



Engineering Encyclopedia

Saudi Aramco DeskTop Standards

BASIC PRESSURE VESSEL CONCEPTS

Note: The source of the technical material in this volume is the Professional Engineering Development Program (PEDP) of Engineering Services.

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INTRODUCTION

MEX 202.01 describes the various components of pressure vessels through the use of drawings and sketches. This module reviews and builds upon information that was previously discussed in CSE 110.02. MEX 202.01 also briefly discusses the primary pressure vessel process functions. By the end of the module, the Participant will be able to describe the various components of pressure vessels and the basic process functions of pressure vessels.

MAIN COMPONENTS OF PRESSURE VESSELS

Pressure vessels are containers for fluids that are under pressure. The petroleum and petrochemical industry uses pressure vessels in all stages of the processing cycle. Within the processing cycle, pressure vessels convert crude oil or petrochemical feedstocks into useful products, such as gasoline, diesel fuel, or jet fuel. This conversion process takes place at elevated pressure and temperature levels and often in the presence of a catalyst. Saudi Aramco also uses pressure vessels extensively to produce crude oil, to manufacture oil products, to operate utilities, and to store products.

Pressure vessels have different characteristics, and they are typically custom-designed for particular service applications. Large vessels that are used in refinery processes may be 9 m (30 ft.) or more in diameter and over 60 m (200 ft.) in height. Typical pressures for Saudi Aramco applications range from 103 kPa (ga) (15 psig) to 34 470 kPa (ga) (5 000 psig), but most of the pressure vessels operate below 6 895 kPa (ga) (1 000 psig). Pressure vessel temperatures typically range from -29°C (-20°F) to over 538°C (1 000°F). Carbon steel is the material that is most often used to construct pressure vessels. Chrome alloys, stainless steels, and other alloys are also used to meet specific service needs. MEX 202.02 covers the construction materials that are used in the fabrication of pressure vessels.

The sections that follow discuss the main components of pressure vessels. Figures 1 through 5 are drawings of typical pressure vessel types. These typical pressure vessel types are as follows:

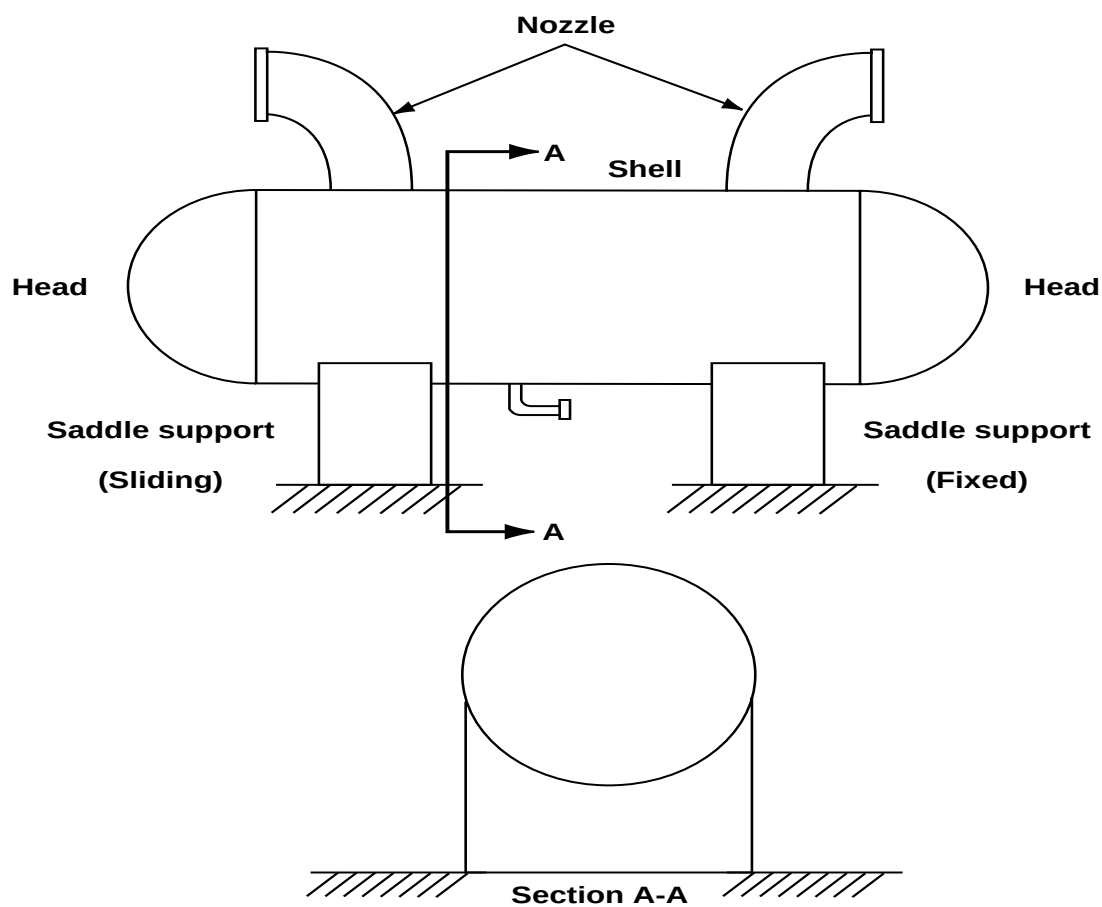
- Horizontal Drum on Saddle Supports
- Vertical Drum on Leg Supports
- Tall Vertical Tower
- Vertical Reactor
- Spherical Pressurized Storage Vessel

