INTRODUCTION & ASME BPV CODE, SECTION VIII

DESIGN OF PRESSURE VESSELS FOR INDUSTRIAL PLANTS

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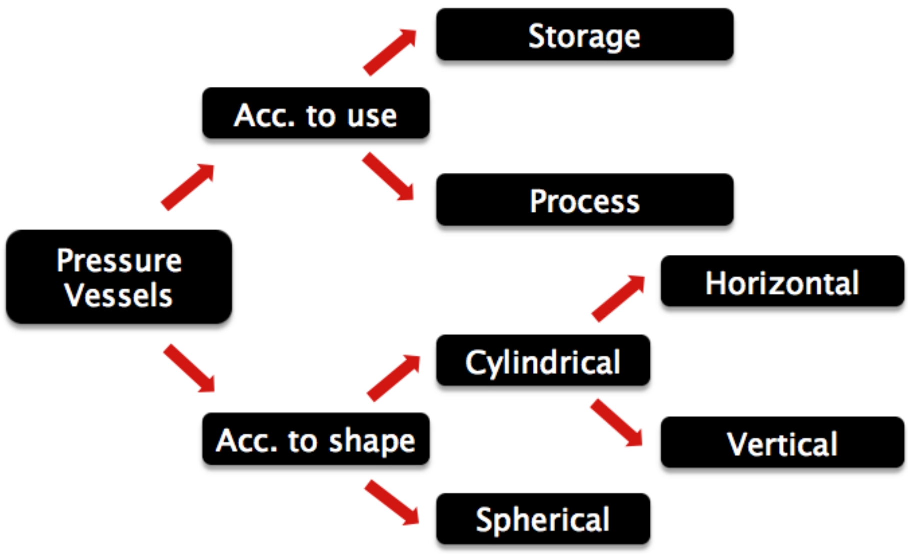
Introduction

A pressure vessel is any closed vessel that is capable of storing a pressurized fluid, whether the pressure is internal or externally applied, regardless of their shape and dimensions. This guide covers vessels which can be calculated and analysed as thin-walled cylinders.

The first step in designing a vessel is choosing the most appropriate type for its intended service. **The factors influencing this choice are the function of the vessel, the location, the nature of the fluid to be stored, the operating temperature and operating pressure** and their ability to store the volume needed by the process.

Pressure vessels can be classified according to their intended service, temperature and pressure, materials and geometry. Different types of pressure vessels can be classified as follows:



Classification of pressure vessels according to their use and shape.

Based on the intended use of the pressure vessel, they can be divided into storage vessels and process vessels.

The first classification is only used for storing fluids under pressure, and in accordance with the service are known as storage tanks.

Process pressure vessels have multiple and varied uses, for example heat exchangers, reactors, fractionating towers, distillation towers, etc.

Pressure vessels may be cylindrical or spherical (classification according to shape). Cylindrical vessels may be horizontal or vertical, and in some cases may have coils to increase or lower the temperature of the fluid.

Source: *Courtesy of Innovative Industrial Fabrication*

Example of Spherical and Cylindrical vessels.

