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]:

a. Depth filtration
    - Slow sand filtration
    - Rapid porous and compressible medium filtration
    - Intermittent porous medium filtration
    - Recirculating porous medium filtration
b. Surface filtration
    - Laboratory filters used for TSS test
    - Diatomaceous earth filtration
    - Cloth or screen filtration
c. 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	Particles larger than the pore space of the filtering medium are strained out mechanically.
b) Chance contact	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 b) Chemical interaction	Once a particle has been brought in contact with the surface of the filtering medium or with other particles, either one of these 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.

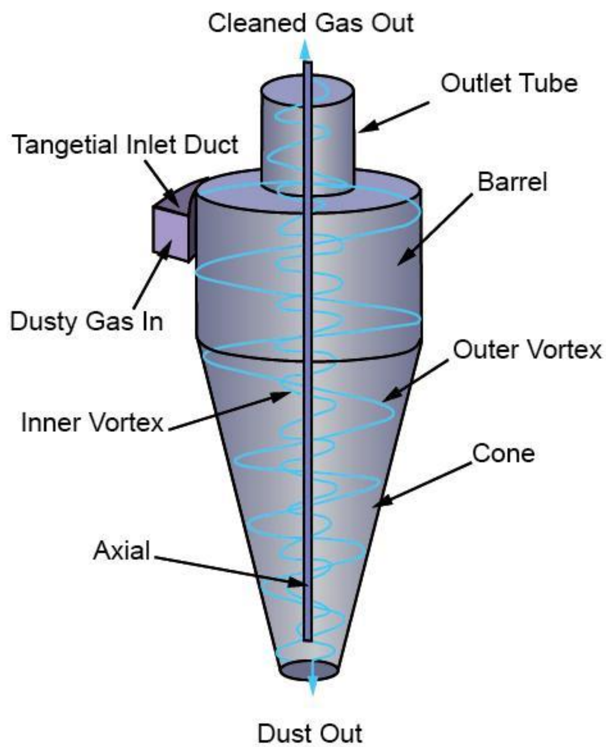

Figure schematic diagram of cyclone separator

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.

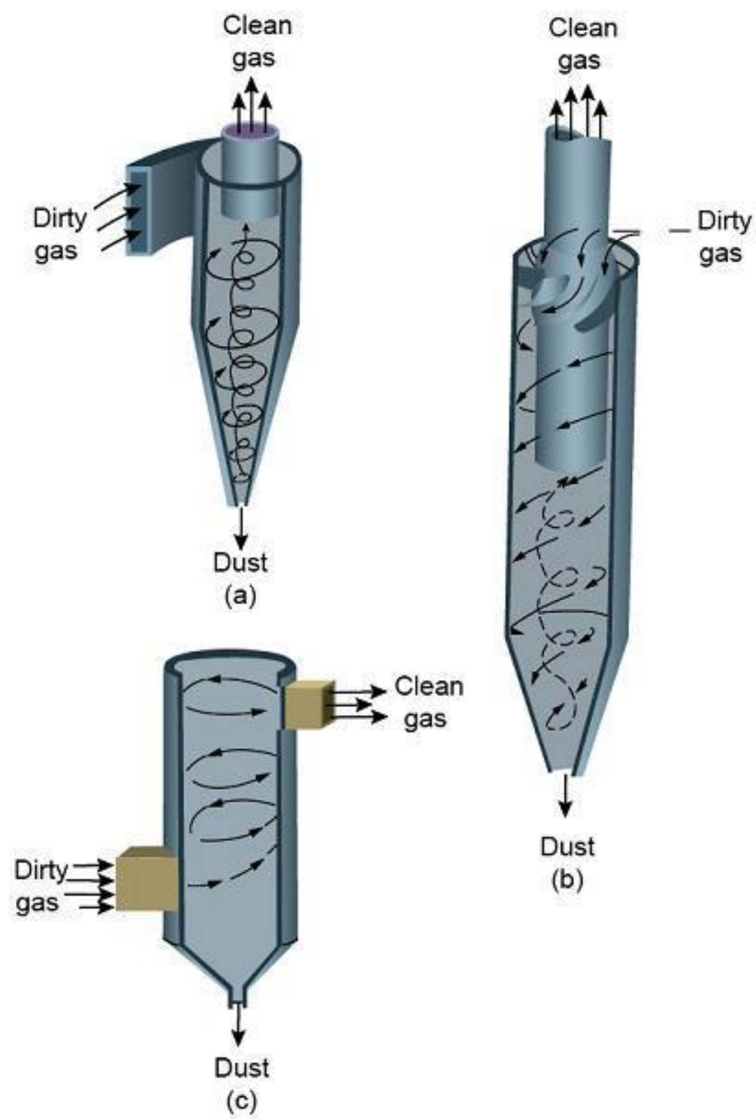

Figure different types of cyclone

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.

$$F = \frac{\rho_p d_p^3 v_p^2}{r} \tag{5.1}$$

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:

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

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.

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

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

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

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

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

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

$= 8.9$ µm

d_p, µm	w_i	d_p/d_{pc}	E_i, %	w_iE_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
2. Radioactive materials
3. Oxidizing materials
4. Nuclear materials
5. Highly flammable materials
6. Reactive materials
7. Corrosive 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.

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

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

h. *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.

i. *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.

j. *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.

k. *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.

l. *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 (Mahajani and Umarji, 2009). 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.

1. 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. 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

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Department of Chemical Engineering

Course Material

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