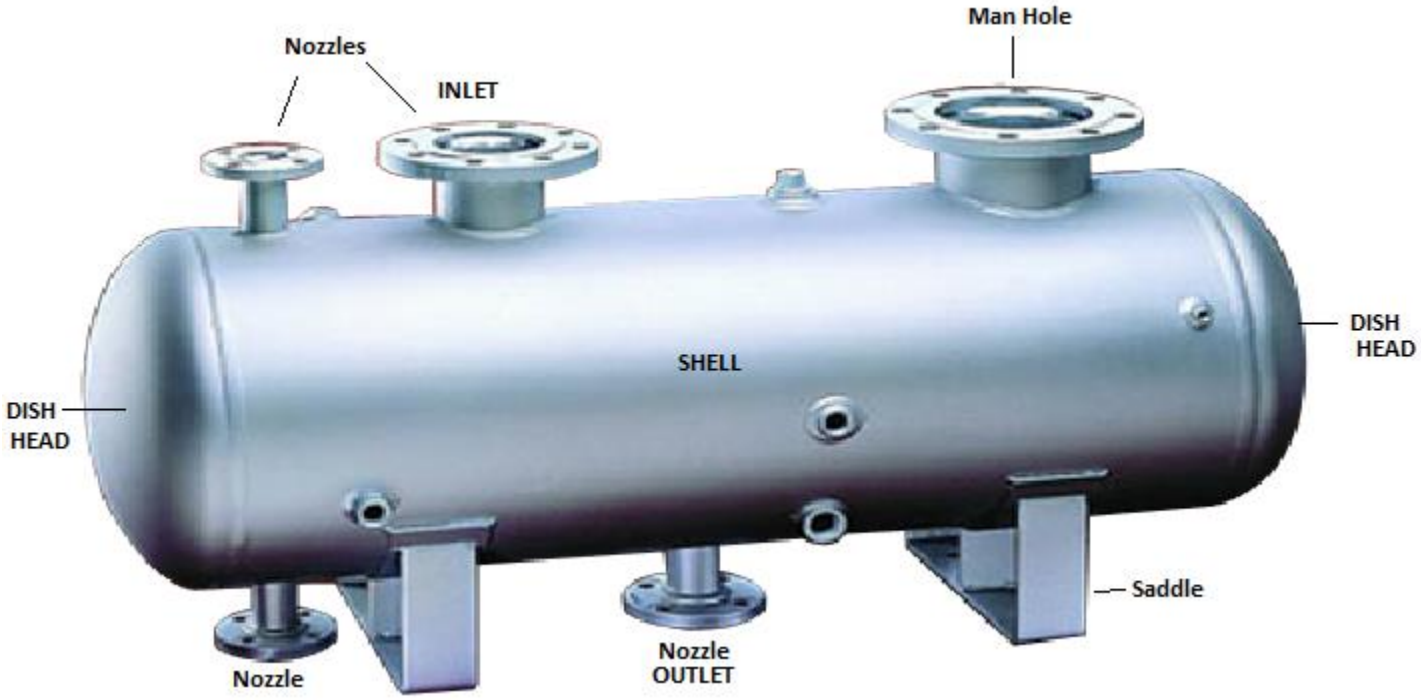
Pressure Vessel Inspection- Non Destructive Testing In Service



What is pressure vessel?

Pressure vessel is closed container which holds liquids or gasses at a pressure greater than the atmospheric pressure.

Definition of Pressure vessel as per ASME BPVC section VIII , Div 1, U1.

Pressure vessel are containers for containment of pressure, either external or internal. This pressure may be obtained from a external source or by application of heat.Heat applied is either by a direct or indirect source, or any combination thereof.

Types of pressure vessel based on their purpose :

Storage vessel- used primarily for storage of liquids or gases in a pressurized state.

Process vessel – vessels in which any of the below operations are performed,

- separation of products
- combining products
- breaking down and
- removing various elements as by products or impurities

(Ex. Separator, reactor, distillation tower, heat exchanger, drums, fractioning tower, etc.)

Fired and Unfired pressure vessel

Fired pressure vessel – are pressure vessels where external heat source is used to keep the liquid or gas pressurized (fire source may be direct or indirect).

Unfired Pressure Vessel- no external heat is applied.

