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Pressure Vessel Safety

A pressure vessel is a closed container designed to withstand pressure, whether internal or external. The pressure may be imposed by an external source, by application of heat from a direct or indirect source or by any combination thereof. The pressure vessels are usually subjected to an internal or external pressure greater than 15psig(103 kPa).

Internal pressure in a vessel is developed from the fluid in process application. External pressure on a vessel may be imposed by an internal vacuum or pressure of the fluid between an outer jacket and vessel wall. The components of the vessel may fail, causing dangerous accidents, if the vessel cannot withstand the internal or external pressure.

Pressure vessels are designed and constructed in various shapes. They may be cylindrical with heads, spherical, spheroidal ,boxed or lobed. Common types of pressure vessels include boilers, water heaters, expansion tanks, feed water heaters, columns, towers, drums, reactors, heat exchangers, condensers, air coolers, oil coolers, accumulators, air tanks, gas cylinders, and refrigeration systems.

Pressure vessels contain fluids such as liquids, vapours and gases at pressures greater than atmospheric pressure. Some of the fluids may be corrosive or toxic. All types of workplaces, from workshops and power generators to pulp and paper processors and large petrochemical refiners use pressure vessels. Small workshops use compressed air tanks. Petrochemical industries use hundreds of vessels that include towers, drums, and reactors for processing purposes. Depending upon the application, the vessels are constructed of either carbon steel or alloy steel.

Most pressure vessels are designed in accordance with the codes developed by the American Society of Mechanical Engineers(ASME) and the American Petroleum Institute (API). In addition to these codes, design engineers use engineering practices to make vessels safe. A pressure vessel bears the symbol stamping of the code under which it has been designed and constructed. Because a pressure vessel operates under pressure, safety is the main consideration during its design, construction, installation, operation, maintenance, inspection and repair.

The main components of a typical pressure vessel are the shell, the head and the nozzles. This cylindrical vessel a horizontal and may be supported by steel columns, cylindrical plate skirts, or plate lugs attached to the shell. The vessel may be used for any type of industrial process application under internal pressure.

Like any other machine, a pressure vessel in comprised of many components and fitted with controls and safety devices. The major components of a pressure vessel are as follows.

Shell : The main component – the outer boundary metal of the vessel.

Head : The end closure of the shell. Heads may be spherical, conical, elliptical, or hemispherical.

Nozzle : A fitting to inlet and outlet connection pipes.

Types of Pressure Vessels

There are many types of pressure vessels, but they are generally classified into two basic categories :

1. Fired pressure vessels burns fuels to produce heat that in turn boils water to generate steam. Boilers and water heaters are fired pressure vessels.

2. Unfired pressure vessels store liquid, gas, or vapor it pressures greater than 15 psig (103 KPa) and include air tanks, heat exchangers, and towers.

This article will limit its discussion to unfired pressure vessels, and use of terminology should be assumed to reflect this throughout.

Most pressure vessels are cylindrical in shape. Spherical vessel may be used for extremely high pressure operation. Vessels may range from a few hundred pounds per square inch (psi) up to 150,000 psi. the operating range of temperature may vary from - 100^{0}F to 900^{0}F. The American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section – VIII – Division I (ASME 2011b) has exempted the following vessels from the definition of pressure vessel :

1. Pressure containers that are integral components of rotating or reciprocating mechanical devices, such as pumps, compressors, turbines, generators, and so on
2. Piping systems components, flanges, gaskets, valves, expansion joints, and similar devices
3. Vessels for containing water under pressure, including those containing air compression to serve merely as a cushion, when neither of the following limitations are exceeded :
   a. design pressure of 300 psi
   b. design temperature of 210^{0}F

4. Hot water supply storage tanks heated by steam or any other indirect means when none of the following limitations are exceeded :
   a. heat input of 200,000 Btu/hr
   b. water temperature of 210^{0}F
   c. nominal water containing capacity of 120 gal

5. vessels having an internal or external operating pressure not exceeding 15 psi, regardless of size
6. vessels having an inside diameter, width, height, or cross-section diagonal not exceeding 6 in, regardless of vessel length or pressure
7. pressure vessels designed for human occupancy

Pressure vessel code

Pressure vessels are designed, constructed, inspected, and certified according to the ASME's Boiler and Pressure Vessel Code (ASME 2011a), the American Petroleum Institute (API) Code, and the Tubular Exchanger Manufacturers Association (TEMA) Code:

1. ASME Boiler and Pressure Vessel Code (2011a).

   ASME Code Section VIII is used internationally for construction of pressure vessels. This Code has three separate divisions – Division 1 : Pressure Vessels (2011b), Division 2 : Alternative Rules (2011c), and Division 3 : Alternative Rules for Construction of High pressure Vessels (2011d).