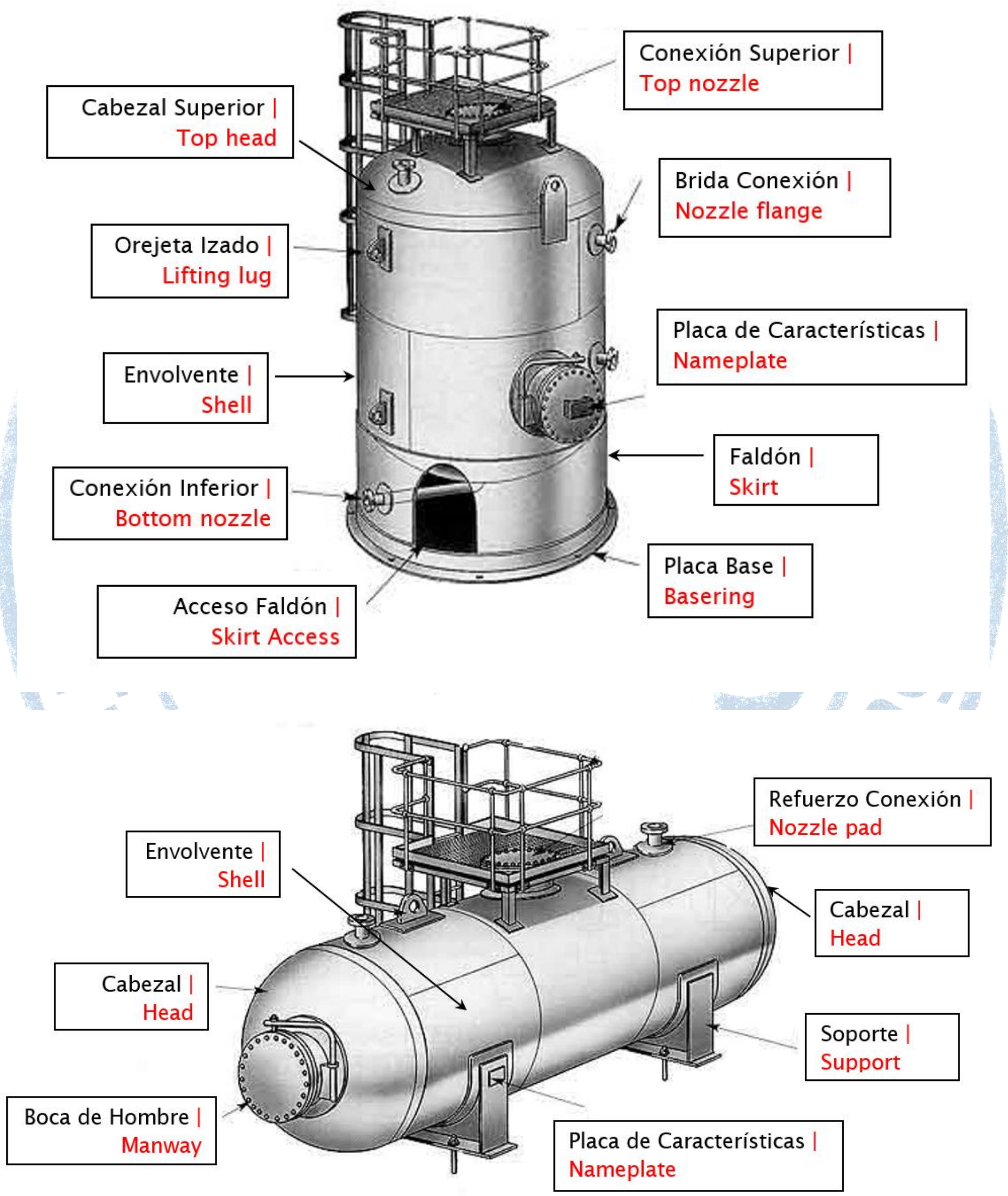
Spherical pressure vessels are usually used as storage tanks and are recommended for storing large volumes.

Since the spherical shape is the "natural" form bodies adopt when subjected to internal pressure, this would seem to be the most economical way to store pressurized fluids. However, the manufacture of these vessels is much more expensive compared to cylindrical vessels.

1. Configuration and design codes

1.1) Pressure vessel components

Two sample vessels are presented: vertical and horizontal. In both cases the main components are shown:



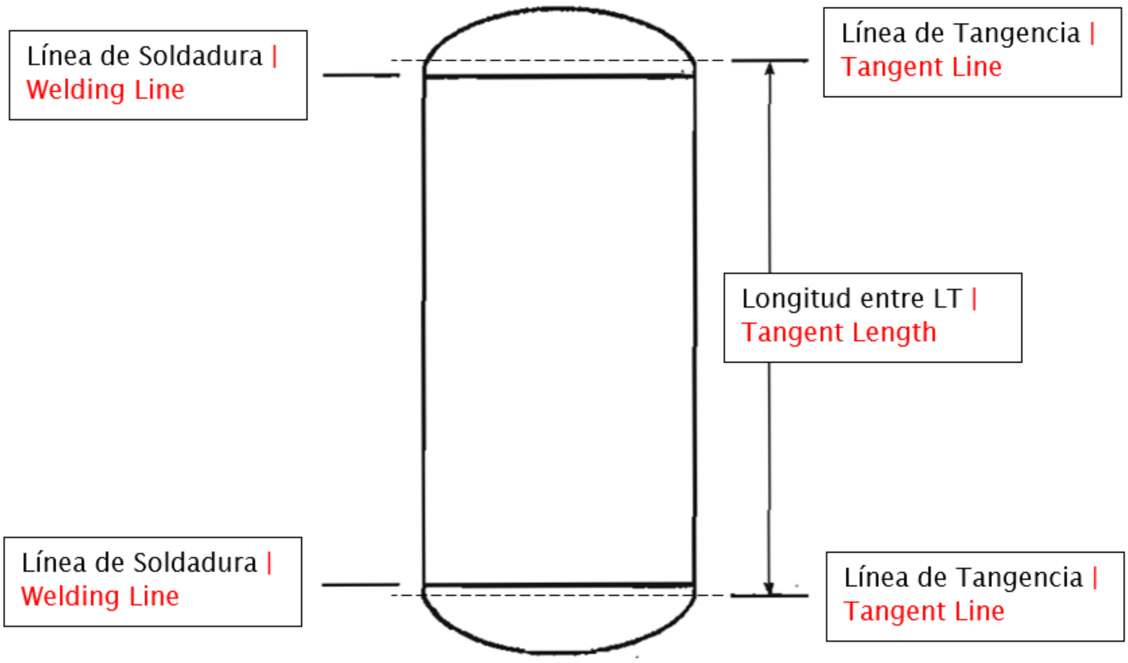
Components of vertical and horizontal pressure vessels.

