My Engineering World

An Introduction To Pressure Vessels

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Thessaloniki, Greece – 17/2/2014

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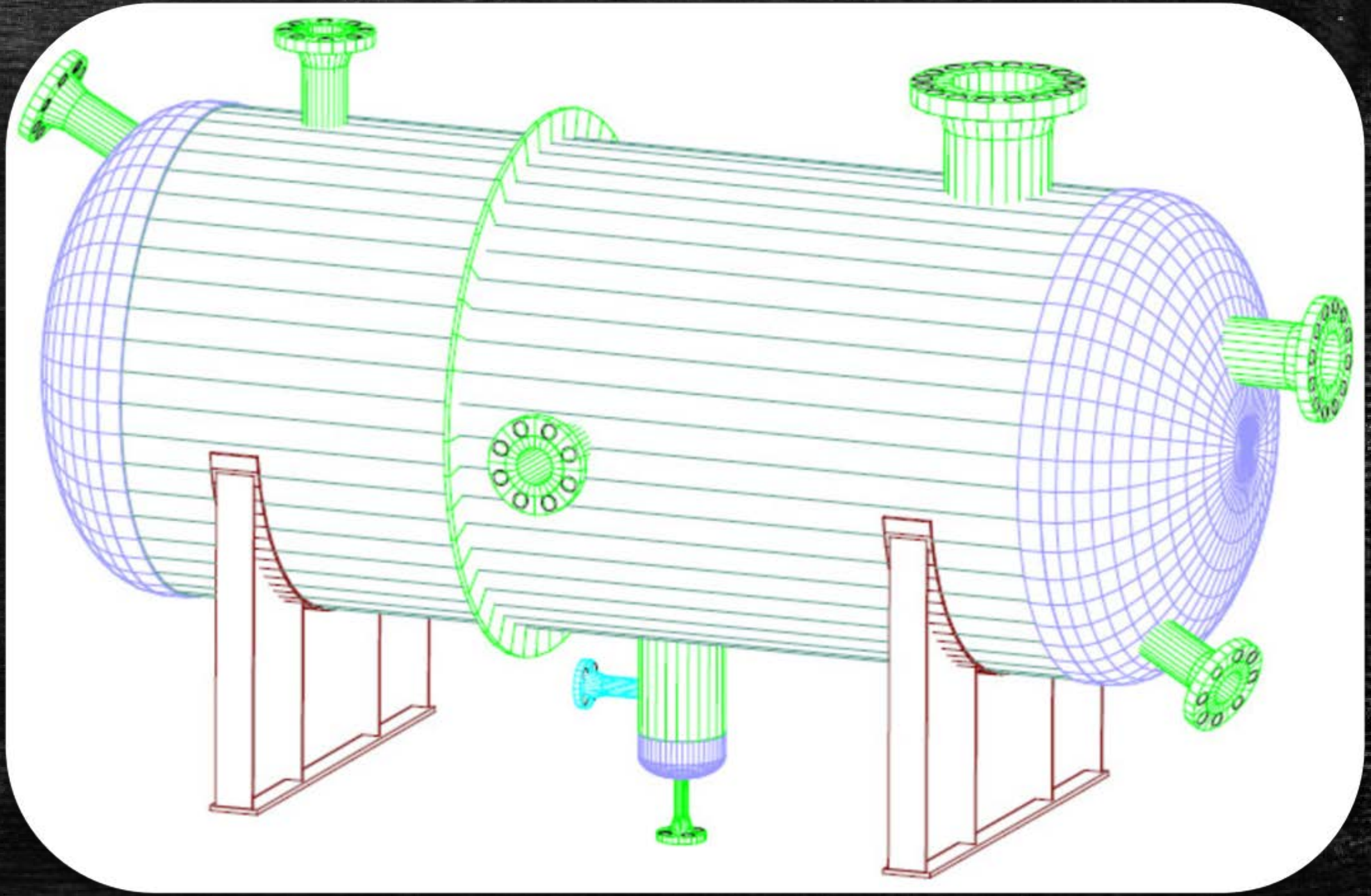


