MECHANICAL DESIGN OF PRESSURE VESSEL BY USING CODEWARE COMPRESS SOFTWARE

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Abstract

Both the yield strength and the tensile stress for material allowance are related to the pressure vessel's safety factor. These two are completely covered in ASME Code Section VIII's pressure vessel building guidelines. This section of the code covered pressure relief, vessel materials, design, manufacturing, examination, inspection, testing, and required and optional appendix requirements. It also covered specific prohibitions. Based on this specification, mechanical design work had been done with PV ELITE software for a horizontal pressure vessel. Head, shell, nozzle, and saddle analyses were performed. The input parameters include the material type, the pressure, the temperature, the diameter, and the corrosion allowance. Internal and external pressure, element weight, permissible stresses, vessel longitudinal stress check, nozzle check, and saddle check calculations were done by analysis. The calculations for internal and external pressure, element weight, permissible stresses, vessel longitudinal stress check, nozzle check, and saddle check were done by analysis.

Keywords: Circumferential stress, longitudinal stress, end closures, pressure vessel and compress.
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Introduction:

As the name suggests, pressure vessels are leak-proof containers with the primary function of holding a specific material under pressure and heat. In the industrial setting, pressure vessels are frequently utilized to transport liquids and gases within specified pressure and temperature ranges. An external source, heat applied from a direct or indirect source, or any combination of them, is where the pressure and temperature are generated. They can be of any size and shape, from simple ones seen in engineering applications to more complex ones like beer cans, car tires, or gas storage tanks. Common shapes for pressure vessels include cylindrical, spherical, elliptical, conical, or a combination of these.

However, some pressure vessels are given their names based on the kind of task they must carry out. For instance, a vessel used in the refinement of oil and petroleum is the distillation column. The function of the heat exchanger, which is employed in numerous industries to transfer heat from one fluid to another, was the same. Additionally, a reactor is a container used for the chemical reaction of a substance inside. The material that makes up the vessel is stressed in all directions due to pressure loading. The normal stresses that emerge from this pressure depend on the diameter of the components being considered, the shape of the pressure vessel, and the pressure being applied.

Fig1: Pressure Vessel

Design Codes:

Pressure vessels frequently contain deadly compounds that are dangerous for both people and the environment while also operating under a specific pressure and temperature. There is an evident need to standardize engineering and fabrication procedures given these factors, as well as the safety implications and risks associated with the operation of pressure vessels. There are numerous design codes that have been designed and produced to guarantee minimal safety standards. The most common national codes in Europe are: -

GERMANY - AD MARKBLATTER, BRITISH – BS1500, BS 1515, ITLAY – CCPA

The American Society of Mechanical Engineers' (ASME) boiler and pressure vessel code, which is used most frequently in the United States and Canada (ASME). Pressure vessel design, material specifications, fabrication, opening and reinforcement, testing and marking, inspection, and additional necessary or optional appendices are covered in ASME section VIII. Three sections make up Section VIII, covering the various pressure ranges.

- Division 1: up to 3000 psi (200 bar)
- Division 2: up to 10000 psi (690 bar)
- Division 3: above 10000 psi (above 690 bar)

Division 1 of ASME Section VIII deals with traditional pressure vessels and design by rule, Division 2 with strict alternative rules and design by analysis, and Division 3 with design of nuclear equipment.

Four main categories, each of which provides an explanation for why a vessel fails, can be used to group vessel failures. Failures are also categorized into failure categories, which define how each kind of failure differs from the others in terms of its cause, history, and mode of occurrence. There are many reasons of vessels failure such as:

- Choosing the wrong materials or using defective materials

- improper design data, an unreliable design process, or insufficient shop testing.
- Insufficient fabrication processes, including welding, heat treatment, and forming techniques. Poor quality control.

Fig. 2. Failure of pressure vessel during hydro Test.

A designer must be knowledgeable about the aforementioned failure and its causes in order to achieve a safe design. Designing a safe pressure vessel depends on a few key elements. The analysis of the safety parameters for the permitted operating pressure is the main goal of this study. Using CODEWARE COMPRESS software, which complies with ASME Section VIII, standards for constructing pressure vessels, allowable working pressures are determined. The study's goals are to use CODEWARE COMPRESS software to design pressure vessels in accordance with input data and to examine the safety parameters of each component for its permissible working pressure.