1.2) Geometry

To define the geometry of a pressure vessel, the inner diameter of the vessel and the distance between tangent lines is used.

The inner diameter should be used, since this is a process requirement.

- Welding line: point at which the head and shell are welded
- Tangent line: point at which the curvature of the head begins



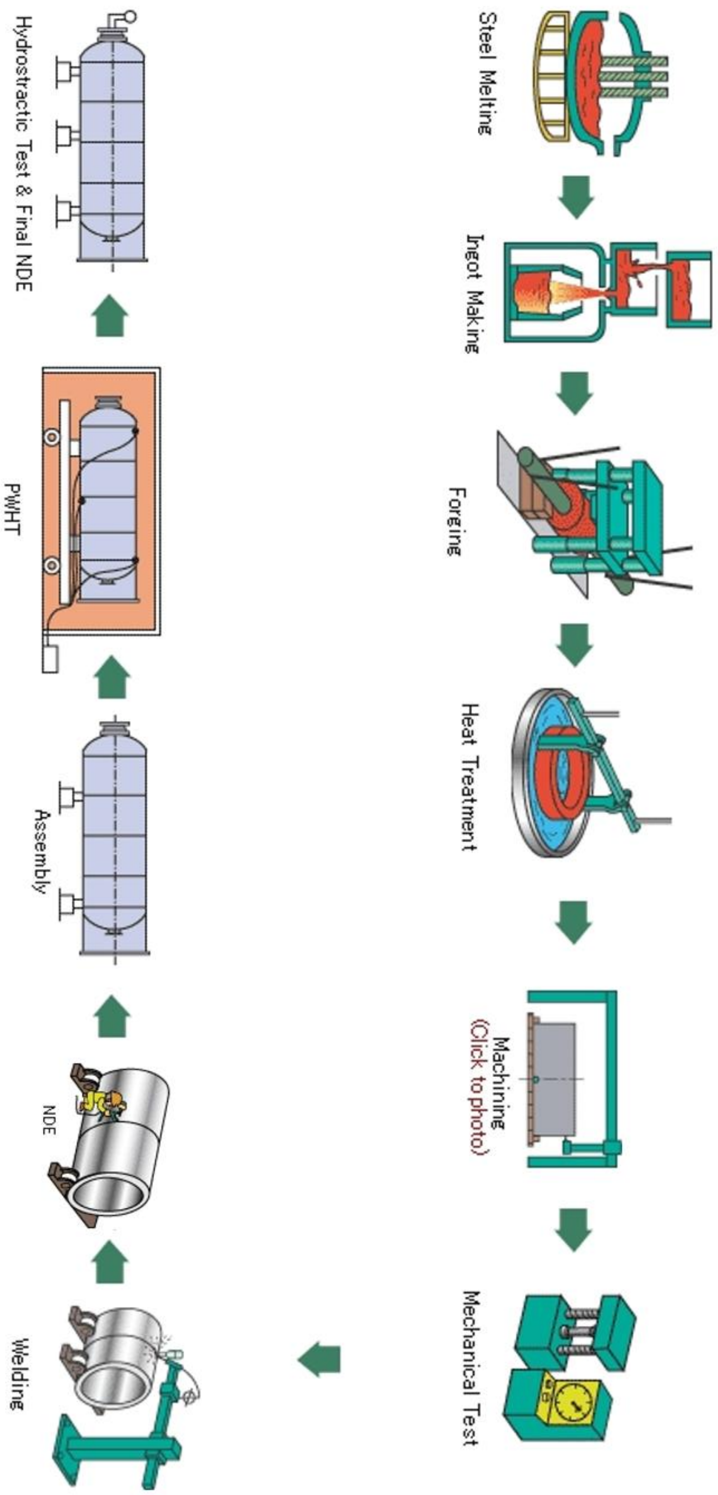
Welding and Tangent lines in pressure vessels.

Depending on the head fabrication method, heads come with a straight skirt.

The distance between tangent lines is used to determine the length of a pressure vessel since this distance is not dependent on the head manufacturing method. It is very rare for the weld and tangent lines to coincide.

1.3) Manufacturing sequence

The manufacturing sequence of a pressure vessel involves the following steps:



Typical manufacturing sequence in pressure vessels.

1.4) Design codes

The purpose of using design codes is to avoid disasters that can affect humans and/or the environment. They comprise a wide range of experiences and good practices.