1. Definition

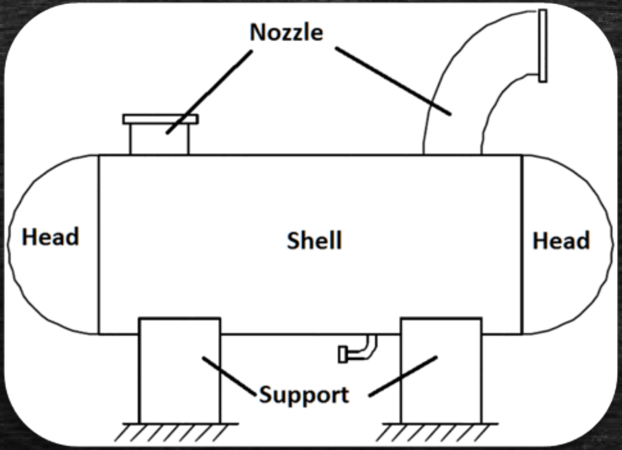
- A pressure vessel is a container designed to hold gases or liquids at a pressure different from the ambient pressure.
- According to ASME (Section VIII, Division 1): " *Pressure Vessels are containers for the containment of pressure either external or internal. The pressure may be obtained from an external source, or by the application of heat from a direct or indirect source, or any combination thereof".*
- Pressure vessels can be found in a variety of industries like:
  - Petroleum refining
  - Chemical
  - Power
  - Food & beverage
  - Pharmaceutical

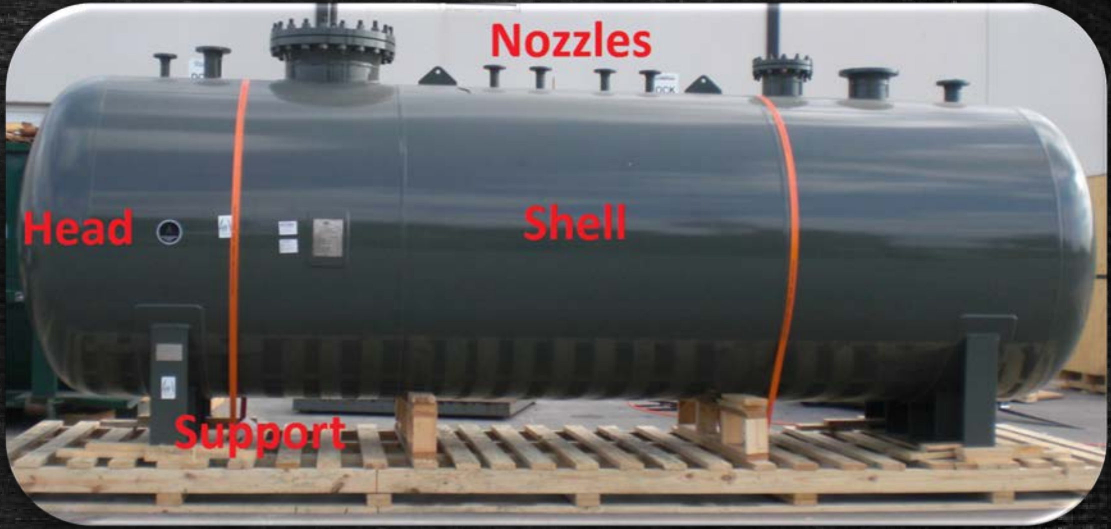
2. Classification

- Manufacturing method:
  - Welded
  - Forged
  - Multiwall
  - Multiwall wrapped
  - Band wrapped
- Manufacturing material:
  - Steel
  - Non ferrous
  - Non metallic
- Geometric shape:
  - Cylindrical
  - Spherical
  - Rectangular
  - Combined
- Installation method:
  - Horizontal
  - Vertical
- Pressure-bearing situation:
  - Internal
  - External
- Wall thickness:
  - Thin-wall
  - Thick-wall
- Technological process:
  - Reaction
  - Heat exchanger
  - Separation
  - Storage container
- Operating temperature:
  - Low (<= -20°C)
  - Normal (-20°C – 150°C)
  - Medium (150°C – 450°C)
  - High (>=450°C)
- Design pressure:
  - Low (0.1MPa – 1.6MPa)
  - Medium (1.6MPa – 10MPa)
  - High (10MPa – 100MPa)
  - Ultra High (>100MPa)
- Usage mode:
  - Fixed
  - Mobile

3. Main Components

- In general, the main components of a pressure vessel are:
  - ➢ Shell
  - ➢ Heads
  - ➢ Nozzles
  - ➢ Supports





- **Shell:**
  - ➢ The primary component that contains the fluid, and, consequently, the pressure.
  - ➢ Different plates are welded together to form a structure that has a common rotational axis.
  - ➢ Is usually cylindrical, spherical or conical in shape.
  - ➢ Horizontal drums have cylindrical shells and are constructed in a wide range of diameter and length.
  - ➢ The shell section of a tall tower can be constructed from different materials, thicknesses and diameters due to process and phase change of the fluid.
  - ➢ A spherical pressure vessel has a spherical shell as well.

3. Main Components (continue…)

- **Head:**
  - All pressure vessels must be closed with heads or other shell sections.
  - Heads are typically curved rather than flat. Curved configurations are stronger and allow the heads to be thinner, lighter and less expensive than flat heads.
  - When heads are used inside the pressure vessel – intermediate heads – separate the vessel into sections, allowing different design conditions in each section.