About ASME BPVC section VIII,

American Society of Mechanical Engineers, Boiler & Pressure Vessel Code section VIII , has 3 divisions

Division 1 : construction of pressure vessel, (15 psi to 3000 psi) It's scope covers Designing, fabrication, Inspection, testing and certification of pressure vessel, with internal or external pressure, operating more than 15 psi. The pressure vessel may be fired or Unfired (max pressure is normally 3000 psi).

Division 1 also contains mandatory and non-mandatory appendices for supplementary design requirements. NDT non destructive testing and acceptance criteria.

Division 2 : Alternative rules. (3,000psi to 10,000 psi)

Division 3 : Alternative rules for very high pressure vessel.(Greater than 10,000 psi)

Standard for Construction of Pressure vessel

- ASME BPVC Section VIII- Division 1 (Part UG)
- Materials Selection – Section II (Part A – Ferrous, Part B- Non Ferrous, Part D- Properties)
- Welding Materials Selection- Section II (Part C)
- Material Thickness, of Shell & tube are calculated based on the Design Pressure, Design Temperature, Radius of Shell & the Weld Joint Efficiency,

Weld Joint Efficiency – Selection (as per ASME Sec VII, Div 1, Table UW-12)

Table UW-12
Maximum Allowable Joint Efficiencies for Arc and Gas Welded Joints

Type No.	Joint Description	Limitations	Joint Category	Degree of Radiographic Examination (a) Full [Note (1)]	(b) Spot [Note (2)]	(c) None
(1)	Butt joints as attained by double welding or by other means which will obtain the same quality of deposited weld metal on the inside and outside weld surfaces to agree with the requirements of UW-35. Welds using metal backing strips which remain in place are excluded.	None	A, B, C & D	1.00	0.85	0.70
(2)	Single welded butt joint with backing strip other than those included under (1)	*(a)* None except as in (b) below	A, B, C & D	0.90	0.80	0.65
		(b) Circumferential butt joints with one plate offset; see UW-13(b)(4) and Figure UW-13.1, sketch (l)	A, B & C	0.90	0.80	0.65
(3)	Single welded butt joint without use of backing strip	Circumferential butt joints only, not over $\frac{5}{8}$ in. (16 mm) thick and not over 24 in. (600 mm) outside diameter	A, B & C	NA	NA	0.60
(4)	Double full fillet lap joint	*(a)* Longitudinal joints not over $\frac{3}{8}$ in. (10 mm) thick	A	NA	NA	0.55
		(b) Circumferential joints not over $\frac{5}{8}$ in. (16 mm) thick	B & C [Note (3)]	NA	NA	0.55
(5)	Single full fillet lap joints with plug welds conforming to UW-17	*(a)* Circumferential joints [Note (4)] for attachment of heads not over 24 in. (600 mm) outside diameter to shells not over $\frac{1}{2}$ in. (13 mm) thick	B	NA	NA	0.50
		(b) Circumferential joints for the attachment to shells of jackets not over $\frac{5}{8}$ in. (16 mm) in nominal thickness where the distance from the center of the plug weld to the edge of the plate is not less than $1\frac{1}{2}$ times the diameter of the hole for the plug.	C	NA	NA	0.50
(6)	Single full fillet lap joints without plug welds	*(a)* For the attachment of heads convex to pressure to shells not over $\frac{5}{8}$ in. (16 mm) required thickness, only with use of fillet weld on inside of shell; or	A & B	NA	NA	0.45
		(b) for attachment of heads having pressure on either side, to shells not over 24 in. (600 mm) inside diameter and not over $\frac{1}{4}$ in. (6 mm) required thickness with fillet weld on outside of head flange only	A & B	NA	NA	0.45
(7)	Corner joints, full penetration, partial penetration, and/or fillet welded	As limited by Figure UW-13.2 and Figure UW-16.1	C & D [Note (5)]	NA	NA	NA
(8)	Angle joints	Design per U-2(g) for Category B and C joints	B, C & D	NA	NA	NA

GENERAL NOTES:
(a) The single factor shown for each combination of joint category and degree of radiographic examination replaces both the stress reduction factor and the joint efficiency factor considerations previously used in this Division.
(b) $E = 1.0$ for butt joints in compression.