Their main components and several secondary components are identified in these drawings. The main components are the shell, head, nozzle and support. The secondary components are noted during the discussion. These figures are referenced during the discussion that follows.

Shell

The shell of a pressure vessel is the primary component that contains the pressure. Pressure vessel shells are welded together to form a structure that has a common rotational axis. Most pressure vessel shells are either cylindrical, spherical, or conical in shape.

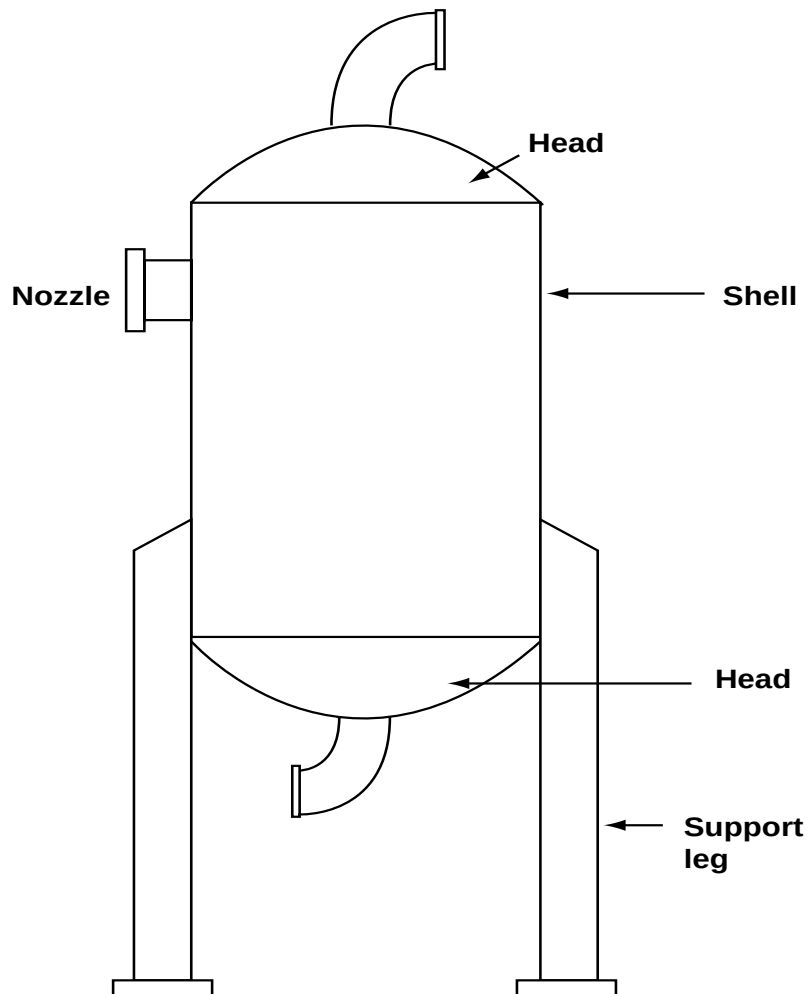
Figure 1 shows a typical horizontal drum. Horizontal drums have cylindrical shells, and they are fabricated in a wide range of shell diameters and lengths.