- **Nozzle:**
  - A nozzle is a cylindrical component that penetrates into the shell or the head of the pressure vessel.
  - They are used for the following applications:
    - ✓ Attach piping for flow into or out of the vessel.
    - ✓ Attach instrument connection (pressure gauges etc.).
    - ✓ Provide access to the vessel interior (manway).
    - ✓ Provide for direct attachment of other equipment items (e.g. heat exchangers).

3. Main Components (continue…)

- **Support:**
  - Supports are used to bear all the load of the pressure vessel, along with earthquake, as well as wind loads.
  - They are the non-pressurized part of the vessel.
  - There are different types of supports which are used depending on the size and orientation of the pressure vessel. Typical support types:
    - ✓ Saddle support
    - ✓ Leg support
    - ✓ Lug support
    - ✓ Ring support
    - ✓ Skirt support

Saddle support

- **Saddle support:**
  - Horizontal drums are typically supported at two locations by saddle support.
  - It spreads over a large area of the shell to prevent an excessive local stress in the shell at support point.
  - One saddle support is anchored whereas the other is free to permit unstrained longitudinal thermal expansion of the drum.

3. Main Components (continue…)

- **Leg support:**
  - Small vertical drums 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 are welded to the shell first to provide additional local reinforcement and load distribution.
  - The number of legs depends on the drum size and loads to be carried.
  - Support legs are also used for spherical pressurized storage vessels.
  - Cross bracing between the legs is used to absorb wind or earthquake loads.

- **Lug support:**
  - Vertical pressure vessels may also be supported by lugs.
  - The use of lugs is typically limited to pressure vessels of small and medium diameter (1 to 3 m/1 to 10 ft) .
  - Also moderate height to diameter ratios in the range of 2:1 to 5:1.
  - The lugs are typically bolted to horizontal structural members in order to provide stability against overturning loads.

3. Main Components (continue…)

- **Ring support:**
  - ➢ Ring supports are used when the local stresses at the lugs become excessively high.
  - ➢ Typically, vessels supported by rings or lugs are contained within a structure rather than supported at grade.
  - ➢ Vessels supported on rings should only be considered for lower or intermediate temperatures (below 400 or 500 °C). Using ring supports at higher temperatures could cause extremely large discontinuity stresses in the shell immediately adjacent to the ring due to the differences in expansion between the ring and the shell.

- **Skirt support:**
  - ➢ Tall vertical cylindrical pressure vessels are typically supported by 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 (for cylindrical vessels).
  - ➢ The skirt is normally long enough to provide enough flexibility so that radial thermal expansion of the shell does not cause high thermal stresses at its junction with the skirt.

4. Materials

- The mechanical design of a pressure vessel can proceed only after the materials have been specified. The ASME Code does not state what materials must be used in each application. It specifies what materials may be used for ASME Code vessels, plus rules and limitations on their use. But, it is up to the end user to specify the appropriate materials for each application considering various material selection factors in conjunction with ASME Code requirements. Typical materials used: steel, aluminum, other metals, carbon fibers and polymers.

- The main factors that influence material selection are:
  - Strength
  - Corrosion resistance
  - Resistance to hydrogen attack
  - Fracture toughness
  - Fabricability
  - Cost
  - Availability
  - Ease of maintenance

4. Materials (continue…)

- **Strength:**
  - Strength is the material's ability to withstand an imposed force or stress.
  - Strength determines how thick a component must be to withstand the imposed loads.
  - The overall strength of a material is determined by its yield strength, ultimate tensile strength, creep and rupture strengths. These strength properties depend on the chemical composition of the material. Creep resistance (a measure of material strength at elevated temperature) is increased by the addition of alloying elements such as chromium, molybdenum, and/or nickel to carbon steel. Therefore, alloy materials are often used in elevated temperature applications.

- **Corrosion resistance:**
  - Corrosion is the deterioration of metals by chemical action.
  - A material's resistance to corrosion is probably the most important factor that influences its selection for a specific application.
  - The most common method that is used to address corrosion in pressure vessels is to specify a corrosion allowance. A corrosion allowance is supplemental metal thickness that is added to the minimum thickness that is required to resist the applied loads. This added thickness compensates for thinning (i.e., corrosion) that will take place during service.
  - The corrosion resistance of carbon steel could be increased through the addition of alloying elements such as chromium, molybdenum, or nickel. Alloy materials, rather than carbon steel, are often used in applications where increased corrosion resistance is required in order to minimize the necessary corrosion allowance.