2013 SECTION VIII - DIVISION 1

UW-13

Inspection of New Pressure Vessel

- Check the Welding Procedure
- Check the Welder Qualification Records
- Check Material Test Reports
- Check the Post Weld Heat Treatment Practice
- Pneumatic or Hydraulic Test
- Non Destructive Examinations

Preheating Requirements

- Pre-heating requiremets for P-Numbers are mentioned in Non-Mandatory Appendix R of ASME section VIII , Division1

An example of such table is shown below:

cedure specification.

R-1 P-NO. 1 GROUP NOS. 1, 2, AND 3

(a) 175°F (79°C) for material which has both a specified maximum carbon content in excess of 0.30% and a thickness at the joint in excess of 1 in. (25 mm);

(b) 50°F (10°C) for all other materials in this P-Number.

R-2 P-NO. 3 GROUP NOS. 1, 2, AND 3

(a) 175°F (79°C) for material which has either a specified minimum tensile strength in excess of 70,000 psi (480 MPa) or a thickness at the joint in excess of $^{5}/_{8}$ in. (16 mm);

(b) 50°F (10°C) for all other materials in this P-Number.

R-8 P-NO. 9 GROUPS

250°F (121°C) for P-No. 9A Group No. 1 materials
300°F (149°C) for P-No. 9B Group No. 1 materials

R-9 P-NO. 10 GROUPS

175°F (79°C) for P-No. 10A Group No. 1 materials
250°F (121°C) for P-No. 10B Group No. 2 materials
175°F (79°C) for P-No. 10C Group No. 3 materials
250°F (121°C) for P-No. 10F Group No. 6 materials

For P-No. 10C Group No. 3 materials, preheat is neither required nor prohibited, and consideration shall be given to the limitation of interpass temperature for various thicknesses to avoid detrimental effects on the mechanical properties of heat treated material.

For P-No. 10D Group No. 4 and P-No. 10I Group No. 1 materials, 300°F (149°C) with interpass temperature maintained between 350°F and 450°F (177°C and 232°C)

Post weld Heat Treatment Requirement

- PWHT requirements are given in Tables UCS-56 (of ASME BPVC section VIII div 1) for Steels of Different P-Number and Group number classification, Example of such table is given below

Table UCS-56-1
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 1

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40(f)] Up to 2 in. (50 mm)	Over 2 in. to 5 in. (50 mm to 125 mm)	Over 5 in. (125 mm)
P No. 1 Gr. Nos. 1, 2, 3	1,100 (595)	1 hr/in. (25 mm), 15 min minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)
Gr. No. 4	NA	None	None	None

GENERAL NOTES:
(a) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table UCS-56.1.
(b) Postweld heat treatment is mandatory under the following conditions:
(1) for welded joints over $1^{1}/_{2}$ in. (38 mm) nominal thickness;
(2) for welded joints over $1^{1}/_{4}$ in. (32 mm) nominal thickness through $1^{1}/_{2}$ in. (38 mm) nominal thickness unless preheat is applied at a minimum temperature of 200°F (95°C) during welding. This preheat need not be applied to SA-841 Grades A and B, provided that the carbon content and carbon equivalent (CE) for the plate material, by heat analysis, do not exceed 0.14% and 0.40%, respectively, where

$$CE = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Cu+Ni}{15}$$

(3) for welded joints of all thicknesses if required by UW-2, except postweld heat treatment is not mandatory under the conditions specified below:
(a) for groove welds not over $^{1}/_{2}$ in. (13 mm) size and fillet welds with a throat not over $^{1}/_{2}$ in. (13 mm) that attach nozzle connections that have a finished inside diameter not greater than 2 in. (50 mm), provided the connections do not form ligaments that require an increase in shell or head thickness, and preheat to a minimum temperature of 200°F (95°C) is applied;
(b) for groove welds not over $^{1}/_{2}$ in. (13 mm) in size or fillet welds with a throat thickness of $^{1}/_{2}$ in. (13 mm) or less that attach tubes to a tubesheet when the tube diameter does not exceed 2 in. (50 mm). A preheat of 200°F (95°C) minimum must be applied

Pressure Test on Pressure Vessel

Hydro Test Pressure:

- Hydrostatic Pressure = 1.3 x MAWP

(MAWP- Maximum Allowable Work Pressure)

or

- Hydrostatic Pressure = 1.3 x Design Pressure

(if MAWP is not calculated)

When : stress value of material at design temperature is less than the stress value of material at test temperature, then

