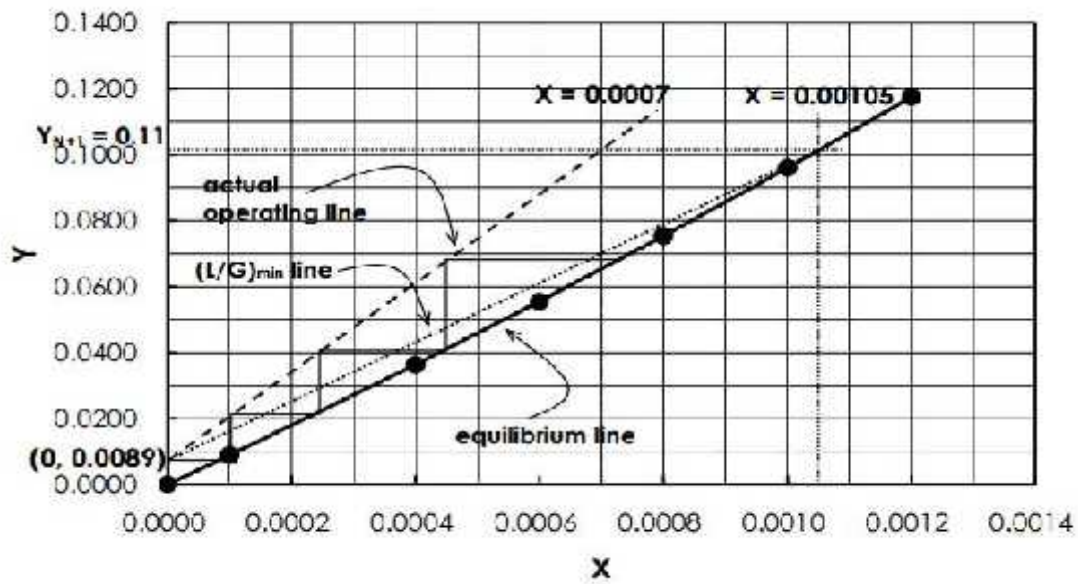
The slope of the min L/G minimum is found to be 97.2

Hence, the slope of the actual operating line is 1.5 times of minimum = 1.5 x 97.2 = 145. 8

$X_1 = 0.0007$

Yields the number of equilibrium stages of ~3.8 = 4

4.1 Pressure vessel

Self supporting tall equipments are widely used in chemical process industries. Tall vessels may or may not be designed to be self supporting. Distillation column, fractionating columns, absorption tower, multistage reactor, stacks, chimneys etc. comes under the category of tall vertical vessels. In earlier times high structure (i.e. tall vessels) were supported or stabilized by the use of guy wires. Design of self supporting vertical vessels is a relatively recent concept in equipment design and it has been widely accepted in the chemical industries because it is uneconomical to allocate valuable space for the wires of guyed towers. In these units ratio of height to diameter is considerably large due to that these units are often erected in the open space, rendering them to wind action. Many of the units are provided with insulation, number of attachments, piping system etc. For example distillation and absorption towers are associated with a set of auxiliary equipments i.e. reboiler, condenser, feed preheater, cooler and also consists of a series of internal accessories such as plates or trays or variety of packings. Often the vertical vessels/columns are operated under severe conditions, and type of the material these columns handles during operation may be toxic, inflammable or hazardous in other ways. Structural failure is a serious concern with this type of columns. As a result the, the prediction of membrane stresses due to internal or external pressure will not be sufficient to design such vessels. Therefore, special considerations are necessary to take into account and predict the stresses induced due to dead weight, action of wind and seismic forces.

4.2. STRESSES IN THE SHELL

Primarily the stresses in the wall of a tall vessel are: a) circumferential stress, radial stress and axial stress due to internal pressure or vacuum in the vessel, b) compressive stress caused by dead load such as self weight of the vessel including insulation, attached equipments and weight of the contents.

Dead load is the weight of a structure itself, including the weight of fixtures or equipment permanently attached to it; *Live load* is moving or movable external load on a structure. This includes the weight of furnishing of building, of the people, of equipment etc. but doesn¨t include wind load. If the vessels are located in open, it is important to note that wind load also act over the vessel. Under wind load, the column acts as cantilever beam as shown (Figure 6.1). Therefore while designing the vessel stresses induced due to different parameters have to be considered such as i) compressive and tensile stress

induced due to bending moment caused by wind load acting on the vessel and its attachments; ii) stress induced due to eccentric and irregular load distributions from piping, platforms etc. iii) stress induced due to torque about longitudinal axis resulting from offset piping and wind loads and iv) stress resulting from seismic forces. Apart from that, always there are some residual stresses resulting due to methods of fabrication used like cold forming, bending, cutting, welding etc.
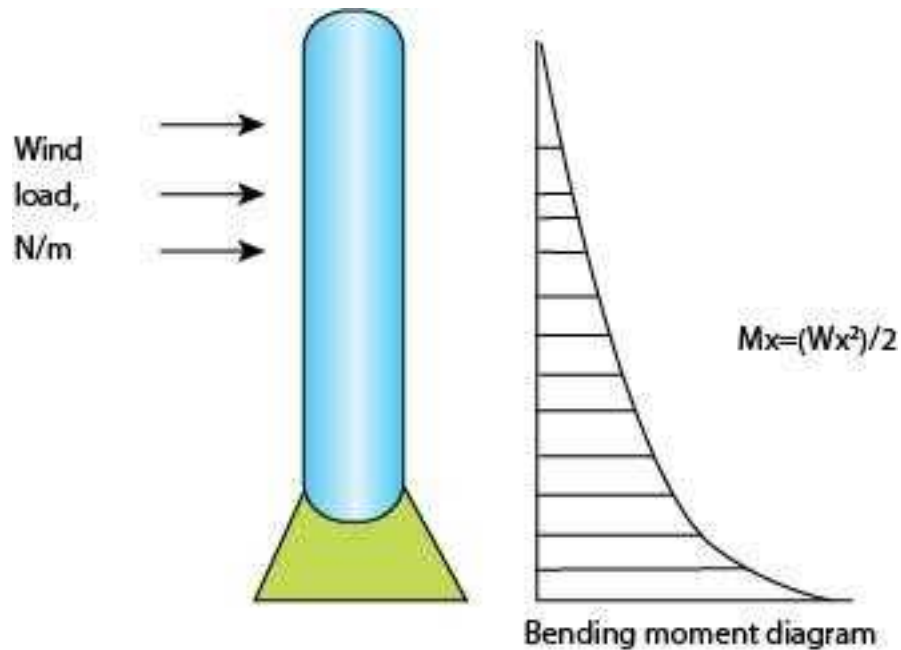
4.3. AXIAL AND CIRCUMFERENTIAL PRESSURE STRESSES

Tensile stresses resulting from internal pressure

The simple equation may be derived to determine the axial and circumferential stresses due to internal pressure in the shell of a closed vessel. Figure (6.2a) shows a diagram representing a thin walled cylindrical vessel in which a unit form stress, *f*, may be assumed to occur in the wall as a result of internal pressure.