The most internationally recognized and the most commonly used code is Section VIII "Pressure Vessels" part of the Boiler and Pressure Vessel Code (BPVC) of the American Society of Mechanical Engineers (ASME).

There are other codes, developed by countries with recognized technical expertise. The most commonly used codes for pressure vessels are:

- Europe: EN-13445
- Germany: A. D. Merkblatt Code
- United Kingdom: British Standards BS 5500
- France: CODAP
- China: GB-150

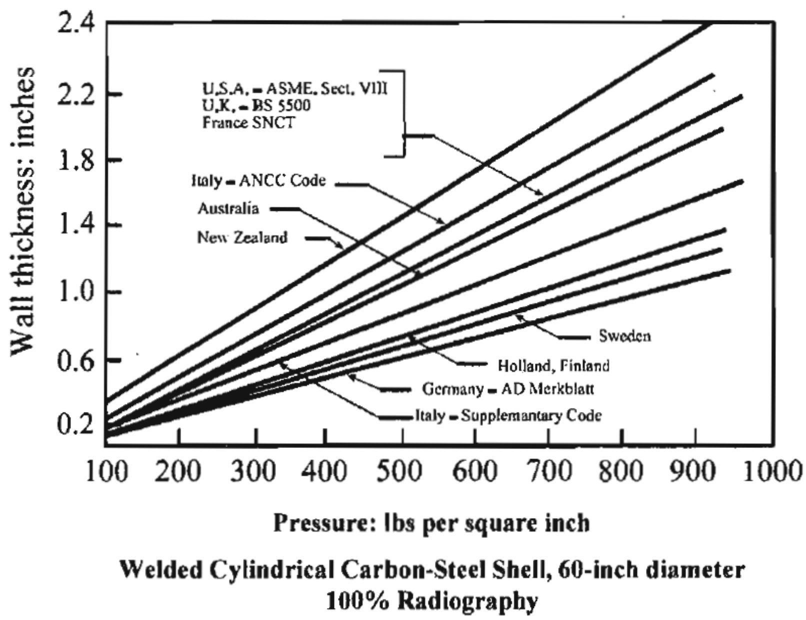
The rules found in the design codes represent many years of experience. If used properly, the code requirements:

- Communicate design requirements
- Utilize know-how and technology
- Keep equipment costs low
- Reduce insurance costs
- Provide rules for the design of equipment adequate for a wide range of design conditions.
- Usually provide guidance for new construction only, not revamps, repairs or rerates.
- Do not provide rules or guidance for the determination of design conditions.
- Do not provide rules or guidance for the determination of the required material(s) of construction or corrosion allowance.

1.4.1) Codes comparison

Design code provisions are an interrelated set of design, fabrication, inspection, and testing requirements. For example, using a higher design stress may require the use of more stringent material, analysis, examination, and testing requirements.

Using different codes can result in different wall thicknesses, yet have equivalent degrees of reliability.



Minimum required thicknesses as per different design codes.

2. ASME BPVC – Boiler and pressure vessel code

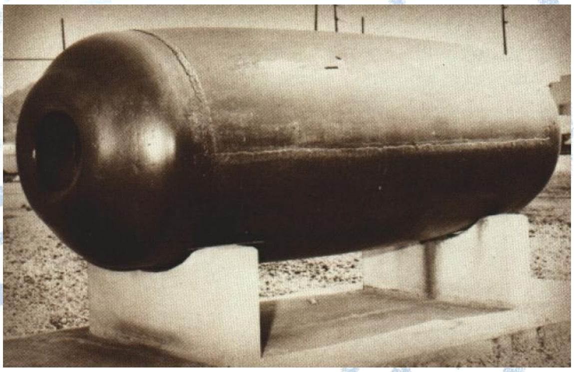
2.1) Historical review

By the end of the 18th century the use of boilers operating at pressures much higher than the atmospheric increased dramatically, due to the industrial revolution. In many cases, the result of operating these boilers and vessels were catastrophic, and there were many injuries and fatalities.

Several attempts were made to standardize the design criteria and calculations, but in 1911, due to the lack of uniformity in boiler fabrication, manufacturers and users of boilers and pressure vessels requested the ASME association to correct this situation.

Finally, in 1915, that association published the first ASME Boiler Code (now Section I) in the United States of America. The codes were established to provide manufacturing methods, records and to report design data.

Until 1930, when the first welded vessel was manufactured, pressure vessels and boilers were riveted. Joints were made "overlapping" the plates or using strips, placed on the joints, drilling and tightening the rivets. Each rivet added pressure in a certain influence area, thus guaranteeing the integrity of the equipment.



Riveted pressure vessel (left) and first welded Pressure Vessel (right).