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Figure 1: Horizontal Drum on Saddle Supports

Figure 2 shows a small vertical drum. Small vertical drums are normally located at grade. The maximum shell length-to-diameter ratio for a small vertical drum is about 5:1.



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Figure 2: Vertical Drum on Leg Supports

Figure 3 shows a typical tall, vertical tower. Tall vertical towers are constructed in a wide range of shell diameters and heights. Towers can be relatively small in diameter and very tall (for example, a 1.2 m [4 ft.] diameter and 60 m [200 ft.] tall distillation column), or very large in diameter and moderately tall (for example, a 9 m [30 ft.] diameter and 45 m [150 ft.] tall pipestill tower).

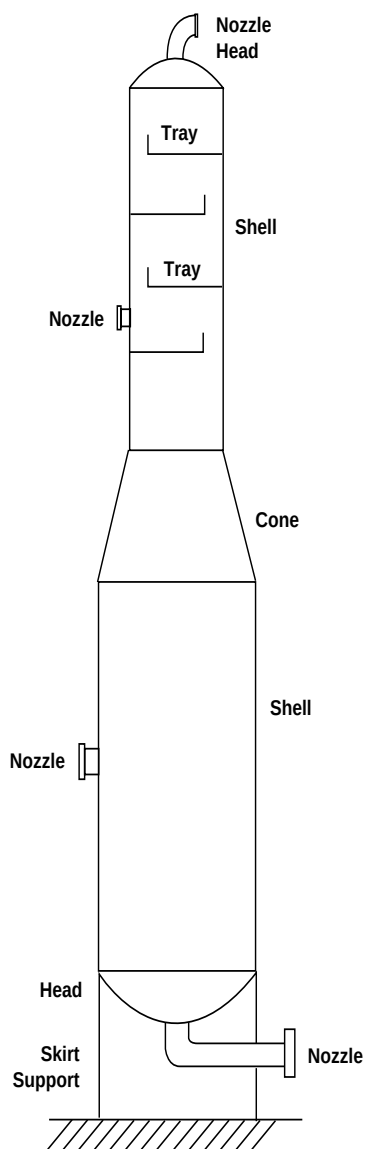


Figure 3: Tall Vertical Tower

The shell of a tower will often have multiple diameters in order to meet particular process needs. The transition between shell sections of different diameters is achieved through the use of a conical shell section, as shown in Figure 3. A tower typically also contains internal trays in the cylindrical shell section. These internal trays, which are also shown in Figure 3, are needed for flow distribution.

Several types of tower trays are available, such as the bubble-cap, valve, sieve, and packed. The choice of the tray type that is used is based on the particular process application.

- Bubble-cap trays are perforated to allow liquid to run through the tray and down to the bottom of the tower. Vapors rise up through the tray perforations to higher tower elevations. The perforations in the trays are made with umbrella-like caps over them, called bubble-caps. The purpose of the bubble-caps is to force the rising vapors to bubble through the liquid that is present on each tray before the vapors move up to the tray at the next higher tower elevation.
- Valve trays are also perforated; however, their perforations are covered by disks. The disks are designed to rise or fall in order to open or close the perforation openings depending on the fluid flow rates across the trays.
- Sieve trays and packed trays each employ fill material to control the flow of liquid and vapor through the area of the tray. The fill material may be composed of components such as grating, screen, wire mesh, or metallic rings.

The shell sections of a tall tower can be constructed of different materials, thicknesses, and diameters. Alloys, or a corrosion-resistant lining, are sometimes used in vertical tower sections where corrosion is a critical factor. Corrosion was discussed in COE 103 and COE 105, and will be included in MEX 202.02. If there is a major change in the corrosiveness of the process fluid in different tower sections, two different materials may be used in the construction of the vertical tower. Two factors that affect the corrosiveness of the process fluid are temperature and phase changes (liquid versus vapor) of the process fluid. Both factors vary along the tower's length.