Where, l = length, inches

d = inside diameter, inches

t = thickness of shell, inches and p = internal pressure, pounds/square inch gage

Longitudinal stress: In case of longitudinal stress, if the analysis limits to pressure stresses only, the longitudinal force, *P*, resulting from an internal pressure, *p*, acting on a thin cylinder of thickness *t*, length *l*, and diameter *d* is:

$$P \quad = \quad \text{force tending to rupture vessel}$$

$$= \quad (p \, \pi \, d^2)/4$$

area of metal resisting longitudinal rupture

$$= \quad t \, \pi \, d$$

Therefore

$$f \quad = \quad stress$$

$$\frac{p\pi d^2/4}{t\pi d} = \frac{pd}{4t} = \text{induced stress, pounds per square inch}$$

or

$$t = \frac{p\,d}{4\,f}$$
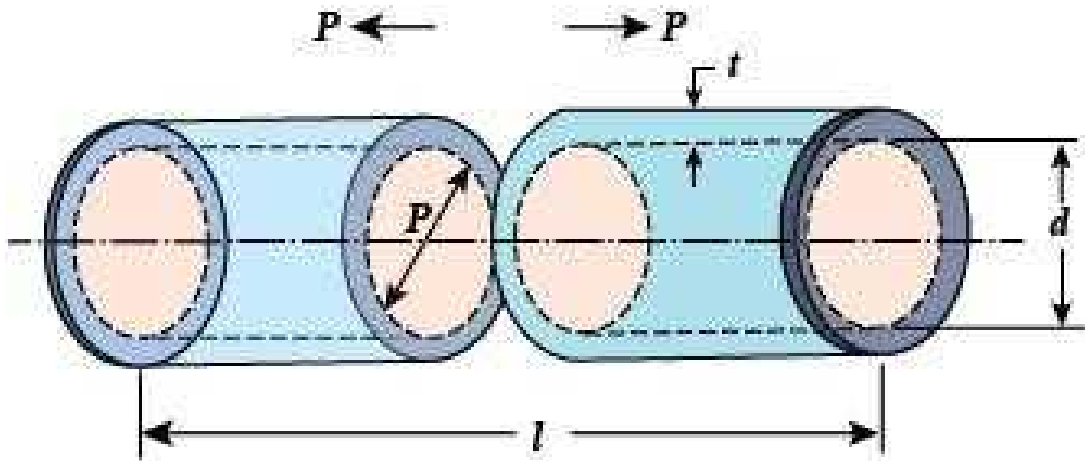
Figure Longitudinal forces acting on thin cylinder (internal pressure)

Circumferential stresses: Figshows the circumferential force acting on the thin cylinder under internal pressure. The following analysis may be developed, if one considers the circumferential stresses are induced by the internal pressure only.

P   =   force tending to rupture vessel circumferentially = $p \times d \times l$

a   =   area of metal resisting force = $2 \times t \times l$

f =   stress = $\dfrac{P}{a} = \dfrac{pdl}{2tl} = \dfrac{pd}{2t}$

or $t = \dfrac{pd}{2f}$
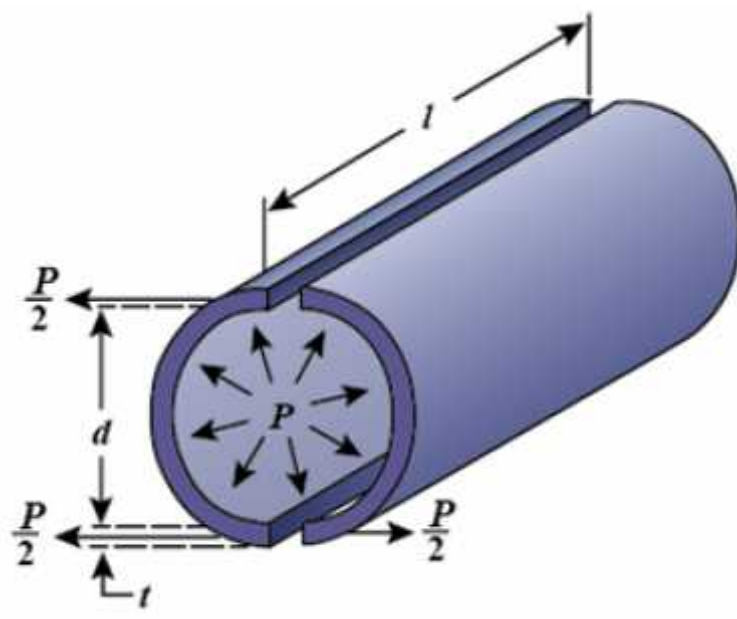
Figure 6.2b: Circumferential forces acting on thin cylinder (internal pressure)

Equation 6.1 and 6.2 indicates that for a specific allowable stress, fixed diameter and given pressure, the thickness required to restrain the pressure for the condition of eq. (6.2) is double than that of the equation (6.1). Therefore, the thickness as determined by equation (6.2) is controlling and is the commonly used thin walled equation referred to in the various codes for vessels. The thickness of metal, c, allowed for any anticipated corrosion is then added to the calculated required thickness, and the final thickness value rounded off to the nearest nominal plate size of equal or greater thickness.

Equation (6.1) and (6.2) rewritten based on the foregoing discussion as

$$t = \frac{p\,d}{4\,f\,j} + c \qquad (6.3)$$

$$t = \frac{p\,d}{2\,f\,j} + c \qquad (6.4)$$

Where,   t = thickness of shell, inches

p = internal pressure, pounds per square inch

d = inside diameter, inches

f = allowable working stress, pounds per square inch

E = joint efficiency, dimensionless

c = corrosion allowance, inches

4.4. COMPRESSIVE STRESS CAUSED BY DEAD LOADS

The major sources of the load acting over tall vertical vessel are the weight of the vessel shell and weight of the vessel fittings which includes the internal, external and auxiliary attachments. Internal fittings: trays, packing, heating and cooling coils. External fittings: platforms, piping, insulation, ladders. Auxiliary attachments: instruments, condenser etc. Therefore, Stresses caused by dead loads may be considered in three groups for convenience: (a) stress induced by shell and insulation (b) stress induced by liquid in vessel (c) stress induced by the attached equipment.

Stress induced by shell and insulation: Stress due to weight of shell and insulation at any distance, X from the top of a vessel having a constant shell thickness,

$$W_{shell} = \frac{\pi}{4}\left(D_o^{\,2} - D_i^{\,2}\right) \times \rho_s \times X \qquad (6.5)$$

Where, W = weight of shell above point X from top

D_0 & D_i = outside and inside diameter of shell

X = distance measured from the top of the vessel

ρ_s = density of shell material,

stress due to weight of insulation at height „X"

$$W_{insulation} = \pi \ D_{ins} \times \rho_{ins} \times X \times \ t_{ins} \tag{6.6}$$

Where, W_{ins} = weight of insulation

D_{ins} = mean diameter of insulation

X = height measured from the top of the
column t_{ins} = thickness of insulation

ρ_{ins} = density of insulation

Compressive stress is force per unit area,

$$f_{d_{wt \ shell}} = \frac{\pi/4 \times (D_o^2 - D_i^2) \times X \times \rho_s}{\pi/4(D_o^2 - D_i^2)} = \ X\rho_s \tag{6.7}$$

Similarly, the stress due to dead weight of the insulation is:

$$f_{d_{wt \ ins}} = \frac{\pi \times (D \ \rho t)_{ins} \ X}{\pi \ D_m \ t_s} \tag{6.8}$$

D_m = mean diameter of shell ($D_m = (D_o + D_i)/2$)
$D_{ins} \ D_m$ = diameter of insulated vessel

t_s = thickness of shell without corrosion allowance

Therefore,

$$f_{d_{wt \ ins}} = \frac{\rho_{ins} \ t_{ins} \ X}{t_s} \tag{6.9}$$

Stress induced due to liquid retained in column. It will be depend upon internal e.g. in tray column, total number of plates, hold up over each tray, liquid held up in the down comer etc. will give the total liquid contents of the column.

$$f_{d_{liquid}} = \frac{\sum W_{liquid}}{\pi \, D_m t_s} \qquad (6.10)$$

D_m = mean diameter of vessel, feet t_s = thickness of shell without corrosion allowance

Stress induced by the attachment, like trays, over head condenser, instruments, platform, ladders etc.

$$f_{d_{attachments}} = \sum \frac{W_{attachments}}{\pi \, D_m t_s} \qquad (6.11)$$

The total dead load stress, f_{total}, acting along the longitudinal axis of the shell is then the sum of the above dead weight stresses.

$$f_{total} = f_{dead\ wt\ shell} + f_{dead\ wt\ ins} + f_{dead\ wt\ liq} + f_{dead\ wt\ attach.}$$

4.5. AXIAL STRESSES DUE TO PRESSURS

The stress due to wind load may be calculated by treating the vessel as uniformly loaded cantilever beam. The wind loading is a function of wind velocity, air density and shape of tower.