Hydrostatic Pressure = 1.3 x Pdesign or MAWP x (stress value design temperature / stress value test temperature)

Pressure Test on Pipe line

Minimum Test As per ASME B 31.1, B 31.3

- Hydrostatic Pressure = 1.5 x Design Pressure
- Pneumatic Pressure = 1.2 x Design Pressure (as per ASME B31.1)
- Pneumatic Pressure = 1.1 x Design Pressure (as per ASME B31.3)
- Pneumatic Pressure = 1.1 x Design Pressure (as per ASME B31.5)

Inspection During Installation of Pressure Vessel

- The life of Pressure vessel is determined based on the factors. Corrosion Allowance, Safety Factor and Corrosion Rate, with their Design Pressure and Design Temperature kept constant.
- Pressure vessel is inspected during installation by the Inspector. The purpose of this inspection is to verify the equipment is safe for operation. That no unacceptable damage occurred during transportation to the installation site, and to initiate plant inspection records for the equipment.
- This inspection also provides an opportunity to collect desired base line information and to obtain the initial thickness readings at designated CMLs

The minimum installation inspection should include the following

a) Verify the nameplate information is correct per the manufacturer’s data reports and design requirements;

b) verify equipment is installed correctly, supports are adequate and secured. Exterior equipment such as ladders and platforms are secured. Insulation is properly installed and flanged, and other mechanical connections are properly assembled and the vessel is clean and dry; and

c) verify pressure-relieving devices satisfy design requirements (correct device and correct set pressure) and are properly installed.

If damage did occur, document it and recommend appropriate repairs or engineering assessment that may be necessary to ensure the vessel is fit for service.

In-Service Inspection: Intervals

- **External Inspection**: Visual Inspection at every 5 years or earlier.
- **Internal, On-stream & Thickness Measurements**

At Half Period of the estimated Life of Pressure Vessel (or) 10 years , whichever is lesser

- Pressure-relieving devices should be inspected, tested, and maintained in accordance with API 576
- Unless documented experience and/or a RBI assessment indicates that a longer interval is acceptable
- test and inspection intervals for pressure-relieving devices in typical process services should not exceed:
- 5 years for typical process services, and
- 10 years for clean (non-fouling) and noncorrosive services.

Case Study of In-service Pressure vessel Inspection

An In-service Inspection is being carried out on below described Pressure Vessel

Calculation of Minimum thickness

To evaluate the remaining life of any equipment, minimum thickness is necessary. As mentioned in the introduction, data is not available. The minimum required thickness is presented in Tables 2 and 3 below. Calculation bas been done according to two standards: ASME Section VIII Division 1 and EN 13445-3, with variation of joint efficiency (F). Joint efficiency is a function of NDT. Only values for sl

Inputs:

$t_{required}$ – minimal required thickness (in)
P – design pressure (psi)
R – inside radius (in)
S – maximum allowable stress value (psi)
E – joint efficiency

Example

Shell

$$t_{required} = \frac{P \cdot R}{S \cdot E - 0.6P} = \frac{192.02 \cdot 66.93}{20000 \cdot 1 - 0.6 \cdot 192.02}$$

$t_{required} = 0.647$ in. ($t_{required} = 16.43$ mm)

Heads

$$t_{required} = \frac{P \cdot D}{2S \cdot E - 0.2P} = \frac{192.02 \cdot 133.86}{2 \cdot 20000 \cdot 1 - 0.2 \cdot 192.02}$$

$t_{required} = 0.643$ in. ($t_{required} = 16.33$ mm)

During inspection activities, ultrasonic measurement of thickness is performed.
The minimal measured value is 17.18 mm.

CORROSION RATE

- **In order to calculate the remaining life, the data for corrosion rate are necessary. Hereunder is presented the determination of the corrosion rate for the shell and heads**

Corrosion rate for shell – long term, CR(LT):

$$CR(LT) = \frac{t_{initial} - t_{actual}}{\text{time between } t_{initial} \text{ and } t_{actual} \text{ (years)}}$$

$$CR(LT) = \frac{26 - 17.18}{6.2} = 1.42 \ \frac{mm}{year}$$

The initial thickness, $t_{initial}$, is taken from manufacturing data for both shell and heads. The actual thickness, t_{actual}, is the measured value during inspection activities.