The thickness of individual shell sections of a tall tower can vary along the tower's length. This variation in thickness is due to changes in design conditions, external loads, or material. MEX 202.03 discusses the calculation of required shell thicknesses in greater detail.

Figure 4 is a typical reactor vessel with a cylindrical shell. This cylindrical type of vertical reactor often has two internal catalyst beds. The upper catalyst bed is supported by a structural grid that is supported from the inside of the cylindrical shell.

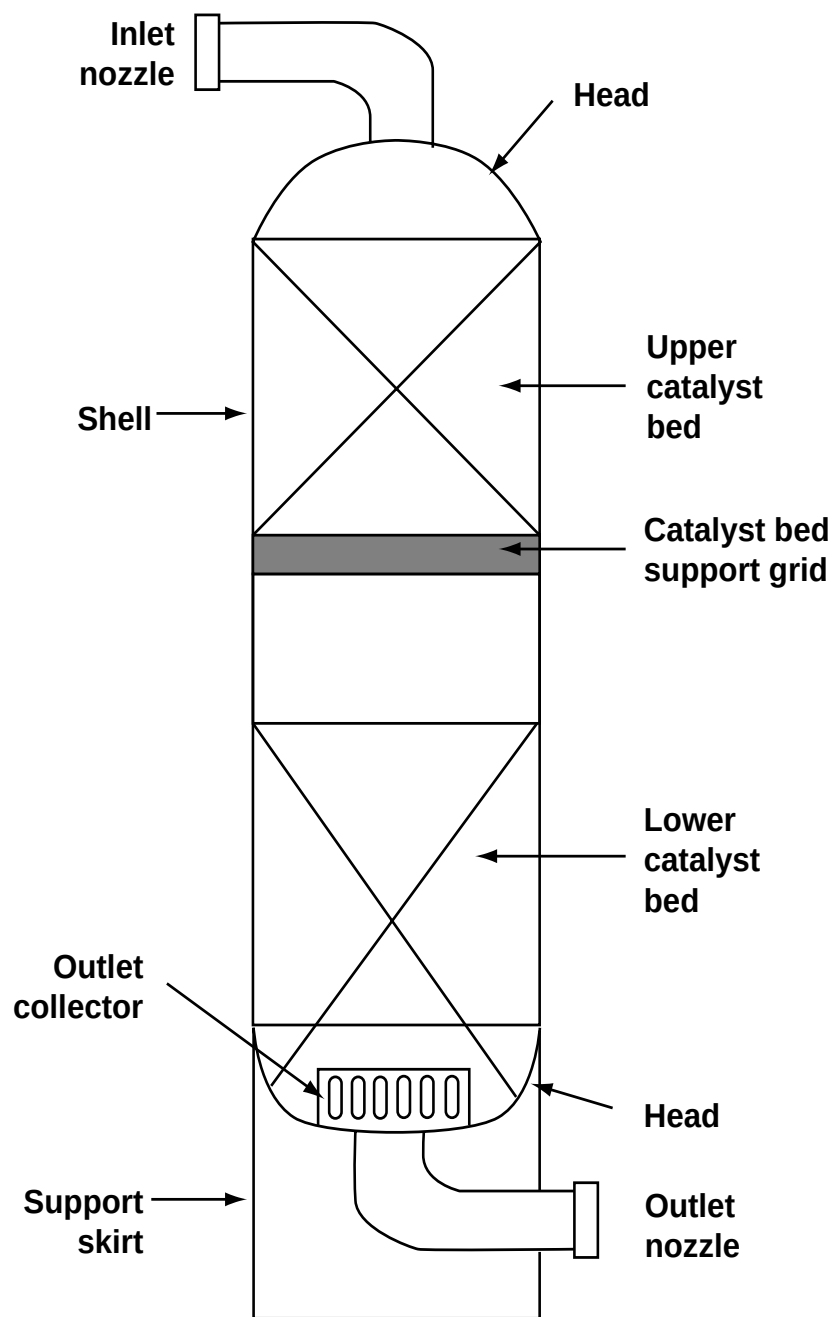
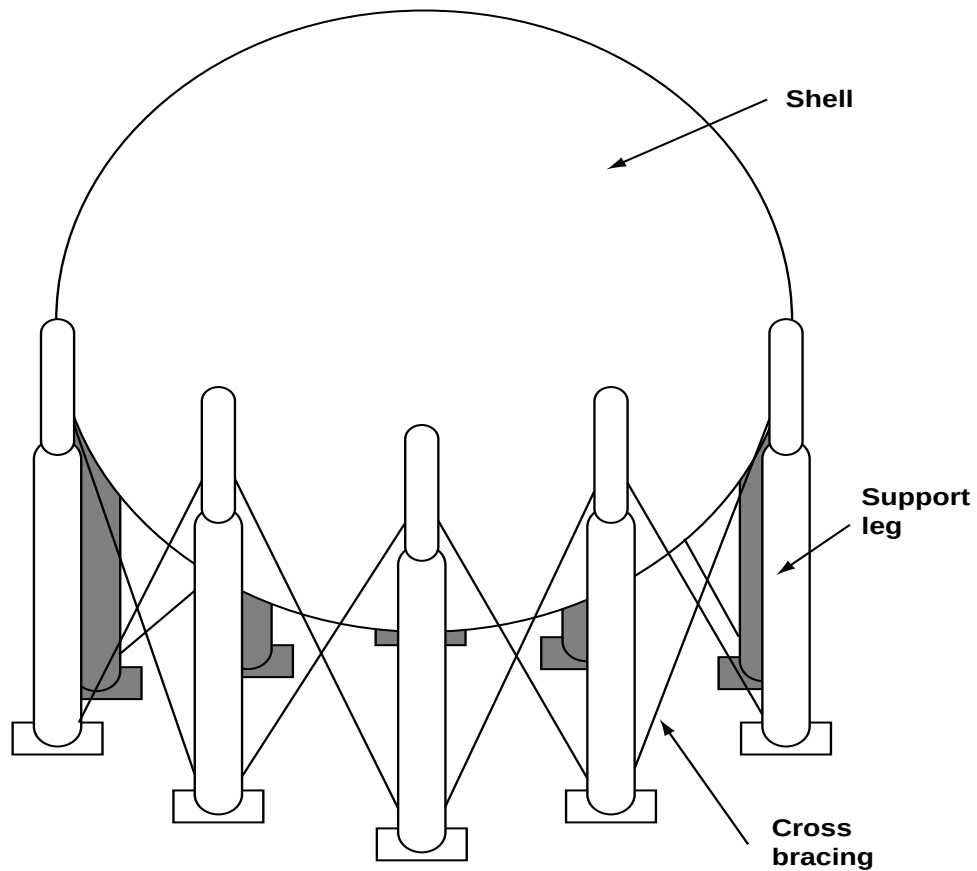