The wind load on the vessel is given by

$$P_w = \tfrac{1}{2} \times C_D \times \rho \times V^2_w \times A \qquad (6.13)$$

Where,

C_D = drag coefficient

ρ = density of air

V_w = wind velocity

A = projected area normal to the direction of wind

If wind velocity is known approximate wind pressure can be computed from the following simplified relationship.

$$P_w = 0.05 \; V^2_w \qquad (6.14)$$

P_w = min wind pressure to be used form moment calculation, N/m^2

V_w = max wind velocity experienced by the region under worst weather condition, km/h

Wind velocity varies with height. This can be observed from the figure shown below (Figure 6.3). The velocity of wind near the ground is less than that away from it. Therefore, to take into account this factor a variable wind force may be taken. It is recommended to calculate the wind load in two parts, because the wind pressure does not remain constant through the height of the tall vessel. Say for example in case of vessel taller than 20 m height, it is suggested that the wind load may be determined separately for the bottom part of the vessel having height equal to 20 m, and then for rest of the upper part.

Load due to wind acting in the bottom portion of the
vessel. $P_{bw} = K_1 K_2 p_1 h_1 D_o$

Where,

P_{bw} – total force due to wind load acting on the bottom part of the vessel with
height equal to or less than 20 m.

D_o - outer diameter of the vessel including the insulation thickness

h_1 – height of the bottom part of the vessel equal to or less than 20 m

K_1 – coefficient depending upon the shape factor (i.e. 1.4 for flat plate; 0.7 for cylindrical
surface)
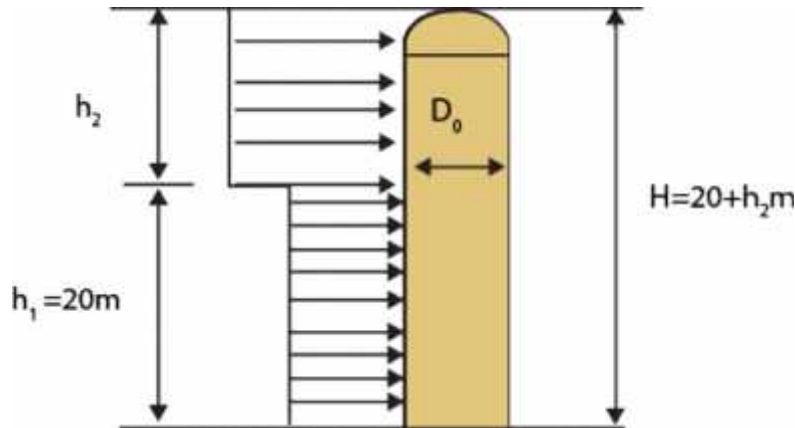
Figure 6.3: Tall column subjected to wind pressure

Load due to wind acting in the upper portion of the
vessel. $P_{uw} = = K_1 K_2 p_2 h_2 D_o$

Where,

P_{uw} – total force due to wind load acting on the upper part above 20
m. D_o - outer diameter of the vessel including the insulation thickness

h_2 – height of the upper part of the vessel above 20 m

K_2 – coefficient depending upon the period of one cycle of vibration of the vessel

(K_2 = 1, if period of vibration is 0.5 seconds or less; K_2 = 2, if period exceeds 0.5
seconds)

Stress due to bending moment: Stress induced due to bending moment in the
axial direction is determined from the following equations.

(i) $M_w = P_{bw} h_1/2$; $h_1 \le 20m$

(ii) $M_w = P_{bw} h_1/2 + P_{uw} (h_1 + h_2/2)$; $h_1 > 20m$

Therefore, the bending stress due to wind load in the axial direction

$$f_w = \frac{4 M_w}{\pi t (D_i}$$ (6.15)

4.6. THE STRESS RESULTING FROM SEISMIC LOADS

The seismic load is assumed to be distributed in a triangular fashion, minimum at the base of the column and maximum at the top of the column. It is a vibrational load, it produces horizontal shear in self supported tall vertical vessel (Figure 6.4).
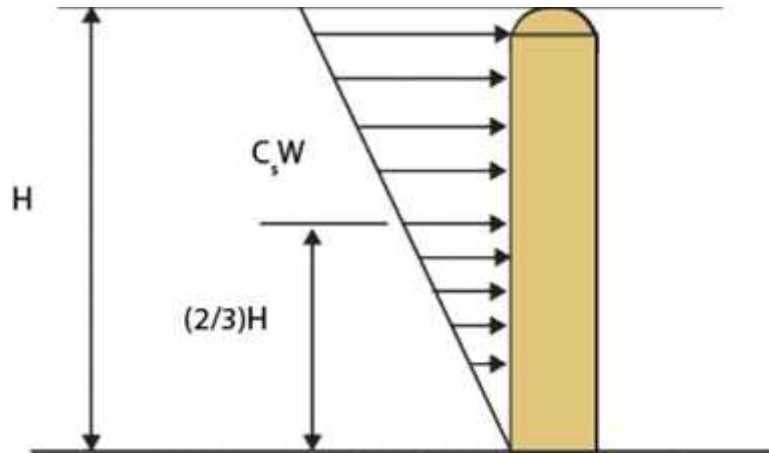
Figure 6.4a: Seismic forces on tall column

$+ t) D_i$
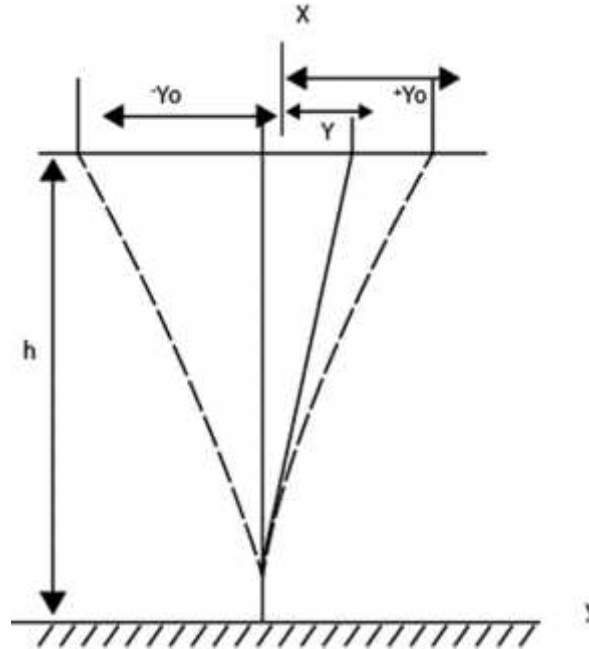
Figure 6.4b: Seismic forces on tall column

The load may, therefore be considered as acting at a distance 2/3 from the bottom of the vessel.

$$\text{Load, } F = S_c W \qquad (6.16)$$

Where, W = weight of the vessel

S_c = seismic coefficient

Seismic coefficient depends on the intensity and period of vibrations. For example if the vibration lasts for more than one second seismic coefficient value varies from minimum, moderate to maximum S_c = 0.02, 0.04, and 0.08 respectively.