Design Input Data

Component	Units	Components	Units
Shell		**Design**	
Length	4100 MM	**Temp.**	
Internal dia	1600 MM	Internal	100 DEG C
Thickness	14 MM	External	100 DEG C
Material	SA515GR70		
C.A	3 MM		
Dished end (both side)		**Design**	
Type	Ellipsoidal	**Pressure**	
Internal dia	1600 MM	Internal	1.7 MPA
Material	SA515GR70	External	0.103 MPA
C.A	3 MM		
Nozzle no.1		**Saddle**	

NPS	2 INCH	Width	260 MM
Schedule	80	Wear plate width	450 MM
Material	SA106B	Contact angle	120 deg.
Length	200 MM	Wear plate thickness	14 MM

Table 1. Design Input Data

Results:

The horizontal pressure vessel is drawn according to the input data for the elements, and it is simple to identify each element's icon. As visible on the screen, the input parameters for each element are also typed into the appropriate bar. The pressure vessel would resemble the one illustrated in the picture once all the components were connected. After the design in COMPRESS was finished, a design analysis was done to illustrate the outcomes for each component based on the input data. The outcomes demonstrated safe and failure circumstances in accordance with ASME standard. Equations, substitutions, and code references have all been used to analyse the results.

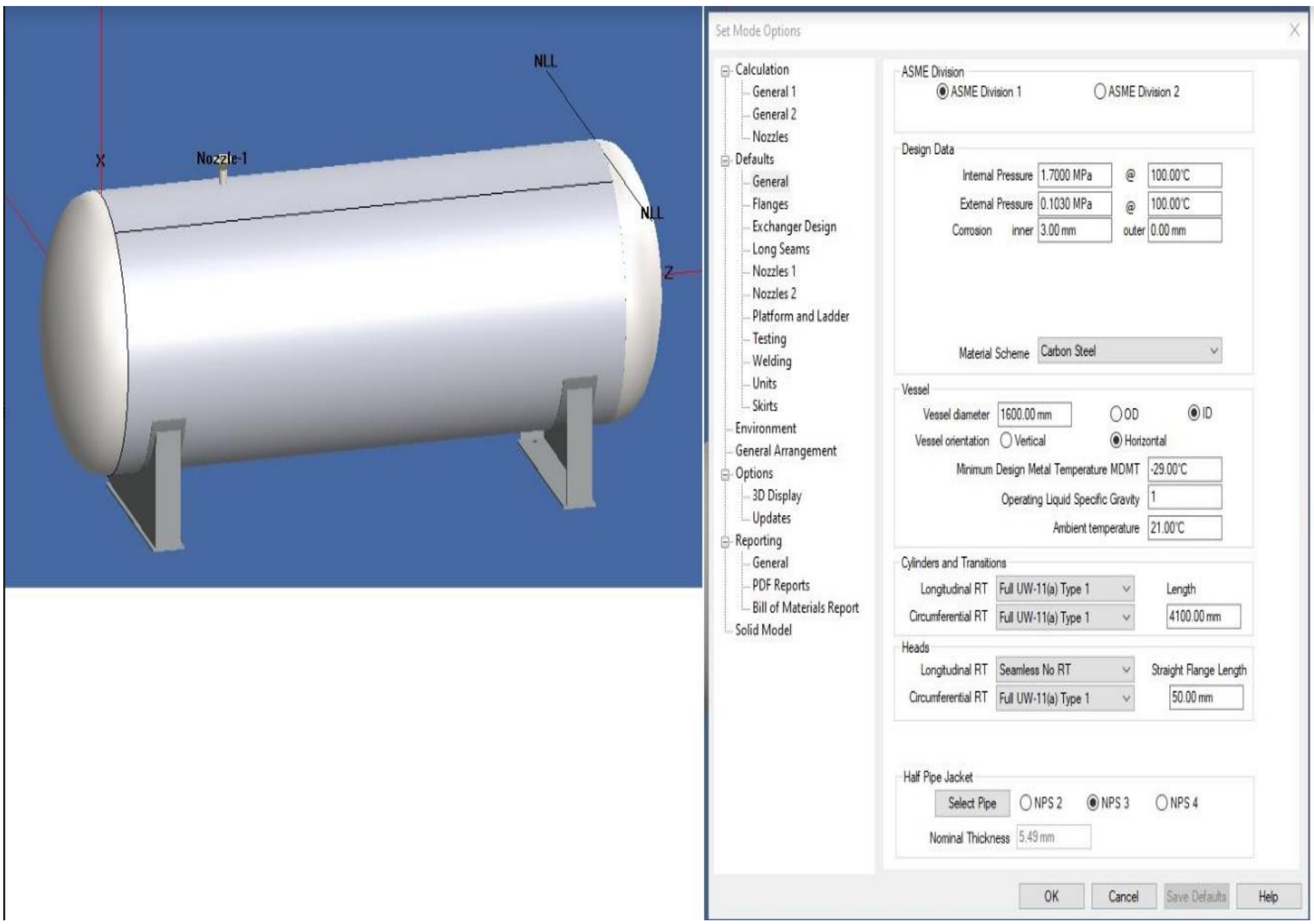


Fig. 3. COMPRESS Software Design Data Input

Shell

ASME Section VIII Division 1, 2021 Edition Metric	
Component	Cylinder

<table>
<tr><th colspan="2">Material</th><td colspan="3">SA-516 70 (II-D Metric p. 20, ln. 45)</td></tr>
<tr><th>Impact Tested</th><th>Normalized</th><th>Fine Grain Practice</th><th>PWHT</th><th>Maximize MDMT/No MAWP</th></tr>
<tr><td>No</td><td>No</td><td>No</td><td>No</td><td>No</td></tr>
<tr><th colspan="2"></th><th>Design Pressure (MPa)</th><th>Design Temperature (°C)</th><th>Design MDMT (°C)</th></tr>
<tr><th colspan="2">Internal</th><td>1.7</td><td>100</td><td rowspan="2">-29</td></tr>