Figure 4: Vertical Reactor

Figure 5 shows a pressurized storage vessel with a spherical shell.



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Figure 5: Spherical Pressurized Storage Vessel

Head

All pressure vessel shells must be closed at the ends by heads (or another shell section). Heads are typically curved rather than flat. Curved configurations are stronger and allow the heads to be thinner, lighter, and less expensive than are heads with a flat shape. The shape of the curve is usually semi-elliptical or hemispherical. The semi-elliptical shape is more common. Figures 1 through 4 show heads closing the cylindrical sections of the subject pressure vessels. The spherical pressurized storage vessels that is shown in Figure 5 does not have separate closure heads. Additional heads are not needed because the spherical shell completely closes the vessel.

Note that in Figure 4 there is an external outlet collector at the bottom head. The outlet collector is designed with openings that are sized to permit the required flow but not to allow any catalyst to escape downstream.

Nozzle

A nozzle is a cylindrical component that penetrates the shell and/or heads of a pressure vessel. Nozzles may be used for the following applications:

- Attaching piping systems that are used for flow into or out of the vessel.
- Attaching instrument connections, such as level gauges, thermowells, or pressure gauges.
- Providing access to the vessel interior at manways.
- Providing for direct attachment of other equipment items, such as a heat exchanger.

Nozzles may range in diameter from a 19 mm (0.75 in.) instrument connection to very large diameter process nozzles.