Historically, engineers have applied the traditional strength of materials rules for designing pressure vessels. They are still used today, but are combined with:

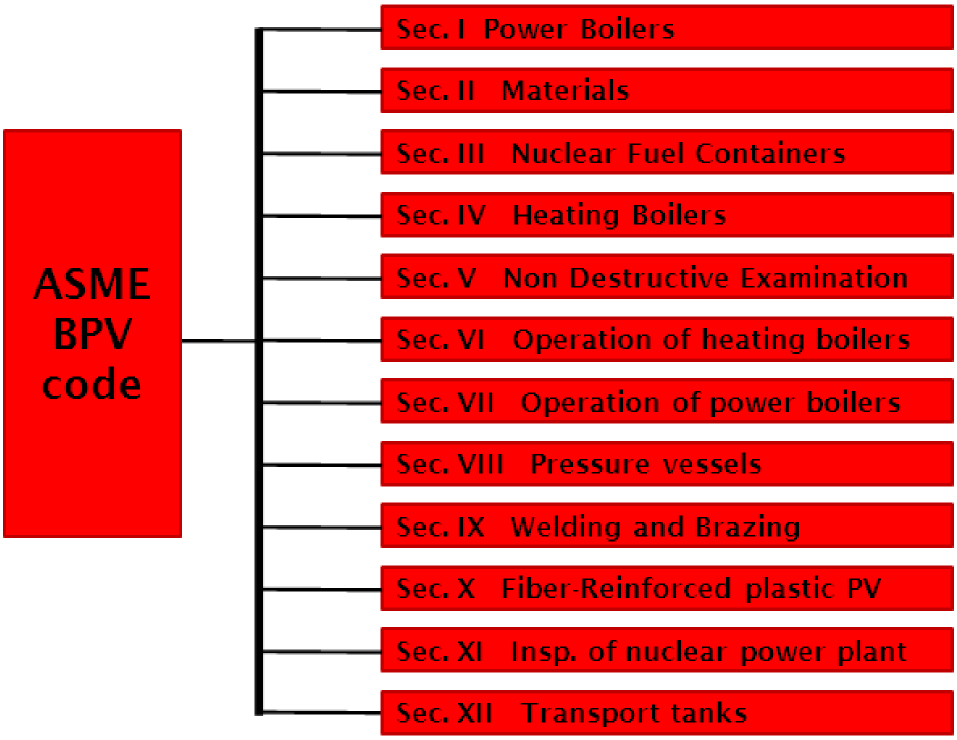
- Non-destructive examination (NDE)
- Safety coefficients
- Lessons learned

In addition to the aforementioned; nowadays checks using Finite Element Analysis (FEA) are done extensively, with outstanding results. Therefore, this powerful tool should be used if necessary.

2.2) BPVC Sections

The ASME BVPC code is a set of standards, specifications, and design rules based on many years of experience, all applied to the design, fabrication, installation, inspection, and certification of boilers and pressure vessels.

It was created because several insurance companies demanded a design code in order to reduce losses and casualties. The ASME Boiler and Pressure Vessel is divided into the following sections:



Boilers and Pressure Vessels Code organization.

The twelve sections of the code are shown in the above figure. To properly design a pressure vessel, it is necessary not only to understand and utilize Section VIII, but additionally, the designer needs to be familiar with Sections II, V and IX.

The 12 parts can be grouped as follows, according to the scope of each section:

- Construction codes: Sections I, III, IV, VIII, X & XII
- Reference codes: Sections II, V, IX
- Rules for operating, inspection and in-service maintenance: Sections VI, VII & XI.

2.3) Section VIII Divisions

The ASME Code Section VIII is a fabrication code. It contains mandatory requirements, specific prohibitions, and rules for construction and non-mandatory appendices. The code does not cover all possibilities related to these activities, therefore, aspects not specifically mentioned should not be considered prohibited.

The code is written by recognized people from different areas: academics, inspection agencies, owners, users, manufacturers of pressure vessels and notified bodies or professional associations.

Understanding the code's organization and knowing where to look things up is an important aspect of using the code. IT IS ALSO IMPORTANT TO READ UNTIL THE END OF THE PARAGRAPH; EVEN THOUGH IT MIGHT SEEM AS IF THE SOLUTION IS OBVIOUS.

There are 3 divisions in ASME Section VIII: divisions 1, 2 and 3. Division 3 is used to calculate and design high-pressure equipment, around 703 barg (10,000 psig), while Div. 2 and Div. 1 are used for the remaining applications.

Equipment design according to Div. 1 is based on rules that do not require detailed assessment of all stresses. There are large secondary stresses and also bending stresses present, but the conservative safety factors compensate for these stresses.

When designing according to Div. 2 a more detailed analysis is performed enabling the designer to consider higher allowable stresses and thus produce much more realistic, economical and precise results.

Another difference between the ASME VIII Div. 2 and Div. 1 lies in failure theory used to establish the calculation equations. While Div. 1 is based on the theory of normal stress, Div. 2 is based on the theory of maximum distortion energy (Von Mises).