Stress induced due to bending moment up to height X from the top of the column is given by:

$$M_{sX} = \frac{S_c W X^2}{3} \times \frac{(3H - X)}{H^2} \qquad (6.17)$$

Where X = H, maximum bending moment is at the base of column

$$M_{sb} = 2/3 \times S_c W H \qquad (6.18)$$

The resulting bending stress due to seismic bending moment is given by:

$$f_{sb} = \frac{4 M_{sX}}{\pi D_0^2 t} \qquad (6.19)$$

The maximum bending moment is located at the base of the vessel (X = H). Thus substituting H for X in Eq. (6.17)

$$f_{sb} = 4 \times \frac{\frac{Sc\,W\,H^2}{3} \times \overline{(3H-H)}}{H^2 \pi D^2 t} \qquad (6.20)$$

o

$$f_{sb} = \frac{2\,Sc\,W\,H}{3\pi R^2 t} \qquad (6.21)$$

The possibility of the wind load and seismic load acting simultaneously over the column is rare. So both the loads are computed separately and whichever is more severe is used to calculate the maximum resultant stress.

Maximum tensile stress at the bottom of the
skirt $f_{tensile} = (f_{wb}$ or $f_{sb}) - f_{db}$

Maximum compressive stress on the
skirt

$f_{compressive} = (f_{wb}$ or $f_{sb}) + f_{db}$,   here, f_{db} - *dead load stress*

Taking into account the complexity of the final equation for maximum stresses, it is customary to assume a suitable thickness „t" of the skirt and check for the maximum stresses, which should be less than the permissible stress value of the material.

4.7 STORAGE TANKS

Storage tanks containing organic liquids, non organic liquids, vapors and can be found in many industries.

Types of storage tanks

BASICALLY THERE ARE EIGHT TYPES OF TANKS USED TO STORE LIQUIDS:

1. Fixed-roof tanks
2. External floating roof tanks
3. Internal floating roof tanks
4. Domed external floating roof tanks
5. Horizontal tanks
6. Pressure tanks
7. Variable vapor space tanks
8. LNG (Liquefied Natural Gas) tanks

Fixed Roof Tanks

- A fixed roof tank is the least expensive kind of storage tank consisting of a cylindrical shaped frame with a fixed roof that is cone or dome shaped.
- A breather valve is installed in the tank that releases the excess vapor during slight variations of temperature and liquid levels.

External Cone Roof

Roof Seal

Floating Roof
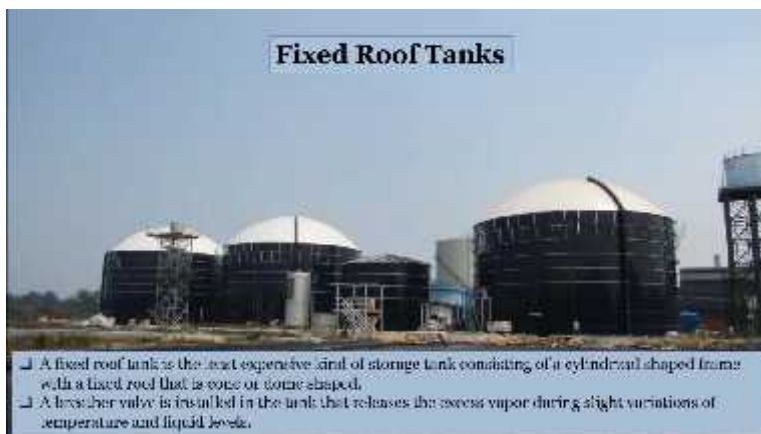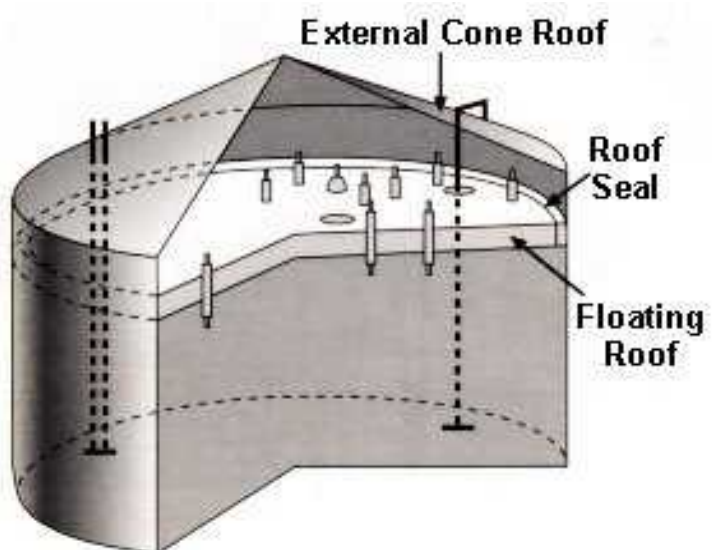
Filtration

          Water filtration is a mechanical or physical process of separating suspended and colloidal particles from fluids (liquids or gases) by interposing a medium through which only the fluid can pass. Medium used is generally a granular material through which water is passed. In the conventional water treatment process, filtration usually follows coagulation, flocculation, and sedimentation. During filtration in a conventional down-flow depth filter, wastewater containing suspended matter is applied to the top of the filter bed. As the water passes through the filter bed, the suspended matter in the wastewater is removed by a variety of removal mechanisms. With passage of time, as material accumulates within the interstices of the granular medium, the head-loss through the filter starts to build up beyond the initial value. After some period of time, the operating head-loss or effluent turbidity reaches a predetermined head loss or turbidity value, and the filter must be cleaned (backwashed) to remove the material (suspended solids) that has accumulated within the granular filter bed. Backwashing is accomplished by reversing the flow through the filter. A sufficient flow of wash water is applied until the granular filtering medium is fluidized (expanded), causing the particles of the filtering medium to abrade against each other. Filtration is classified into following three types [1]:

Depth filtration

          Slow sand filtration

          Rapid porous and compressible medium filtration

          Intermittent porous medium filtration

          Recirculating porous medium filtration

Surface filtration

          Laboratory filters used for TSS test

          Diatomaceous earth filtration

          Cloth or screen filtration

Membrane flirtation

5.2 TYPES OF FILTRATION

DEPTH FILTRATION

          In this method, the removal of suspended particulate material from liquid slurry is done by passing the liquid through a filter bed composed of granular or compressible filter medium.

Depth filtration is the solid/liquid separation process in which a dilute suspension or wastewater is passed through a packed bed of sand, anthracite, or other granular media. Solids (particles) get attached to the media or to the previously retained particles and are removed from the fluid. This method is virtually used everywhere in the treatment of surface waters for potable water supply. Depth filtration is also often successfully used as a tertiary treatment for wastewater. Failure of depth filtration affects the other downstream processes significantly and most of the times results in overall plant failure. Performance of a filter is quantified by particle removal efficiency and head loss across the packed bed. The duration of a filter run is limited by numerous constraints: available head, effluent quality or flow requirement. The head loss and removal efficiency of a filter are complicated functions of suspension qualities (particle size distribution and concentration, particle surface chemistry, and solution chemistry), filter design parameters (media size, type, and depth), and operating conditions (filtration rate and filter runtime) [2].

Slow sand filtration (SSF):

It is very effective for removing flocs containing microorganisms such as algae, bacteria, virus, etc. Slow sand filtration (SSF), with flow rates ranging between 0.1 and 0.2 $m^3 h^{-1}$, has been a standard biofiltration treatment for decades in the wastewater industry.

Rapid sand filtration (RSF)

The major difference between SSF and RSF is in the principle of operation; that is, in the speed or rate at which water passes through the media. In Rapid sand filtration (RSF), water passes downward through a sand bed that removes the suspended particles. RSF is used today as an effective pretreatment procedure to enhance water quality prior to reverse osmosis (RO) membranes in desalination plants.

SURFACE FILTRATION

Surface filtration involves removal of suspended material in a liquid by mechanical sieving. In this method, the liquid is passed through a thin septum (i.e., filter material). Materials that have been used as filter septum include woven metal fabrics, cloth fabrics of different weaves, and a variety of synthetic materials.