The nozzle ends are usually flanged to allow for the necessary connections and to permit easy disassembly for maintenance or access. Welded nozzle connections are sometimes used to prevent flange leakage, typically in high pressure and/or high temperature applications, where leakage could be especially dangerous. Nozzles are also sometimes extended into the vessel interior for some applications, such as for inlet flow distribution or in order to permit the entry of thermowells.

Figures 1 through 4 show nozzles that enter pressure vessels through the shell or heads.

Support

The type of support that is used for a pressure vessel depends primarily on the size and orientation of the pressure vessel.

In all cases, the pressure vessel supports must be adequate for the applied weight, wind, and earthquake loads. The design pressure of the vessel is not a consideration in the design of the supports, since the supports are not subjected to the design pressure. Temperature may be a consideration in support design from the standpoint of material selection and provision for differential thermal expansion. The design of pressure vessel supports will be discussed further in MEX 202.03.

Saddle Supports

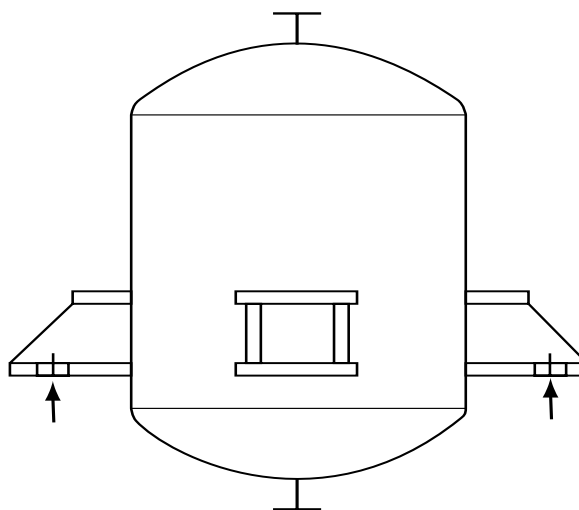
Horizontal drum pressure vessels, as shown in Figure 1, are typically supported at two locations by saddle supports. A saddle support spreads the weight load over a large area of the shell in order to prevent an excessive local stress in the shell at the support points. The saddle is typically in contact with the vessel shell circumference over a 120° angle. The width of the saddle, among other design details, is determined by the specific size and design conditions of the pressure vessel.

Leg Supports

Small vertical drums, as shown in Figure 2, are typically supported on legs that are welded to the lower portion of the shell. The maximum ratio of support leg length to drum diameter is typically 2:1. Reinforcing pads and/or rings must first be welded to the shell in order to provide additional local reinforcement and load distribution in cases where the local shell stresses are excessive. The number of legs that are required depends on the drum size and the loads to be carried. Support legs are also typically used for spherical pressurized storage vessels, as shown in Figure 5. The support legs for small vertical drums and spherical pressurized storage vessels may be made from structural steel columns or pipe sections, whichever provides a more efficient design. Cross bracing between the legs, as shown in Figure 5, is typically used to help absorb wind or earthquake loads.

Lug Supports

Lugs that are welded to the pressure vessel shell, as shown in Figure 6, may also be used to support vertical pressure vessels. The use of lugs is typically limited to vessels of small to medium diameter (0.3 to 3.0 m [1 to 10 ft.]) and moderate height-to-diameter ratios in the range of 2:1 to 5:1. Lug supports are often used within structural steel for vessels of this size range that are located above grade. The lugs are typically bolted to horizontal structural members.



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MEX 20201.F07

Figure 6: Vertical Vessel on Lug Supports

Skirt Supports

Tall, vertical, cylindrical pressure vessels, such as the tower and reactor shown in Figures 3 and 4 respectively, are typically supported by means of skirts. A support skirt is a cylindrical shell section that is welded either to the lower portion of the vessel shell or to the bottom head, in the case of cylindrical vessels. Skirts for spherical vessels are welded to the vessel near the mid-plane of the shell. Most skirt-supported vessels are supported back to grade; however, skirts may also be used for vessels that are elevated within a structure if it is more convenient to do so. In vessels that are elevated within a structure, the bottom of the skirt rests on horizontal structural members.