4. Materials (continue…)

- **Resistance to hydrogen attack:**
  - At temperatures from approximately 300°F to 400°F, monatomic hydrogen diffuses into voids that are normally present in steel. In these voids, the monatomic hydrogen forms molecular hydrogen, which cannot diffuse out of the steel. If this hydrogen diffusion continues, pressure can build to high levels within the steel, and the steel can crack.
  - At elevated temperatures, over approximately 600°F, monatomic hydrogen not only causes cracks to form but also attacks the steel. Hydrogen attack differs from corrosion in that damage occurs throughout the thickness of the component, rather than just at its surface, and occurs without any metal loss. In addition, once hydrogen attack has occurred, the metal cannot be repaired and must be replaced. Thus, it is not practical to provide a corrosion allowance to allow for hydrogen attack. Instead, materials are selected such that they are resistant to hydrogen attack at the specified design conditions.
  - Hydrogen attack is a potential design factor at hydrogen partial pressures above approximately 100 psia. Material selection for these hydrogen service applications is based on API 941, Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants. API 941 contains a family of design curves (the Nelson Curves) that are used to select appropriate material based on hydrogen partial pressure and design temperature.

4. Materials (continue…)

- **Fracture toughness:**
  - Fracture toughness refers to the ability of a material to withstand conditions that could cause a brittle fracture.
  - The fracture toughness of a material can be determined by the magnitude of the impact energy that is required to fracture a specimen using Charpy V-notch test. Generally speaking, the fracture toughness of a material decreases as the temperature decreases (i.e., it behaves more like glass).
  - The fracture toughness at a given temperature varies with different steels and with different manufacturing and fabrication processes.
  - Material selection must confirm that the material has adequate fracture toughness at the lowest expected metal temperature. It is especially important for material selection to eliminate the risk of brittle fracture since a brittle fracture is catastrophic in nature. It occurs without warning the first time the necessary combination of critical size defect, low enough temperature, and high enough stress occurs.

5. Manufacturing Process

- The manufacturing process of pressure vessels involves 8 sub-processes: Forming → Pressing → Spinning → Bending → Welding → Post Weld Heat Treatment (PWHT) → Assembly → Painting.

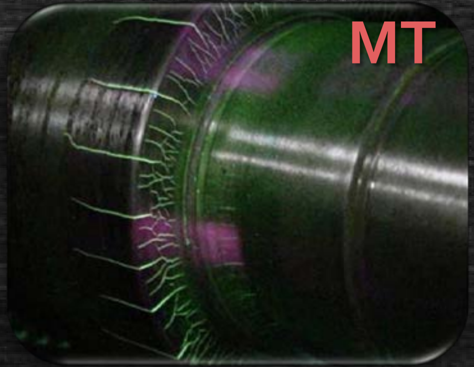
1. Forming:
   - A process in which the size or shape of the part is changed by application of force.
   - Typical types of forming:
     - ✓ Hot forming: fabrication temperature is above the recrystallization temperature of the material.
     - ✓ Warm forming: fabrication temperature is above room temperature but below recrystallization temperature of the material.
     - ✓ Cold forming: fabrication temperature is very much below the recrystallization temperature of the material.
   - Recrystallization: A process in which deformed grains are replaced by new non-deformed grains.
   - Recrystallization temperature: the minimum temperature at which complete recrystallization occurs.

5. Manufacturing Process (continue…)

2. Pressing: A process wherein a pressing machine is used to shape the part needed.
3. Spinning: The process used to shape the end of the pressure vessel, which is called the head. After pressing, the material is loaded into the spinning machine. While spinning, the material is formed using adjustable rollers until the final shape is achieved.
4. Bending process: A process in which the material is curved to the desired radius, using a bending machine. It also called rolling.
5. Welding: Process by which two or more materials are joined permanently by melting both materials.
6. Post Weld Heat Treatment (PWTH): A process of improving the properties of the weldment, using a furnace to heat the product.
7. Assembly: The process of joining the parts of the pressure vessel.
8. Painting: The process of applying paint to protect the product from corrosion.

6. Testing

- **Non-Destructive Tests (NDTs):** A wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. Typical tests include:
  - ➢ Visual inspection (VT)
  - ➢ Liquid penetrant testing (PT)
  - ➢ Magnetic particle inspection (MT)
  - ➢ Ultrasonic testing (UT)
  - ➢ Radiographic testing (RT)



- **Leak testing methods:** Containers, vessels, enclosures, or other fluid system are sometimes tested for leaks - to see if there is any leakage and to find where the leaks are, so corrective action can be taken. There are many different methods for pressure and leak testing in the field. Some typical examples:
  - ➢ Hydrostatic testing
  - ➢ Pneumatic or gaseous-fluid testing
  - ➢ Combined pneumatic and hydrostatic testing
  - ➢ Initial service testing
  - ➢ Vacuum testing
  - ➢ Static head testing
  - ➢ Halogen and helium leak detection test

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