<tr><th colspan="2">External</th><td>0.103</td><td>0</td></tr>
<tr><th colspan="5">Static Liquid Head</th></tr>
<tr><th colspan="2">Condition</th><th>P_S (MPa)</th><th>H_S (mm)</th><th>SG</th></tr>
<tr><th colspan="2">Operating</th><td>0.0157</td><td>1,606</td><td>1</td></tr>
<tr><th colspan="2">Test horizontal</th><td>0.0173</td><td>1,766.4</td><td>1</td></tr>
<tr><th colspan="5">Dimensions</th></tr>
<tr><th colspan="2">Inner Diameter</th><td colspan="3">1,600 mm</td></tr>
<tr><th colspan="2">Length</th><td colspan="3">4,100 mm</td></tr>
<tr><th colspan="2">Nominal Thickness</th><td colspan="3">14 mm</td></tr>
<tr><th rowspan="2">Corrosion</th><th>Inner</th><td colspan="3">3 mm</td></tr>
<tr><th>Outer</th><td colspan="3">0 mm</td></tr>
<tr><th colspan="5">Weight and Capacity</th></tr>
<tr><th colspan="2"></th><th colspan="2">Weight (kg)</th><th>Capacity (liters)</th></tr>
<tr><th colspan="2">New</th><td colspan="2">2,277.66</td><td>8,243.54</td></tr>
<tr><th colspan="2">Corroded</th><td colspan="2">1,792.96</td><td>8,305.48</td></tr>
<tr><th colspan="5">Radiography</th></tr>
<tr><th colspan="2">Longitudinal seam</th><td colspan="3">Full UW-11(a) Type 1</td></tr>
<tr><th colspan="2">Left Circumferentialseam</th><td colspan="3">Full UW-11(a) Type 1</td></tr>
<tr><th colspan="2">Right Circumferentialseam</th><td colspan="3">Full UW-11(a) Type 1</td></tr>
</table>

Results Summary	
Governing condition	Internal pressure
Minimum thickness per UG-16	1.5 mm + 3 mm = 4.5 mm
Design thickness due to internal pressure (t)	13.06 mm
Design thickness due to external pressure (t_e)	10.94 mm
Maximum allowable working pressure (MAWP)	1.8593 MPa
Maximum allowable pressure (MAP)	2.3899 MPa
Maximum allowable external pressure (MAEP)	0.2304 MPa
Rated MDMT	-29 °C

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	14 mm
MDMT =	-29°C
Material is exempt from impact testing per UG-20(f) at the Design MDMT of -29°C.	