PRIMARY PROCESS FUNCTIONS OF PRESSURE VESSELS

This section identifies some of the typical process functions that pressure vessels perform. Process design engineers and mechanical engineers must know how pressure vessels are used, and they should understand how the use of pressure vessels affects mechanical design. Process design engineers must also understand that certain specifications will cause the mechanical design to be more difficult or costly than necessary. Mechanical design engineers can then ensure that the mechanical design will reflect the proper use of the pressure vessel. When process and mechanical design engineers are aware of each other's needs and cooperate in meeting these needs, a more cost-effective mechanical design can be developed to achieve the required process functions.

Process design engineers must also specify all the process design information that is required for the mechanical design of the vessel, such as operating pressure and temperature, vessel size, and overall geometry. The mechanical engineer uses this information for the detailed vessel design.

Fluid Separation

Fluid separation requires the use of either horizontal or vertical drums, such as those drums that are shown in Figures 1 or 2. The needs of a particular process determines the vessel orientation that is used. A fluid separation drum separates two liquids that have different densities, or separates a vapor from a liquid. A drum's internal design details, such as screens, baffles, and distribution pipes, facilitate the separation process. Gas/oil separation plants (GOSPs) use large horizontal drums as production traps, dehydrators, desalters, and slug catchers. Some important mechanical design considerations in these applications include the type and weight of internal components, maximum liquid level, and liquid specific gravity.

Filtration

Some drums, such as in Figures 1 or 2, serve as filters. In this case, a porous medium is installed inside the drum, and the process fluid passes over it. The type and weight of internals, maximum liquid level, liquid specific gravity, the expected pressure drop, and the filtration medium density, must all be specified in order to complete the mechanical design of the vessel internals and overall vessel support.

Distillation

A tall tower usually separates a hydrocarbon stream into different fractions. These fractionated streams are used at other stages in the process system. Separation uses a distillation process that is based on the different boiling points of hydrocarbon fractions. Trays (such as those shown in Figure 3) or packing materials control the flow distribution and velocity and aid the separation process. A temperature gradient exists along the length of the tower, and the bottom of the tower is hotter than the top. Normally liquid is at the bottom of the tower and vapor is at the top. Liquid, liquid/vapor, or vapor states exist along the length of the tower. Nozzles, that are located at several points along the tower, extract the fluid at a particular elevation (that is, at a certain temperature and pressure level) for use in other processing stages. The most significant mechanical design requirements that are determined by the process relate to pressure, temperature, and material selection. These requirements are discussed in later modules.

Other mechanical design factors to consider are as follows:

- Weight of tower internal components
- Operating temperature variations along the length of the tower
- Design pressure in the vapor space above the liquid
- Weight of the stored liquid
- Hydrostatic head of the liquid

Surge Absorption

Vertical or horizontal drums, such as the drums shown in Figures 1 or 2, may be used to absorb liquid flow or pressure surges that are caused by upstream stages of the process system. If a drum is used to absorb surges, the operating liquid level and/or pressure in the drum may vary over a relatively wide range; however, the drum prevents these process variations from affecting downstream equipment. A surge absorption drum is intended to produce more stable operations and eliminate the need to design downstream equipment to absorb these process variations. It should be noted that Saudi Aramco has numerous installed pressure vessels (particularly in instrument air systems) that are serving as "pressure reservoirs," and that they are incorrectly referred to as "surge tanks."

Steam Generation

A steam drum is usually horizontal, as shown in Figure 1, and generates steam from water at a specified pressure and temperature. After feedwater enters the steam drum, the temperature, pressure, and fluid circulation ensure that saturation conditions are maintained in the drum, which causes the water to boil.

The steam that is generated is removed by one or more nozzles that are located at the top of the drum.

Conversion

Reactors convert one hydrocarbon form into another hydrocarbon form that is required at a later stage of the processing operation. A chemical reaction performs this conversion inside the reactor. The chemical reaction normally takes place in the presence of a catalyst. Depending on the process, operating temperatures can reach 538°C (1 000°F) or more at pressures over 6 895 kPa (1 000 psig). Cylindrical reactors are typically used and their design details and volume requirements depend on the particular process. Conversion processes that are used by Saudi Aramco include Hydrotreating, Fluid Catalytic Cracking (FCC) and Hydrocracking.