MEMBRANE FILTRATION

Membrane filtration can be broadly defined as a separation process that uses semi-permeable

membrane to divide the feed stream into two portions: a permeate that contains the material passing through the membranes, and a retentate consisting of the species being left behind. Membrane filtration can be further classified in terms of the size range of permeating species, the mechanisms of rejection, the driving forces employed, the chemical structure and composition of membranes, and the geometry of construction. The most important types of membrane filtration are pressure driven processes including microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO).

MECHANISMS INVOLVED IN THE FILTRATION PROCESSES

The process of filtration involves several mechanisms listed in the table. Straining has been identified as the principal mechanism that is operative in the removal of suspended solids during the filtration of settled secondary effluent from biological treatment processes. Other mechanisms including impaction, interception, and adhesion are also operative even though their effects are small and, for the most part, masked by the straining action.

Table 1 Mechanisms involved in the filtration processes

Mechanism/ phenomenon	Description
Straining a) Mechanical b) Chance contact	Particles larger than the pore space of the filtering medium are strained out mechanically. Particles smaller than the pore space are trapped within the filter by chance contact
Sedimentation	Particles settle on the filtering medium within the filter
Impaction	Heavy particles do not follow the flow streamlines
Interception	Particles get removed during contact with the surface of the filtering medium
Adhesion	Particles become attached to the surface of the filtering medium as they pass through.
Flocculation	It can occur within the interstices of the filter medium.
Chemical adsorption a) Bonding	Once a particle has been brought in contact with the surface of the filtering medium or with other particles, either one of these

b) Chemical interaction	mechanisms, chemical or physical adsorption or both, may occur.

Physical adsorption
  a) Electrostatic forces
  b) Electrokinetic forces	

Biological growth	Biological growth within the filter reduces the pore volume and enhances the removal of particles with any of the above removal mechanisms

5.3 FILTER-MEDIUM CHARACTERISTICS

Grain size is the principle filter-medium characteristic that affects the filtration operation. Grain size affects both the clear-water head loss and the buildup of head loss during the filter run. If too small a filtering medium is selected, much of the driving force will be wasted in overcoming the frictional resistance of the filter bed. On the other hand, if the size of the medium is too large, many of the small particles in the influent will pass directly through the bed. The size distribution of the filter material is usually determined by sieve analysis using a series of decreasing sieve sizes.

5.4 CLASSIFICATION OF FILTERS

Filters that must be taken off-line periodically to be backwashed are classified operationally as semi-continuous. Filters in which is filtration and backwash operations occur simultaneously are classified as continuous. Within each of these two classifications, there are a number of different types of filters depending on bed depth (e.g., shallow, conventional, and deep bed), the type filtering medium used (mono-, dual-, and multi-medium), whether the filtering medium is stratified or unstratified, the type of operation (down-flow or upflow), and the method used for the management of solids (surface or internal storage). For the mono- and dual-medium semi-continuous filters, a further classification can be made based on the driving force (e.g., gravity or pressure).

5.5 TYPES OF DEPTH FILTERS

The five types of depth filters used most commonly for wastewater filtration are

(a) Conventional down-flow filters: Single-, dual-, or multimedium filter materials are utilized in conventional down-flow depth filters. Typically sand or anthracite is used as the filtering material in single-medium filters. Dual-medium filters usually consist of a layer

anthracite over a layer of sand. Dual- and multimedium and deep-bed mono-medium depth filters were developed to allow the suspended solids in the liquid to be filtered to penetrate farther into the filter bed, and thus use more of the solids-storage capacity available within the filter bed.

(b) Deep-bed down-flow filters: The deep-bed down-flow filter is similar to the conventional down-flow filter with the exception that the depth of the filter bed and the size of the filter medium are greater than corresponding values an conventional filter. Because of the greater depth and larger medium size, more solids can be stored within the filter bed and the run length can be extended.

(c) **Deep-bed upflow continuous-backwash filters:** In this filter the wastewater to be filtered is introduced into the bottom of the filter where it flows upward through a series of riser tubes and is distributed evenly into the sand bed through the open bottom of an inlet distribution hood. The water then flows upward through the downward-moving sand. The clean filtrate exits from the sand bed, overflows a weir, and is discharged from the filter. Because the sand has higher settling velocity than the removed solids, the sand is not carried out of the filter.

(d) Pulsed-bed filter: The pulsed-bed filter is a proprietary down-flow gravity filter with an unstratified shallow layer of fine sand as the filtering medium. The shallow bed is used for solids storage, as opposed to other shallow-bed filters where solids are principally stored on the sand surface. An unusual feature of this filter is the use of an air pulse to disrupt the sand surface and thus allow penetration of suspended solids into the bed.

5.6 CYCOLNE SEPARATOR

Cyclone separators provide a method of removing particulate matter from air or other gas streams at low cost and low maintenance. Cyclones are somewhat more complicated in design than simple gravity settling systems, and their removal efficiency is much better than that of settling chamber. Cyclones are basically centrifugal separators, consists of an upper cylindrical part referred to as the barrel and a lower conical part referred to as cone (figure). They simply transform the inertia force of gas particle flows to a centrifugal force by means of a vortex generated in the cyclone body. The particle laden air stream enters tangentially at the top of the barrel and travels downward into the cone forming an outer vortex. The increasing air velocity in the outer vortex results in a centrifugal force on the particles separating them from the air stream. When the air reaches the bottom of the cone, it begins

to flow radially inwards and out the top as clean air/gas while the particulates fall into the dust collection chamber attached to the bottom of the cyclone.

Cyclones have no moving parts and available in many shapes and sizes, for example from the small 1 and 2 cm diameter source sampling cyclones which are used for particle size analysis to the large 5 m diameter cyclone separators used after wet scrubbers, but the basic separation principle remains the same.

Three different types of cyclone are shown in figure 5.2. First figure i.e. 5.2a shows a cyclone with a tangential entry. These types of cyclones have a distinctive and easily recognized form and widely used in power and cement plants, feed mills and many other process industries.
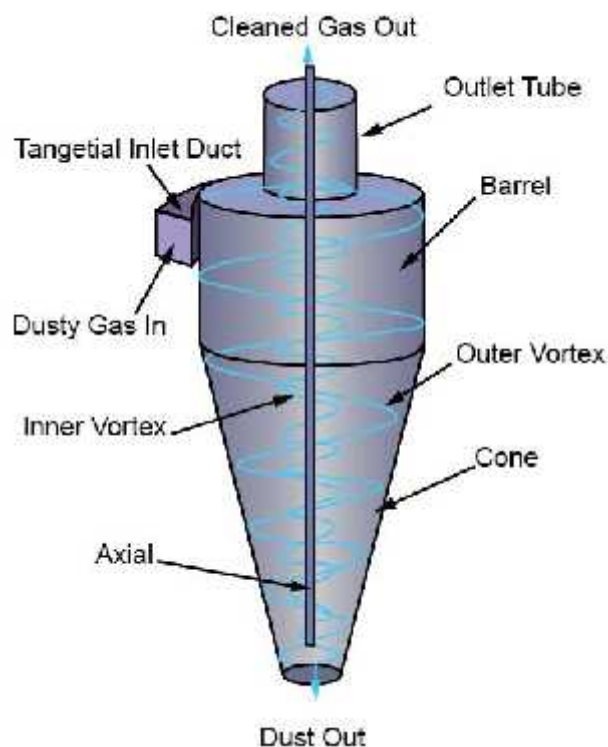
Figure schematic diagram of cyclone separator