Design thickness, (at 100 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 1.7157*803 / (138*1.00 - 0.60*1.7157) + 3
= 13.06 mm

Maximum allowable working pressure, (at 100 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 138*1.00*11 / (803 + 0.60*11) - 0.0157
= 1.8593 MPa

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 138*1.00*14 / (800 + 0.60*14)
= 2.3899 MPa

External Pressure, (Corroded & at 0 °C) UG-28(c)

L / D_o = 4,468.67 / 1,628 = 2.7449
D_o / t = 1,628 / 7.94 = 205.0496

From table G: A = 0.000158
From table CS-2 Metric: B = 15.8401 MPa

P_a = 4*B / (3*(D_o / t))
= 4*15.8401 / (3*(1,628 / 7.94))
= 0.103 MPa

Design thickness for external pressure P_a = 0.103 MPa

t_a = t + Corrosion = 7.94 + 3 = 10.94 mm

Maximum Allowable External Pressure, (Corroded & at 0 °C) UG-28(c)

L / D_o = 4,468.67 / 1,628 = 2.7449
D_o / t = 1,628 / 11 = 147.9965

From table G: A = 0.000256
From table CS-2 Metric: B = 25.5793 MPa

P_a = 4*B / (3*(D_o / t))
= 4*25.5793 / (3*(1,628 / 11))
= 0.2304 MPa

Ellipsoidal Head

ASME Section VIII Division 1, 2021 Edition Metric				
Component		Ellipsoidal Head		
Material		SA-516 70 (II-D Metric p. 20, ln. 45)		
Attached To		Shell		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
No	No	No	No	No
		Design Pressure (MPa)	**Design Temperature (°C)**	**Design MDMT (°C)**
Internal		1.7	100	-29
External		0.103	0	
Static Liquid Head				
Condition		**P_s (MPa)**	**H_s (mm)**	**SG**
Operating		0.0157	1,606	1

Test horizontal	0.0173	1,766.4	1
Dimensions			
Inner Diameter	1,600 mm		
Head Ratio	2		
Minimum Thickness	14 mm		
Corrosion – **Inner**	3 mm		
Corrosion – **Outer**	0 mm		
Length L_{sf}	50 mm		
Nominal Thickness t_{sf}	16 mm		
Weight and Capacity			
	Weight (kg)[1]	**Capacity (liters)[1]**	
New	362.32	636.7	
Corroded	286.79	645.53	
Radiography			
Category A joints	Seamless No RT		
Head to shell seam	Full UW-11(a) Type 1		

[1] includes straight flange

Results Summary	
Governing condition	internal pressure
Minimum thickness per UG-16	1.5 mm + 3 mm = 4.5 mm
Design thickness due to internal pressure (t)	12.95 mm
Design thickness due to external pressure (t_e)	7.14 mm
Maximum allowable working pressure (MAWP)	1.8815 MPa
Maximum allowable pressure (MAP)	2.4108 MPa
Maximum allowable external pressure (MAEP)	0.636 MPa
Straight Flange governs MDMT	-31.25°C

Factor K		
K = (1/6)*[2 + (D / (2*h))^2]		
Corroded	K = (1/6)*[2 + (1,606 / (2*403))^2]	0.995
New	K = (1/6)*[2 + (1,600 / (2*400))^2]	1

Design thickness for internal pressure, (Corroded at 100 °C) Appendix 1-4(c)

t = P*D*K / (2*S*E - 0.2*P) + Corrosion
= 1.7157*1,606*0.995047 / (2*138*1 - 0.2*1.7157) + 3
= 12.95 mm

Maximum allowable working pressure, (Corroded at 100 °C) Appendix 1-4(c)

P = 2*S*E*t / (K*D + 0.2*t) - P_s
= 2*138*1*11 / (0.995047*1,606 +0.2*11) - 0.0157
= 1.8815 MPa

Maximum allowable pressure, (New at 21.11 °C) Appendix 1-4(c)

P = 2*S*E*t / (K*D + 0.2*t) - P_s
= 2*138*1*14 / (1*1,600 +0.2*14) - 0
= 2.4108 MPa

Design thickness for external pressure, (Corroded at 0 °C) UG-33(d)

Equivalent outside spherical radius (R_o)
R_o = K_o*D_o
= 0.8848*1,628

= 1,440.43 mm

A = $0.125 / (R_o / t)$
= 0.125 / (1,440.43 / 4.14)
= 0.000359

t = 4.14 mm + Corrosion = 4.14 mm + 3 mm = 7.14 mm

The head external pressure design thickness (t_e) is 7.14 mm.