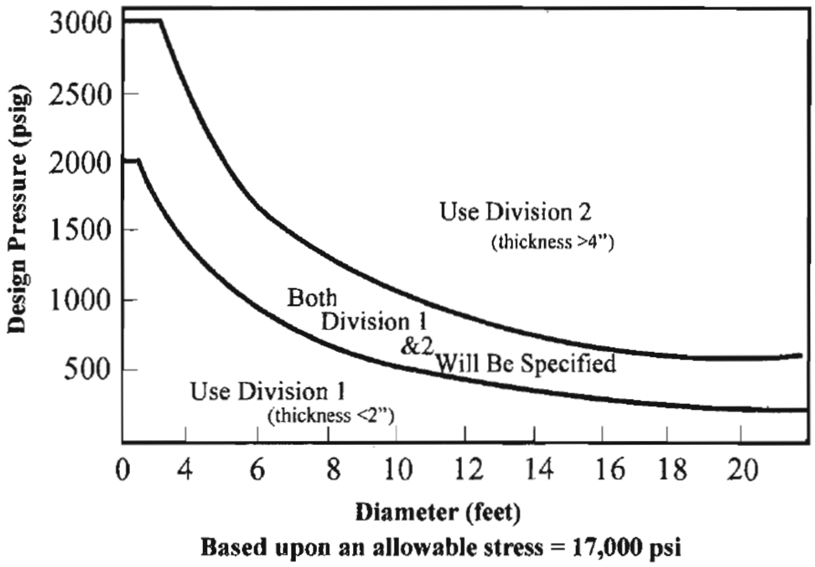
Additionally, the approach is different between divisions; for Div. 1 the design is by rules, whereas for Div. 2 the design is by analysis, a much more exact method.

The most important limitations of Div. 1 are regarding pressure. When the design pressure exceeds 210 bar (3,000 psi); design according to Div. 2 is required. Additionally, Div. 1 cannot be used for pressures below 1.054 bar (15 psi).

Other than the pressure limitation, the scope of both Div. 1 and Div. 2 is the same, and the main differences are:

- Allowable stresses
- Stress calculations
- Cyclic service design
- General design
- Quality control
- Inspection and fabrication requirements

There are no clear rules about when to use each division. Each case is different, and the designer must analyse all design conditions to determine which division to use. If an individual designer deems it appropriate, the design shall be carried out according to both divisions to compare results. Even though a general rule cannot be listed, a chart containing some tips is presented below:



Div. 1 vs Div. 2 indicative selection chart.

Div. 1 specifies general conservative design criteria (design-by-rules), while Div. 2 (design-by-analysis) provides a more precise design, using stresses close to the expected ones. The latter combined with more stringent non-destructive examination, results in a more economical design.

3. ASME BPVC Section VIII, Division 1

3.1) Scope

The extent of coverage of VIII-1 is defined in section U-1. The word "Scope" actually refers to two terms: the type of equipment as well as the geometry of the pressure vessel.

Before any design, it is recommended that the designer carefully reviews paragraph U-1, to determine whether the equipment can be designed according to the code and its implications. The main considerations included in the scope of the code are summarized below:

- U-1(a) (2) pressure vessels are defined as vessels for the "containment" of internal or external pressure. This definition applies to a very wide range of pressure vessels, some of which have not been considered in the development of the rules. In order to avoid confusion about what kind of pressure vessel is covered by VIII-1, the Committee preferred to list the equipment "not covered in the development of the rules" instead of making a list of the ones that were included.

- U-1(c)(2) indicates that VIII-1 is not applicable for the following pressure vessels:

  (a) Those included in the scope of other sections of the ASME Code.

  (b) Process tubular heaters.

  (c) Pressure vessels that are integral part of machines (rotating equipment)

- U-1(c)(2)(d) piping systems are excluded from the scope of VIII-1. Establishing the difference between a piping system and a pressure vessel sometimes can be complicated:

  (a) If the main purpose of the pressure vessel is to transfer fluid from one point to another in the system, then it could be considered to be piping, and it must comply with piping code requirements.

  (b) If the main purpose of internal components such us fractionating trays or demisters is not to transfer fluid, but they are installed for process reasons, they must be included in the scope of VIII-1.

- U-1(c) (2) (h) defines the scope regarding pressure. If a vessel has an internal or external pressure less than 100 kPa than it is outside of the scope of VIII-1.

- U-1(c) (2) (i) pressure vessels smaller than 152mm for either internal diameter, width, height or diagonal, are considered outside of the scope of VIII-1, regardless of their length or design pressure.

- U-1(c) (2) (j) pressure vessels for Human Occupancy (PVHO) are outside the scope of VIII-1. The design code in this case is ANSI/ASME PVHO-1.

