Module # 9

PROCESS HAZARDS AND SAFETY MEASURES IN EQUIPMENT DESIGN: PROCESS HAZARDS, SAFETY MEASURES IN EQUIPMENT DESIGN, PRESSURE RELIEF DEVICES

Lecture 1: INTRODUCTION AND PROCESS HAZARDS

1. INTRODUCTION

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.

2. 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.

3. 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 storage.

4. PROCESS HAZARD

4.1 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.

4.2Special 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.

Lecture 2: SAFETY MEASURES

5. SAFETY MESAURES

In the present global industrial scenario, for any industry to be successful, it is essential to inculcate safety culture, consciousness in health and environment aspects in each personnel of an organization. The word safety used to mean the older strategy of accident prevention through the use of hard hats, safety shoes, and a variety of rules and regulations. The main emphasis was on worker safety. Much more recently, ―safety has been replaced by ―loss prevention. This term includes hazard identification, technical evaluation, and the design of new engineering features to prevent loss. Safety, hazard, and risk are frequently-used terms in chemical process safety. All the manufacturing processes are to some extent hazardous, but in chemical processes there are additional, special, hazards associated with the chemicals used and the process conditions. The chemicals handled during different process poses hazards in the form of fire and toxicity to operators. The Material Safety Data Sheet (MSDS) of all chemicals used in the plant including raw material, intermediates, products by products, etc provides information related to the toxicity and other hazards. The word hazard is associated with toxicity, flammability or combustibility. Flammable liquids burn more easily. On the other hand, combustible liquids do not burn that easily. Let us try to understand the commonly used terms associated with fire hazards.

5.1Flammability

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

5.2 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). Flash points of many volatile materials are below the normal ambient temperature for example, ether -45^0C, petrol (gasoline) – 43^oC.

5.3 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.

5.4 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. Flammability limits for various materials can be obtained from various sources (Sax's handbook, Lewis, 2004).

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.

5.5 Explosions

The major difference between fire and explosions is the rate of energy release. In case of explosion there is a sudden release of energy (micro seconds) causing a pressure wave. While fires release energy slowly. An explosions can occur without fire such as failure through over pressure of a steam boiler or an receiver. Another simple example of how the energy releases rate affects the consequences of an accident is the case of a standard automobile tire. The compressed air in the tire contains energy. If the energy is released slowly through nozzle, the tire deflated without any harm. But if the tire ruptures suddenly and all the energy within the compressed tire releases rapidly, the result is a dangerous explosions.

While discussing the explosions of flammable mixtures it is necessary to differentiate between detonation and deflagration. In a ***deflagration*** the combustion process is same as in the normal boiling of a gas mixture and the combustion zone propagates at sub sonic velocity, if a mixture ***detonates*** the combustion is extremely rapid and the flame velocity is more than that of the velocity of sound (apporx. 30 m/s).

Mechanical explosions this explosions result due to the sudden failure of a vessel containing high pressure (non reactive gas)

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.

Lecture 3: SAFETY MEASURES IN EQUIPMENT DESIGN AND PRESSURE RELIEF DEVICES

6. 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.

6.1 About material of construction

The selection of materials certainly involves a compromise between factors such as strength, corrosion resistance, elasticity, toughness, wear, fatigue resistance and ease of fabrication, as well as availability and cost. In some cases process conditions vary a good deal, which makes the choice of material difficult. The choice of the material is largely based on experience and even small variations in the constituents of the fluid streams make considerable difference to the material to be used. At the design stage, all reasonable hazards should be identified and listed, and a limit set for each variable which can lead to such a hazard. For instance, the consequences of material failure or deterioration should be considered, with limits for wear or corrosion being established. To ensure safe operation a critical analysis of the process conditions and material handled must be made.

6.2 Precautions in design and construction

It is generally known that preventing the effects of industrial accidents/hazards necessitates, above all, a high safety standard of potentially dangerous plants. These will vary according to the type of equipment. A properly designed piece of equipment will have in-built safety and loss prevention features. To prevent such failures the ideas and experience which are already available at various points in connection with emergency measures should be incorporated. These might include, for example, unit 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.

6.3 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.

6.4 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.

i. Provide sufficient heating surface so that excessive rate of heat input per unit area can be avoided

ii. 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.

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

iv. Provision of vent valves at all high spots in the equipment is necessary.

v. An expansion or surge tank may be provided in case of liquid phase systems.

vi. In case of heaters the tubes must be tightly secured to headers and vapour drums.

vii. For high temperature equipments pressure relief devices must be considered in design.

viii. While designing precaution should be taken to keep allowance for the stresses due to thermal expansion.

ix. Choice of the insulation should be appropriate and consistent with the material handled by the equipment.

6.5 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.

6.6 Equipment involving rotary motion

The rotary equipment involves a mechanical drive system that should be protected by guards. The bearings used in the system should be well lubricated and cooled, if necessary, to reduce temperature.

6.7 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 pressure, 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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