   ASME Section VIII - Division 1 : Rules for Construction of Pressure Vessels (2011b). These rules contain mandatory requirements, specific prohibitions, and non mandatory guidance for pressure vessel materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

   ASME Section VIII – Division 2 : Alternative Rules for Construction of Pressure Vessels (2011c). These rules provide an alternative to the minimum construction requirements for the design, fabrication, inspection and certification of pressure vessels with minimum allowable working pressure (MAWP) from 3000 to 10,000 psig.

   ASME Section VIII – Division 3 : Alternative Rules for Construction of High Pressure and Vessels (2011d). These rules have to do with the design, construction, inspection and overpressure protection of metallic pressure vessels with design pressure generally grater than 10,000 psi.

2. American Petroleum Institute (API) Code.

   API 510, Pressure Vessel Inspection Code (2006) is widely used in the petroleum and chemical process industries for maintenance inspection, rating, repair and alteration of pressure vessels. This inspection code is only applicable to vessels that have been placed in service and that have been inspected by an authorized inspection agency or repaired by a repair organization defined in the code. The code has provisions by which to certify pressure vessel inspectors.
   API RP 572, Inspection of Pressure Vessels (2009a) is a recommended practice (RP) standard for inspection of pressure vessels (towers, drums, reactors, heat exchangers and condensers). The standard covers reasons for inspection, causes of deterioration, frequency and method of inspection, methods of repair, and preparation of records and reports.

   API 620, Recommended Rules of Design and Construction of Large, Welded, Low-Pressure Storage Tanks (2008) provides rules for the design and construction of larges, welded, low pressure carbon steel above ground storage tanks. The tanks are designed for metal temperature not grater than 250^0F and with pressures in their gas or vapor spaces of not more than 15 psig. These are low pressure vessels that are not covered by ASME Section VIII – Division 1 Code (2011b).

   API Standard 950, Welded Steel Tanks for Oil Storage (2007) covers materials, design. Fabrications, erection, and testing requirements of above ground, vertical, cylindrical, closed and open-top, welded steel storage tanks in various sizes and capacities. This standard is applicable to tanks having internal pressures of approximately atmospheric pressure, but higher pressures are permitted when additional requirements are met.

ANSI/API Standard 660, Shell and Tube Heat Exchangers for General Refinery Services (2007a) defines the minimum requirements for the mechanical design, material selection, fabrication, inspection, testing, and preparation for shipment of shell and tube heat exchangers for general refinery services.

ANSI/API Standard 661, Air-cooled Heat Exchangers for General Refinery Service, Petroleum and Natural Gas Industries (2007b) covers the minimum requirements for the design, materials , fabrication, inspection, testing and preparation for shipment of refinery process air-cooled heat exchangers.

3. Tubular Exchangers Manufactures Association (TEMA) Standards.

The TEMA Standards [9^{th} ed. (2007)] covers nomenclature, fabrication tolerance, general fabrication, and performance information, installation, operation, maintenance, mechanical standard class RCB heat exchangers, flwo0induced vibration, thermal relations, physical properties of fluids, and recommended good practices of shell and tube heat exchangers.

Potential Hazards

When a substance is stored under pressure, the potential for hazards exists. Improper vessel design and maintenance increase the risk of pressure vessel failure, posing a serious safety hazard. The risk increases when vessels contain toxic or gaseous substances. A pressure vessel is considered hazardous equipment.

Every year accidents occur to many pressure vessels that are in the use in the industry. OSHA statistics indicate that 13 people were injured in 1999, 1 in 1983, 3 in 1997, and 9 in 1996 by pressure vessel accidents. A survey by the National Board of Boiler and Pressure Vessel Inspectors in 2002 shows 1663 accidents involving unfired pressure vessels that caused 5 fatalities and 22 injuries.

Pressure vessel accidents can be very serious. A serious accident take human, life, damages property, and increased costs for downtime production. Most accidents are caused by one of several thins.

Slow rupture. A small crack can allow fluid to escape. The vessel typically remaining intact, without fragments. The crack becomes larger over a period of time if not repaired early. Leak hazards are usually determined by the contents of the vessel. Fluid types, such as toxic gases, flammable vapors and so on, determine the severity of leakage. High pressure inside the vessel may generate high velocity gases that can create tremendous cutting or puncturing forces.

Rapid rupture. Sudden increases of internal pressure can cause total structural failure of the vessel. The container is rapidly destroyed, producing fragments and sometimes a shock wave. If the vessels releases toxic or flammable materials,this may increase the likelihood of injury, death , or property damage. Generally, rupture occurs when the internal pressure exceeds the design limits or when structural damage caused by normal wear and tear corrosion, galvanic action, or acute accident reduces the strength of the vessel.

Negative pressure: Many vessels collapse under negative pressure. Vacuum breakers can protect structural integrity.

Explosion of reactive chemicals: Rapid chemical reactions in the vessel may produce a large volume of gas in a short period of time. The mixture of gas expands, rapidly producing high temperatures and a shock wave having substantial destructive potential.