- U-1(g) some equipment to generate steam are included in the scope of VIII-1.

  (a) U-1(g)(1): unfired boilers can be fabricated according to Section I or Section VIII-1 (see UG-125(b) and UW-2(c))

(b) U-1(g)(2) the following pressure vessels, in which steam is generated, are included in the scope of VIII-1.

- U-1(g) (2) (a): pressure vessels known as evaporators or heat exchangers.
- U-1(g) (2) (b): pressure vessels in which steam is generated due to heat present in a system or process.

- U-1(e) defines the scope in terms of geometry. The restrictions and extent of the pressure vessel are defined according to the following:

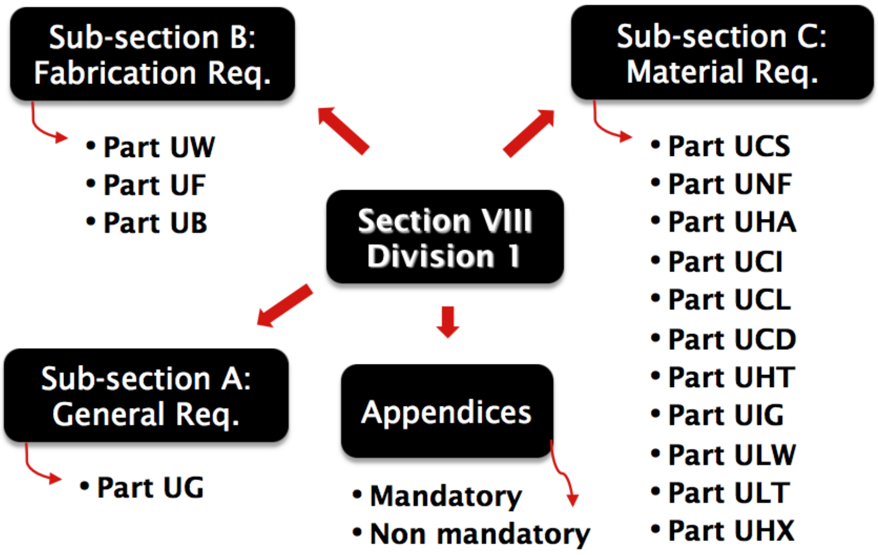
(a) Welded nozzles (no flange): the first circumferential joint in the nozzle neck. The limit might be located in the vessel.

(b) Threaded nozzles (no flange): the first thread.

(c) Flanged Nozzles: the first flange face

3.2) Code organization

Section VIII, division 1 is organized and divided according to the following:



Sections and organization of the ASME VIII Div. 1 Code.

3.2.1) Sub-section A: General Requirements

Part UG

General requirements for all construction methods and all materials. Paragraphs range from UG-1 to UG-137.

Since they are general requirements, they are the most important part of all. If the goal is to create safe, technically and economically feasible designs, the designer should be familiar with all paragraphs and figures

A simplified summary of the division of this part is as follows:

UG-4 to UG-15: Materials

UG-16 to UG-55: Design

UG-36 to UG-45: Openings and reinforcements

UG-75 to UG-85: Fabrication

UG-90 to UG-103: Inspection and tests

3.2.2) Sub-section B: Requirements pertaining fabrication methods

Part UW

Requirements for pressure vessels manufactured by welding. Paragraphs range from UW-1 to UW-65. Since most pressure vessels are made by welding, this is one of the main parts of the Code.

A simplified summary of the division of this section is as follows:

UW-2: Service restrictions

UW-3: Joint categories

UW-5: Materials

UW-8 to UW-21: Design

UW-11: Radiographic test (RT)

UW-12: Joint efficiencies

UW-26 to UW-42: Fabrication

UW-46 to UW-53: Inspection and tests

Part UF

Requirements for pressure vessels manufactured by forging. Paragraphs range from UF-1 to UF-125. Fully forged vessels are very rare. They are used for small applications and for very specific processes.

Part UB

Requirements for pressure vessels manufactured by brazing. Paragraphs range from the UB-1 to UB-60.

As is the case with vessels manufactured by forging, this type of welding is not common. The "brazing" process is generally more expensive and less productive than the electric arc welding process, now that arc welding technology has improved.

3.2.3) Sub-section C: Requirements pertaining classes of materials

Part UCS

Requirements for pressure vessels constructed out of carbon steel and low alloy steel (Cr-Mo, Cr-Mo-V). Paragraphs range from UCS-1 to UCS-160.

Since the majority (90%) of pressure vessels are constructed out of carbon and low alloy steel, this section is vital.

A simplified summary of the division of this section is as follows:

UCS-5 to UCS-12: Materials

UCS-16 to UCS-57: Design

UCS-65 to UCS-68: Low temperature operations

UCS-75 to UCS-85: Fabrication

UCS-90: Inspection and tests

Part UNF

Requirements for pressure vessels constructed out of non-ferrous materials. Paragraphs range from UNF-1 to UNF-125.