Corrosion rate for shell – short term, CR(ST):

$$CR(ST) = \frac{t_{previous} - t_{actual}}{\text{time between } t_{previous} \text{ and } t_{actual} \text{ (years)}}$$

$$CR(ST) = \frac{20 - 17.18}{2.2} = 1.28 \ \frac{mm}{year}$$

REMAINING LIFE

Remaining life (RL) for shell:

$$RL = \frac{t_{actual} - t_{required}}{CR(ST)} = \frac{20 - 16.43}{1.28} = 2.8 \text{ years}$$

Corrosion rate for heads – long term CR(LT):

$$CR(LT) = \frac{t_{initial} - t_{actual}}{\text{time between } t_{initial} \text{ and } t_{actual} \text{ (years)}}$$

$$CR(LT) = \frac{27 - 21.34}{6.2} = 0.91 \ \frac{mm}{year}$$

Corrosion rate for heads – short term CR(ST):

$$CR(ST) = \frac{t_{previous} - t_{actual}}{\text{time between } t_{previous} \text{ and } t_{actual} \text{ (years)}}$$

$$CR(ST) = \frac{22.8 - 21.34}{2.2} = 0.66 \ \frac{mm}{year}$$

REMAINING LIFE

Remaining life for heads:

$$RL = \frac{t_{actual} - t_{required}}{CR(ST)} = \frac{22.8 - 16.33}{0.66} = 9.8 \text{ years}$$

Other References for Inspection

- API 570 Piping Inspection Code: In-Service Inspection, Rating, Repair, and Alteration of Piping Systems
- API Recommended Practice 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*
- API Recommended Practice 572, *Inspection of Pressure Vessels*
- API Recommended Practice 576, *Inspection of Pressure-relieving Devices*
- API Recommended Practice 577, *Welding Inspection and Metallurgy*
- API Recommended Practice 578, *Material Verification Program for New and Existing Alloy Piping Systems*
- API Standard 579-1/ASME FFS-1, *Fitness-For-Service*
- API Recommended Practice 580, *Risk-Based Inspection*
- API Recommended Practice 581, *Risk-Based Inspection Methodology*
- API Recommended Practice 582, *Welding Guidelines for the Chemical, Oil, and Gas Industries*
- API Recommended Practice 583, *Corrosion Under Insulation and Fireproofing*
- API Recommended Practice 584, *Integrity Operating Windows*
- API Recommended Practice 585, *Pressure Equipment Integrity Incident Investigations*
- API 653 Tank Inspection, Repair, Alteration and Reconstruction
- API 610 Centrifugal Pumps for General Refinery Services
- API 6D Steel Gate, Plug, and Check Valves for Pipeline Service
- API 620 Design and Construction of Large Welded, Low Pressure Storage tanks
- API Recommended Practice 939-C, *Guidelines for Avoiding Sulfidation (Sulfidic) Corrosion Failures in Oil Refineries*
- API Recommended Practice 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum*

- *Refineries and Petrochemical Plants*
- API Recommended Practice 2201, *Safe Hot Tapping Practices for the Petroleum and Petrochemical Industries*
- ASME PCC-1 1, *Guidelines for Pressure Boundary Bolted Flange Joint Assembly*
- ASME PCC-2, *Repair of Pressure Equipment and Piping*
- ASME *Boiler and Pressure Vessel Code, Section II: Materials*
- ASME *Boiler and Pressure Vessel Code, Section V: Nondestructive Examination*
- ASME *Boiler and Pressure Vessel Code, Section VIII: Rules for Construction of Pressure Vessels; Division 1*
- ASME *Boiler and Pressure Vessel Code, Section VIII: Rules for Construction of Pressure Vessels; Division 2:Alternative rules*
- ASME *Boiler and Pressure Vessel Code, Section IX: Welding and Brazing Qualifications*
- ASNT CP-189 2, *Standard for Qualification and Certification of Nondestructive Testing Personnel*
- ASNT SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*
- NACE MR0103 3, *Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments*
- NACE SP0170, *Protection of Austenitic Stainless Steels and Other Austenitic Alloys from Polythionic Acid Stress Corrosion Cracking During Shutdown of Refinery Equipment*
- NACE SP0472, *Methods and Controls to Prevent In-service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments*
- National Board NB-23 4, *National Board Inspection Code*
- OSHA 29 *CFR Part 1910 5, Occupational Safety and Health Standards*

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