Causes of Deterioration

A variety of conditions can cause deterioration in pressure vessels. Common conditions are described below :

Corrosion. Corrosion is the most frequent condition found in pressure vessels. Most common corrosions involve pitting, line corrosion, general corrosion, grooving, and galvanic corrosion.

- In pitting, a vessel is weakened by shallow, isolated, and scattered pitting over a small area. Pitting may eventually cause leakage.
- In line corrosion, pits are closely connected to each other in a narrow line. Line corrosion is frequently found near the intersection of the support skirt with the bottom of the vessel.
- General corrosion covers a considerable area of the vessel, reducing material thickness. Safe working pressure should be calculated based on the remaining material thickness.
- Grooving is caused by localized corrosion and may be accelerated by stress corrosion. Grooving is found adjacent to riveted lap joints or welds on flanged surfaces.
- In galvanic corrosion, two dissimilar metals contact each other, and with an electrolyte, constitute an electrolytic cell. The electric current flowing through the circuit may cause rapid corrosion of the less noble metal (the one having the grater electrode potential). The effects of galvanic corrosion are especially noticeable at rivets, welds, and flanged and bolted connections.

Fatigue. Many vessels are subjected to stress reversals such as cyclic loading. If stresses are high and reversals frequent, failure of components may occur as a result of fatigue. Fatigue failures may also result from cyclic temperature and pressure changes.

Creep. Creep may occur where vessels are subjected to temperatures above those for which they are designed. Because metals become weaker at high temperatures, such distortion may result in failure, especially at points of stress concentration.

Temperature. At subfreezing temperature, water and certain chemical inside a vessel may freeze, causing failure. A number of failures have been attributed to brittle fracture of steels exposed to temperatures below their transition temperature and pressures grater than 20 percent of the hydrostatic test pressure.

Temper embrittlement. This is a loss of ductility and notch toughness caused by post weld heat treatment or high temperature service above 700^{0}F. low alloy steels are prone to temper embrittlement.

Hydrogen embittlement. This is a loss of strength and ductility in steels. Caused by atomic hydrogen dissolved in steel, occurs at low temperatures but is occasionally encountered above 200^{0}F. it is typically caused by hydrogen produced from aqueous corrosion reactions.

Stress corrosion cracking . This cracking of metal is caused by the combined action of stress and a corrosive environment. Stress corrosion can only occur with specific metals in specific environments.

Causes of Accidents

There are many causes of pressure vessel accidents. After accidents, experts use various methods to ascertain causes, such as visual inspection, nondestructive testing, destructive testing and metallurgical analysis. Causes and points of failure may be categorized as follows :

- Safety valves
- Limit controls
- Improper installation
- Importer repair
- Faulty design
- Faulty fabrication
- Operator error
- Poor maintenance
- Irregular inspection

Table 1

Accidents, Injuries, and Deaths involving Unfired Pressure Vessels			
Year	Accidents	Injuries	Death
1993	261	24	6
1994	387	19	5
1995	246	65	6
1996	319	22	6
1997	292	41	13
1998	153	12	9
1999	145	73	6
2000	221	3	4
2001	201	18	4
2002	176	22	5

Accident data

Historical data collected by the National Board shows that more people have died because of accidents involving unfired pressure vessels than because of those associated with fired pressure vessels (such as boilers). Table 1 shows the accidents injuries, and deaths involving unfired pressure vessels that occurred in a recent ten year period.

Accident severity

Any pressure vessel accident can be server, damaging lives and properties. Such an accident can also cause loss of production time and business, as well as employee layoff and fear. The severity of an accident depends on the pressure, temperature and type of fluid inside the vessel involved. Vessel size is also important; the bigger the size the vaster the heating surface exposed to explosive power.

Every accident costs money. For the purpose of cost analysis, work accidents can be classified in two general categories : (1) accidents causing work injuries and (2) accidents causing property damage or interfering with production. Furthermore, there are two types of costs : insured and uninsured.

Each company paying insurance premiums recognized such expenses as part of the cost of accidents. In some cases, medial expenses are covered by insurance. Insurance costs can be obtained directly from the insurance company.

Uninsured costs, sometimes referred to as “hidden costs” include the following :

- Wages paid for time lost by workers who were not injured.
- Damage to material and equipment.
- Wages paid to time lost by the injured workers, other than compensation payments.
- Overtime pay rates necessitated by the accident.
- Wages paid supervisors for time required for activities necessitated by the accident.
- The effect of the decreased output of the injured worker upon return to work
- The effect of the training period for a new worker.
- Uninsured medical cost borne by the company.

Shown below are Pressure Vessels in an extensive selection of reactive and corrosion-resistant alloy materials including Titanium, Tantalum, Zirconium, Hastelloy and Duplex Stainless Steel. Pressure Vessel designs include solid wall, explosive-clad, standard and half pipe jacketed models.

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