Part UHA

Requirements for pressure vessels constructed out of high alloy materials. Paragraphs range from UHA-1 to UHA-109.

Part UCI

Requirements for pressure vessels constructed out of cast iron materials. Paragraphs range from UCI-1 to UCI-125.

Part UCL

Requirements for pressure vessels constructed by means of cladding or weld overlay (linings). Paragraphs range from UCL-1 to UCL-60.

Part UCD

Requirements for pressure vessels constructed out of cast ductile iron. Paragraphs range from UCD-1 to UCD-125.

Part UHT

Requirements for pressure vessels constructed of ferritic steels with tensile properties enhanced by heat treatments. Paragraphs range from UHT-1 to UHT-125.

Part UIG

Requirements for pressure vessels constructed out of impregnated graphite. Paragraphs range from UIG-1 to UIG-125

Part ULW

Requirements for pressure vessels constructed in layers. Paragraphs range from ULW-1 to ULW-125.

Part ULT

Alternative rules for pressure vessels constructed out of materials with higher allowable stresses at low temperatures. Paragraphs range from ULT-1 to ULT-125.

Part UHX

Rules for shell and tube heat exchangers. Paragraphs range from UHX-1 to UHX-20.

3.2.4) Appendices

Appendices of Section VIII are alternative and supplementary rules and considerations to those indicated in the code itself. These guidelines have been included as appendices since their use is less frequent than other paragraphs of the code.

Mandatory

Mandatory appendices are as important as the code itself. They present alternative rules to the ones included in the body of the code. There are 40 mandatory appendices.

Non-mandatory

Non-mandatory appendices are guidelines and sound engineering practices, they are not a requirement and the designer is not obliged to follow them. Even though they are not obligatory, it is advisable to bear them in mind; they have been tested and verified on many occasions with satisfactory results. Appendices range from A to Y, and from DD to KK.

3.3) ASME stamp

When a pressure vessel is ASME stamped, all stages of design, construction, inspection and testing are performed in accordance with the provisions of the code, in addition, an ASME code representative witnesses certain points during each of the above stages.

A pressure vessel can be designed according to the ASME Code but this does not mean that the equipment is ASME stamped. The stamp requirement it is usually associated with quality level, and therefore with safety. It requires more thorough document management and more stringent fabrication and inspection procedures. In some countries, the stamp is a legal requirement (USA, Canada), whilst in others is a requirement of the customer (Europe, Middle East).

An ASME Stamped Pressure vessel must receive an inspection by an authorized "third party" during all the stages mentioned above, to verify compliance with the applicable requirements of the Code. Signature by an authorized third party certifying that the vessel has been manufactured in accordance with the code requirements is a key step for the acceptance of boilers and pressure vessels.

Besides inspecting pressure vessels, Authorized Inspectors can also supervise the installation at site. Also, after the equipment has been put into service, they can periodically inspect the compliance with legal requirements defined by local regulations on boilers and pressure vessels.

Any stamped boiler or pressure vessel must comply with all aspects of the Code, it must be designed, fabricated and inspected by a manufacturer holding an Authorization Certificate issued by ASME.

There are different ASME stamp types applicable to pressure vessels: "U stamp" for equipment in accordance with ASME VIII Div. 1 and "U2 stamp" for equipment in accordance with Div. 2.

3.4) Code revisions

A Code revision is a change from the previous requirements. They can be applied from the date of issue and become mandatory (except for materials) six months after that date (except for vessels contracted before the end of this six months).

3.4.1) Editions cycle

A new version is issued every two years (2015, 2017, 2019, ….).

The revisions reflect new editions of the Code, and they are found in the Summary of Changes, after the preface and the list of people who contributed to the review.

It is strongly recommended to always go directly to the code; it is not prudent to read summaries or abstracts. The code is issued periodically, and summaries can easily become outdated.

3.4.2) Interpretations

The Committee on Boilers and Pressure Vessels provides official interpretations of the requirements and intent of the paragraphs of the Code. Interpretations are issued in response to requests made in accordance with the procedure set out in Appendix 16.

3.4.3) Code cases

A code case is an urgent revision of the ASME code to include certain points not contained in the current edition, or to seek alternatives to the points mentioned in this document. These "revisions" may refer to materials, design, NDE, or manufacturing among others.

Code cases have no expiration date; if they have not been withdrawn or revised (see www.asme.org database), they can be used. **These cases are grouped in a document that is not included in the main body of the code, but must be ordered separately.**

When should we use them? Again, this depends on the complexity of the design and the knowhow of the designer. There are a large number of code cases, covering different issues.

e.g.: Code Case 2235-9: Use of UT in lieu of RT