The same factors that influence the mechanical design of distillation towers also apply to reactors. In addition, the mechanical design engineer must be aware of alternative operating scenarios that may apply which could affect the mechanical design. For example, many reactors must be designed for an in-place catalyst regeneration operation, in addition to the normal operating conditions. The catalyst regeneration operation will typically occur at a much lower pressure than is used for normal operation, but at a much higher temperature. The mechanical design of the reactor components must be based on the more severe of the two conditions.

Storage

Spherical or cylindrical storage vessels may be used to store hydrocarbon liquids at ambient temperature. The liquid may be the result of an intermediate refining step or a final product. The vapor pressure above the liquid in the vessel results from either the vapor pressure of the liquid at ambient temperature or pressurization from an outside source. A pressure vessel rather than a storage tank is used in situations where the required design pressure exceeds 103 kPa (15 psig).

SUMMARY

This module, *Basic Pressure Vessel Concepts*, has discussed the main components of pressure vessels and illustrated the different types of pressure vessels. The module also discussed the primary process functions of pressure vessels, and it identified several mechanical design considerations that apply to pressure vessels. This module, along with the prerequisite course CSE 110, has provided the necessary basis to begin more detailed discussion of pressure vessel design. This detailed discussion will begin with material selection in MEX 202.02.

GLOSSARY

alloy	An intentional combination of two or more substances, at least one of which is a metal that exhibits metallic properties. It can be either a mixture of two types of crystalline structures or a solid solution.
catalyst	A substance that alters the rate of a chemical reaction without changing itself or entering into the reaction.
corrosion	Deterioration of a material, usually a metal, due to its reaction with the environment. Corrosion may be caused either by direct chemical attack or by an electromechanical action.
dehydrator	A pressure vessel or process system for the removal of liquids from gases or solids by the use of heat, absorbents, or adsorbents.
desalter	A pressure vessel or process that extracts inorganic salts from oil.
distillation	The process of producing a gas or vapor from a liquid by heating the liquid in a vessel and collecting and condensing the vapors into liquids.
distillation column	A tall, cylindrical vessel in which liquid hydrocarbon feedstocks are separated into component fractions, rare gases, and liquid products of progressively lower gravity and higher viscosity.
feedstock	The raw or semi-finished material that is processed in a refinery or other processing plant.
feedwater	The water supplied to a boiler or pressure vessel.
filtration	A process of separating particulate matter from a fluid, such as air or a liquid, by passing the fluid carrier through a medium that will not pass the particulates.
fraction	A separate, identifiable part of crude oil; the product of a refining or distillation process.

flange	A projecting rim on an object that is used to keep it attached to another object by means of bolts and a gasket.
head	The end section of a pressure vessel.
hydrostatic pressure	The pressure at a point in a fluid that is at rest because of the weight of the fluid above it.
liquid holdup	A condition in two-phase flow through a vertical pipe; when gas flows at a greater linear velocity than the liquid, slippage takes place and liquid holdup occurs. In pressure vessel design, the level of liquid in a pressure vessel during its operation.
nozzle	A cylindrical opening in a pressure vessel that is used to convey fluid or to monitor operating conditions.
pipestill tower	A distillation tower in which heated oil is circulated, with continuous removal of overhead vapor, liquid bottoms, and other petroleum fractions from the side. This is the first pressure vessel that is used for distillation in a refinery.
pressure drop	The difference in pressure between two points in a flow system. Usually caused by frictional resistance to a fluid flowing through a conduit, filter media, or other system that conducts the flow of liquids.
shell	The outer, primary wall of a pressure vessel; the shell contains pressure.
slug catcher	A pressure vessel used to collect liquid that has accumulated in a gas transmission pipeline and that has been moved to the slug catcher by means of a scraper passed down the pipeline.
specific gravity	The ratio of the density of a material to the density of some standard material, such as water at a specified temperature.
temperature gradient	The temperature variation per unit of distance or time along the flow path of heat.

thermowell	A closed, cylindrical component that contains one or more thermocouples.
tray	A baffle along the height of a tall vertical tower that controls flow distribution of the liquid and vapor in the tower.
upstream	That portion of a process stream that has not yet entered the system or unit under consideration.