Cyclone collectors can be designed for many applications, and they are typically categorized as high efficiency, conventional (medium efficiency), or high throughput (low efficiency). High efficiency cyclones are likely to have the highest-pressure drops of the three cyclone types, while high throughput cyclones are designed to treat large volumes of

gas with a low-pressure drop. Each of these three cyclone types have the same basic design. Different levels of collection efficiency and operation are achieved by varying the standard cyclone dimensions.
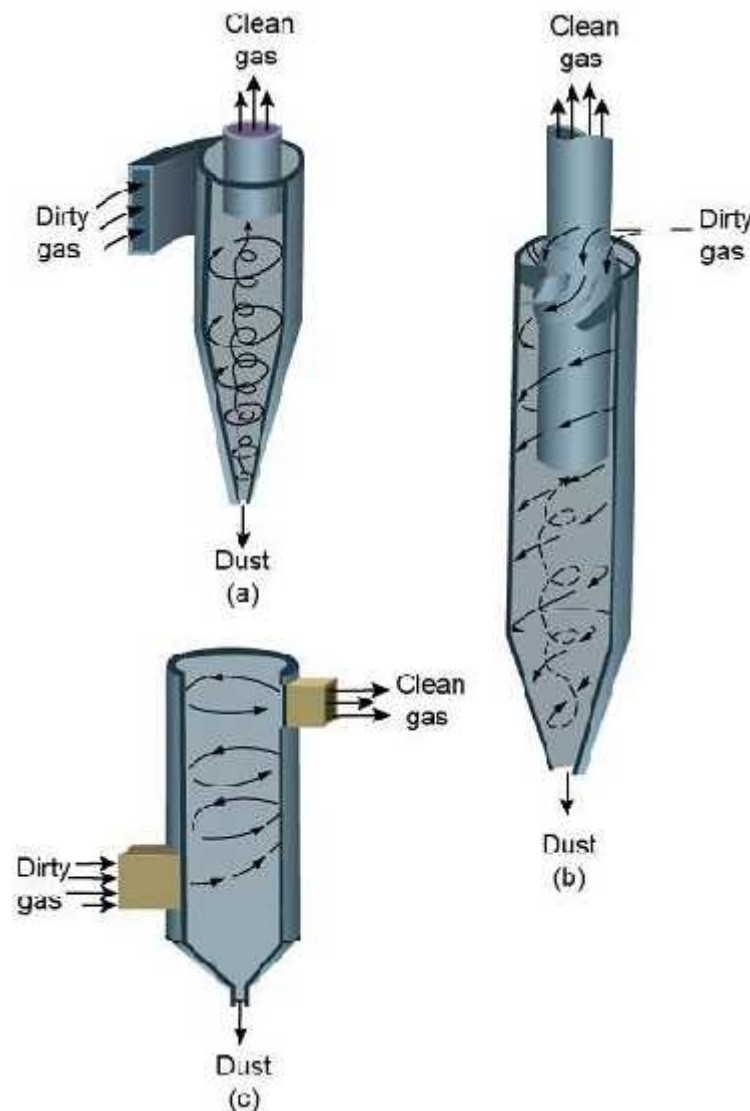
Figure different types of cyclone

The collection efficiency of cyclones varies as a function of density, particle size and cyclone design. Cyclone efficiency will generally increase with increases in particle size and/or density; inlet duct velocity; cyclone body length; number of gas revolutions in the cyclone; ratio of cyclone body diameter to gas exit diameter; inlet dust loading; smoothness of the cyclone inner wall.

Cyclone performance

Cyclones are basically centrifugal separators. They simply transform the inertia force of gas particle to a centrifugal force by means of a vortex generated in the cyclone body. The particle laden gas enters tangentially at the upper part and passes through the body describing the vortex. Particles are driven to the walls by centrifugal forces (an expression for this force is given blow eq. 5.1), losing its momentum and falling down to the cyclone leg. In the lower section, the gas begins to flow radially inwards to the axis and spins upwards to the gas outlet duct.

$$F = \frac{\rho_p \, d_p^3 \, v_p^2}{r} \qquad\qquad (5.1)$$

ρ_p = particle density, (kg/m^3)

d_p = particle diameter, inches (μm) v_p = particle tangential velocity (m/s) r = radius of the circular path, (m)

The main variables describing the cyclone performance are pressure drop, efficiency and cut diameter. Equations involving each of these parameters are provided in this section.

Collection efficiency

The collection or separation efficiency is most properly defined for a given particle size. As mentioned, fractional efficiency is defined as the fraction of particles of a given size collected in the cyclone, compared to those of that size going into the cyclone. Experience shows that collection efficiency of cyclone separator increases with increasing particle mean diameter and density; increasing gas tangential velocity; decreasing cyclone diameter; increasing cyclone length; extraction of gas along with solids through the cyclone legs.

Several equations have been developed to predict the collection efficiency in cyclones through correlation equations. The following section describes two methods of calculating cyclone efficiency. First the theory proposed by Leith and Licht (1973) for calculating fractional efficiency will be discussed and then a convenient graphical method developed by Lappel (1951) will be presented.

The fractional efficiency equation of Leith and Licht is given as:

$$E_i = 1 - e^{\left[-2(C\psi)^{\frac{1}{(2n+2)}} \right]}$$

Where
C = cyclone dimension factor
ψ = impaction parameter
n = vortex exponent

$$\psi = \frac{\rho_p\, d_p^2\, v_i}{18\mu D_c}\,(n+1) \qquad (5.4)$$

In this expression, c is a factor that is a function only of the cyclone's dimensions. The symbol ψ expresses characteristics of the particles and gas and is known as *inertia or impaction parameter*. The value of n is dependent on the cyclone diameter and temperature of the gas stream. And ρ_p times v_i expresses the particle's initial momentum. Although the calculation involved in this method are tedious but are straightforward.

GENERAL DESIGN CONSIDERATIONS
Pressure drop

Pressure drop across the cyclone is of much importance in a cyclone separator. The pressure drop significantly affects the performance parameters of a cyclone. The total pressure drop in a cyclone will be due to the entry and exit losses, and friction and kinetic energy losses in the cyclone. Normally most significant pressure drop occurs in the body due to swirl and energy dissipation. There have been many attempts to predict pressure drops from design variables. The idea is that having such an equation, one could work back and optimize the design of new cyclones. The empirical equation given by Stairmand (1949) can be used to estimate the pressure drop.

$$\Delta P = \frac{\rho_f}{203}\left\{ u_1^2 \left[1 + 2\phi^2\left(\left(\frac{2r}{r_e}\right) - 1 \right) \right] + 2\,u_2^2 \right\} \qquad (5.5)$$

ΔP = cyclone pressure drop

ρ_f = gas density; u_1 = inlet duct velocity; u_2 = exit duct velocity

r_t = radius of circle to which the centre line of the inlet is tangential; r_e = radius of exit pipe

ϕ = cyclone pressure drop factor

$\Psi = f_c\,(A_s/A_1)$

f_c = friction factor, taken as 0.005 for gases

A_s = surface area of cyclone exposed to the spinning fluid

Design considerations

- ¬ Select either the high efficiency or high throughput design, depending on the performance required
- ¬ Obtain an estimate of the particle size distribution of the solids in the stream to be treated.
- ¬ Calculate the number of cyclone needed in parallel.
- ¬ Estimate the cyclone diameter for an inlet velocity of say 15 m/s. Then obtain the other cyclone dimensions from the graphs (refer to page 452, Sinnott, 2005) Then

estimate the scale up factor for the transposition of the figure. (refer to page 452 and 453, Sinnott, 2005)

Estimate the cyclone performance and overall efficiency, if the results are not satisfactory try small diameter.

Calculate the cyclone pressure drop and check if it is within the limit or else redesign.

Estimate the cost of the system and optimize to make the best use of the pressure drop available (Sinnott, 2005).

Example Estimate the cut diameter and overall collection efficiency of a cyclone given the particle size distribution of dust from cement kiln. Particle size distribution and other pertinent data are given below

Avg particle size in range d_p, μm	1	5	10	20	30	40	50	60	>60
Wt percent	03	20	15	20	16	10	06	03	07

Gas viscosity = 0.02 Cp; Specific Gravity of the particle = 3.0

Inlet gas velocity of cyclone = 48 ft/sec

Effective number of turns within cyclone = 5

Cyclone diameter = 8 ft

Cyclone inlet width = 2 ft

Solution:

Cut size d_{pc} can be calculated from the following equation

$$d_{pc} = \left[\frac{9 \mu B_c}{2 \pi N u_i (\rho_p - \rho)} \right]^{1/2}$$

and collection efficiency as a function of the ratio of particle diameter to cut diameter can be obtained by

$$E = \frac{1}{1 + (d_{pc}/d_p)^2}$$

First determine the value of

$$\rho_p - \rho = \rho_p = 3(62.4) = 187.2 \text{ lb/ft}^3$$

$$d_{pc} = \left[\frac{9\mu B_c}{2\pi Nu_i (\rho_p - \rho)} \right]^{1/2}$$

$$= \left[\frac{9 \times 0.02 \times 6.72 \times 10^{-4} \times 2}{2\pi \times 5 \times 48 \times 187.2} \right]^{1/2}$$

$$= 2.92 \times 10^{-5} \text{ ft}$$

$$= 8.9 \text{ µm}$$

d_p, µm	w_i	d_p/d_{pc}	E_i, %	$w_i E_i$%
1	0.03	0.11	0	0.0
5	0.20	0.55	23	4.6
10	0.15	1.11	55	8.25
20	0.20	2.22	83	16.6
30	0.16	3.33	91	14.56
40	0.10	4.44	95	9.5
50	0.06	5.55	96	5.7
60	0.03	6.66	98	2.94
>60	0.07	-	100	7.0

The overall collection efficiency is therefore

$$E = \sum w_i E_i = 0 + 4.6 + 8.25 + 16.6 + 14.56 + 9.5 + 5.7 + 2.94 + 7.0 = 69.15\% = 0.6915$$

5.7 PROCESS HAZARDS

The chemical industry is more diverse than virtually any other process industry. Its products are omnipresent. Chemicals play a major role in manufacturing, essential to the entire range of industries such as pharmaceuticals, automobiles, textiles, paper and paint, agriculture, electronics, appliances and services. It is difficult at the same time to fully specify the uses of chemical products and processes. A world without the chemical industry would lack modern medicine, communications, and consumer products.

The modern technology in developing these tailor made chemicals has been quite successful. However, the process and manufacturing facilities are challenged to maintain their edge in a highly competitive culture while facing continual scrutiny from the public and government to improve the safety of processes involving hazardous materials. The continuous burden of increasing the production of flammable organics, the competition to bring new products from laboratory scale to full scale production, the problem of familiarization with a stream of new technology have all extended the probabilities of hazards. The major hazards encountered in the operation of the plant in the chemical industries are toxic and corrosive chemicals release, fires, explosions, falls and faulty mechanised equipments. In many instances, more than one of these hazards occur either simultaneously or in tandem of each other. For example, a fire may lead to explosion which subsequently causes more fire and toxic release. Therefore, the design engineer must be aware of these hazards and must make every attempt to present a design which needs to be protective of the environment and of human health. Environmental issues must be considered not only within the context of chemical production but also during other stages of a chemical's life cycle, such as transportation, use by customers, recycling activities, and ultimate disposal.

ANALYSIS OF HAZARDS

An initial process hazard analysis must be made of the probable sources of hazards and it is performed on the processes, appropriate to the complexity to identify, evaluate and control the hazard. Take corrective measures to improve the safety of the process and plan actions that would be necessary if safety controls failed. Process hazard analysis is required for any process involving a highly hazardous chemical as identified in the standard. A process includes any manufacturing or use of a highly hazardous chemical, including storage, handling or movement of the chemical. Most simplified, any facility that has a designated hazardous chemical on-site in the quantities named in the standard must conduct a process hazard analysis for the equipment and process in which the material is used. The entire approach can be summarized as follows:

1. Identify the hazards: "what can possibly go wrong"
2. Evaluate the hazards: "what are all the causes and how bad it can be"
3. Control the hazards: "what should be done about it"

The sources of the hazard can be divided into two categories, namely, material hazards and process hazards.

5.8 MATERIAL HAZARD

These are mainly because of quantity, concentration, or physical or chemical characteristics of the materials which poses a significant present or potential hazard to human health and safety or to the environment.

1. Combustible solids, liquids or gases	5. Highly flammable materials
2. Radioactive materials	6. Reactive materials
3. Oxidizing materials	7. Corrosive materials
4. Nuclear materials	8. Toxic materials

Apart from this, some materials react with water to produce a combustible gas and some materials subjects to spontaneous heating, polymerization, or explosive decomposition. It is important to keep such materials separate during both use and

General process hazard

The general process hazards might arise due to several factors, some of which

are listed below.

a. Exothermic chemical reaction, in this case there is a strong possibility of the reaction getting out of control.

b. Endothermic reaction that could react due to an external heat source such as fire or combustion of fuel.

c. Material handling and transfer, accounts for the hazard involved in the handling, transfer/pumping and warehousing of the material

d. Enclosed or indoor process units, accounts for the additional hazard where the process units preventing dispersion of the escaped vapors.

e. Limited access for emergency equipments

f. Drainage and spill control, inadequate design of drainage would cause large spills of the flammable material adjacent to process equipment.

Special process hazard

The special process hazards are the factors that are known from experience to contribute to the probability of incident involving loss.

a. *Toxic materials*: after an incident the presence of toxic material at site will make the work of emergency personnel more difficult. The factor applied in this case ranges from 0 to 0.8. Zero implies for non toxic material and 0.8 for materials that can cause death after short exposure.

b. *Low pressure process* operating at sub atmospheric conditions allows for the hazard of air leakage into equipments.

c. *Operation in or near flammable limits* covers for the possibility of air mixing with material in equipment or storage tanks, under conditions where the mixture will be within the explosive range.

d. *Dust explosion risks* may arise in processes which involve handling of materials that could create dust. The degree of risk is largely determined by the particle size and nature of the material.

e. *Relief pressure* hazard results from the potentially large expansion of fluid to the atmosphere from elevated pressure. Equipment design and operation

becomes more crucial as the operating pressure in increased. The factor to apply in this case depends on the relief device setting and physical nature of the process materials.

Low temperature processes allows for the possibility of the embrittlement of carbon steel vessels, or other metals, at low temperatures.

Quantity of flammable material the probable loss will be greater, if greater the quantity of the flammable material in the process or in storage.

Corrosion and erosion of the process unit structure even with good design and material selection, some corrosion and problems may arise in the unit process, both internally and externally. Anticipated corrosion rate predicts the penalty factor. The severest factor is applied if stress corrosion is likely to occur.

Leakage around packings and joints this factor allows for the possibility of leakage from gasket, pump and other shaft seals, and packed glands. The severity of the factor varies where there is a minor leak to the process that have sight glasses, bellows or other expansion joints.

Use of fired heaters providing a ready ignition source boilers and furnaces are heated by the combustion of the fuel and the presence of such units increases the probability of ignition due to leak of combustible material from the process unit. The risk involved depends on the siting of the fired equipments and the flash point of the process material.

Hot oil heat exchange systems in most of the cases heat exchange fluids are flammable and are often used above their flash points, therefore their use in the unit increases the risk of fire or explosions.

Rotating equipment this covers the hazards that arise from the use of large pieces of rotating equipment: compressors, centrifuge, mixers.

Apart from these, in many cases equipment or instruments in the process fails due to thermocouple burnt out, loss of electrical power, steam or cooling water failure, plugging of lines or equipment, etc.

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Flammability

The hazards caused by the flammable material depend upon number of factors.

  a. flash point of the material
  b. auto ignition temperature of the material
  c. flammability limit of the material
  d. energy released in the combustion

Flash point

Flash point gives a relative idea of the lowest temperature at which enough vapour pressure exists to generate vapour that can ignite the from an open flame. It is a function of the vapour pressure and the flammability limits of the material. It is measured in standard apparatus (both open and closed cup apparatus).

Auto ignition temperature

It is the temperature material at which the material will ignite spontaneously in air, without any external source of ignition that may lead to uncontrolled fire and explosions.

Flammability limits

Prevention of unwanted fires and gas explosion disasters requires knowledge of flammability characteristics i.e. flammability limits, ignition requirements, and burning rates of pertinent combustible gases and vapors likely to be encountered under various conditions of use (or misuse). For a particular application the available data may not always be sufficient for use, as the data may have been obtained at temperature and pressure lower than is encountered in practice. The lower and upper flammability limits of a vapour/gas are the lowest and highest concentrations in air at normal pressure and temperature, at which the flame will propagate through mixture. They show the range of concentration will burn in air, if ignited. The flammability limit are determined experimentally. For example, the lower limit of flammability for hydrogen is 4.1 percent by volume and upper limit of 74.2 per cent by volume, whereas, for petrol the range is only 1.3 to 7.0 per cent. In some cases existence of flammable mixture in the space above liquid surface in a storage tank might occur. In such cases the vapour space above the liquid surface (highly flammable) is usually purged with inert gas or floating head tanks are used. The floating roof of the tank on the top of liquid eliminates the vapour space.

Explosions

Confined vapour cloud explosions (CVCE)

An explosion occurs within a vessel or a building due to release of a relatively small amount of flammable material (few kg).

Unconfined vapour cloud explosions (UCVCE)

Unconfined explosions results from the leakage of a considerable quantity of flammable gas, or vapour into atmosphere, and its subsequent ignition. In case of UCVCE the gas is dispersed and mixed with air until it comes in contact with an ignition source. Such explosion can caused extensive damage since large quantities of gas and large areas are frequently involved.

Boiling liquid expanding vapour explosions (BLEVE)

This type of explosions occur due to ruptures of a vessel which contains a liquid at a temperature above its atmospheric pressure boiling point, when an external fire heats the contents of a tank of volatile material. As the tank contents heat up, the vapour pressure of the liquid within tank increases and its integrity reduces due to excess heating. In such conditions if the tank ruptures the hot liquid volatilizes explosively.

Dust explosions: this type of explosions results from rapid combustion of finely divided solid particles. Metal such as iron and aluminium become very flammable when reduced to s fine powder.

5.9 SAFETY MEASURES IN EQUIPMENT DESIGN

Till now we have discussed about number of safety measures for preventing or controlling hazards. Some of these measures are significant in equipment design problems. Here main focus is on considering equipment such as pressure vessels (i.e. reactors, heat exchangers etc.) and the equipment which involves rotary motion (example filters, agitators etc.). During the design stages of these items of equipment some important safety measures need to be considered are discussed in the following sections. reliability and flexibility, ease of operations, provision for future expansion, inspection and maintenance, emergency shutdown facility, standardization of equipment for rapid replacement, design to withstand probable pressure and temperature range, with facility to over pressure/temperature control etc. But at the same time it is not possible to give the list of precautions for each and individual unit operations, some are specified below.

Pressure vessels

For design and construction of pressure vessel and storage tanks Indian standards codes should be followed and vessels should be tested at 1.3 times the design pressure. The design should be made to keep the vessels as simple as possible and it should not be overloaded with supplementary

equipments. Thick weld joints made on the vessel should be given special attentions. The fatigue strength should be regularly monitored particularly if the vessel is exposed to pressure cycling, system changes, vibrations or similar factors which are likely to create fatigue conditions. Important point need to consider is that flange joints must be leak proof. All pressure vessels should be provided with pressure relief devices.

Heat transfer equipments

The heat transfer equipment such as evaporator, reactors, furnaces, heat exchangers require some type of heating which may be directly fired with the help of fuel, electric heating, or using heat transfer media like steam or heating fluids. While designing such equipment special precaution should be taken which would not only prevent over heating but protect from fire and explosions this can be accomplished by different ways.

(d) Provide sufficient heating surface so that excessive rate of heat input per unit area can be avoided

(e) In such equipments the heat absorbed by the tubes must be continuously removed by circulating the fluids and to prevent excess temperature rise through the liquid film heat transfer coefficient should be sufficiently high.

(f) Periodic inspection of the equipment is necessary and for that reason sufficient numbers of inspection opening must be provided, if applicable.

(g) Provision of vent valves at all high spots in the equipment is necessary.

Equipment involving electrical energy

All the electrical installations are inherent source for ignition. Special design features are required to prevent the ignition of flammable vapors and dusts from electrical devices. The fire and explosion hazard is directly proportional to the number and types of electrically powered devices in a process area. The process areas are divided into two major types of environment explosion proof and non explosion proof. Explosion proof means flammable material may be present at certain times, and non explosion proof means that flammable materials are not present even under abnormal conditions (for example: the areas like open flames, heated elements and other sources of ignition may be present). The explosion proof design should include the use of conduit with special sealed connections around all junction boxes.

The design of electrical equipment and instrumentations is based on the nature of the process hazards or specific process classifications. It is a function of the nature and degree of the process hazards within a particular area. For example in petroleum industries we always have a

classification of hazardous areas of electrical work also.

Class 1: Location where flammable gases or vapors are present.

Class 2: In normal operation explosive mixtures is most likely to occur.

Class 3: Hazard locations where combustible fibers or dusts are present but not likely to be in suspension.

5.10 Pressure relief devices

Selection, design and specification of appropriate pressure relieving facilities is the most important safety device used in the process equipment to prevent the failure of equipment due to over pressure. The more common causes of over pressure are external fire, closed outlets, liquid expansion, failure of reflux. The relief devices fall into six categories.

2.2. Safety valve - It is an automatic pressure-relieving device actuated by the static pressure upstream of the valve and characterized by rapid full opening or pop action. It is used for gas or vapor service. (In the petroleum industry it is used normally for steam or air)

2.3. Relief Valve - A relief valve is an automatic pressure-relieving device actuated by the static pressure upstream of the valve, and which opens in proportion to the increase in pressure over the opening pressure. It is used primarily for liquid service.

3. Safety Relief Valve - A safety relief valve is an automatic pressure-relieving device suitable for use as either a safety valve or relief valve, depending on application. (In the petroleum industry it is normally used in gas and vapor service or for liquid). These safety relief valves are classified as conventional or balanced, depending on the effect of back pressure on their performance.

   a. Conventional Safety Relief Valve - A conventional safety relief valve is a closed-bonnet pressure relief valve that has the bonnet vented to the discharge side of the valve and is Therefore unbalanced. The performance characteristics, i.e., opening pressure, closing pressure, lift and relieving capacity, are directly affected by changes in the back pressure on the valve

   b. Balanced Bellows Safety Relief Valve - A balanced safety relief valve incorporates means for minimizing the effect of back pressure

variation on the performance characteristics; opening pressure, closing ressure, lift and relieving capacity. This is usually achieved by the installation of a bellows

4. Pressure Relief Valve - This is a generic term applying to relief valves, safety valves or safety relief valves and it is commonly abbreviated to "PR Valve".

5. Rupture Disc Device - A rupture disc device is actuated by inlet static pressure and is designed to function by the bursting of a pressure-retaining diaphragm or disc. Usually assembled between mounting flanges, the disc may be of metal, plastic, or metal and plastic. It is designed to withstand pressure up to a specified level, at which it will fail and release the pressure from the system being protected