Maximum Allowable External Pressure, (Corroded at 0 °C) UG-33(d)

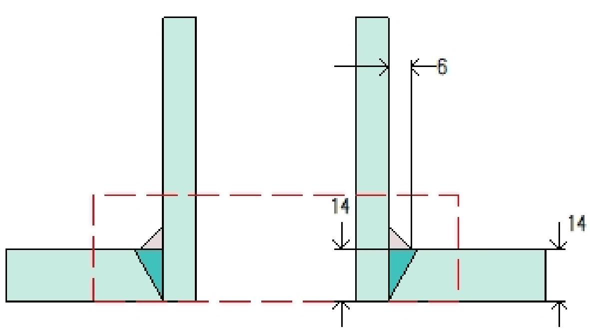
Equivalent outside spherical radius (R_o)

R_o = K_o*D_o
= 0.8848*1,628
= 1,440.43 mm

A = $0.125 / (R_o / t)$
= 0.125 / (1,440.43 / 11)
= 0.000955

The maximum allowable external pressure (MAEP) is 0.636 MPa.

Nozzle-1 (Nozzle-1)

ASME Section VIII Division 1, 2021 Edition Metric	
	
Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Shell
Orientation	0°
Nozzle center line offset to datum line	1,000 mm

End of nozzle to shell center	966.4 mm
Passes through a Category A joint	No
Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 16, ln. 16)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	3 mm
Projection available outside vessel, Lpr	88.9 mm
Projection available outside vessel to flange face, Lf	152.4 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0 MPa
Welds	
Inner fillet, Leg_{41}	6 mm
Nozzle to vessel groove weld	14 mm
Radiography	

ASME B16.5-2017 Flange	
Description	NPS 2 Class 150 WN A105 N
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p.410, ln. 32)
Blind included	No
Rated MDMT	-36.28°C
Liquid static head	0 MPa
MAWP rating	1.77 MPa @ 100°C
MAP rating	1.96 MPa @ 21.11°C
Hydrotest rating	3 MPa @ 21.11°C
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	Yes
Impact Tested	No

Circumferential joint radiography	Spot UW-11(a)(5)(b) only Type 1
Notes	
Flange rated MDMT per UCS-66(b)(1)(b) = -36.28°C (Coincident ratio = 0.8703)Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 1.7058*24.42 / (118*1 - 0.6*1.7058) =	0.36 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.36*1 / (7.65 - 3) =	0.0767
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of -29°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary(cm^2)							UG-45 Summary (mm)	
For P = 1.7 MPa @ 100 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							6.42	7.65

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (mm)	Actual weld throat size (mm)	Status
Nozzle to shell fillet (Leg_{41})	4.02	4.2	weld size is adequate

Calculations for internal pressure 1.7 MPa @ 100 °CParallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))

= MAX(48.85, 24.42 + (8.74 - 3) + (14 - 3))

= 48.85 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)

= MIN(2.5*(14 - 3), 2.5*(8.74 - 3) + 0)

= 14.34 mm

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)

= 1.7*24.42 / (118*1 - 0.6*1.7)

= 0.36 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)

= 1.7*803 / (138*1 - 0.6*1.7)

= 9.97 mm

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 19 mm
or t_n or t = 5.74 mm$t_{c(min)}$ = lesser of
6 mm or 0.7*t_{min} = 4.02 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*6 = 4.2 mm

The fillet weld size is satisfactory.

Discussion:

The design of a pressure vessel can be completed fast by using multiple computerized computations. In relation to the program, the drawing process was easier. This study only looked into a small portion of the parameter design. Other factors like heat loads, wind loads, seismic loads, transportation loads, erection loads, and fabrication procedures are not taken into account, although this deficiency can be fixed by becoming an expert with software.

Conclusion:

Utilizing graphical-based tools, the mechanical design of the pressure vessel was completed. The drawing process was incredibly simple, and input was possible on the same screen. The end product was utilized in the practical design of pressure vessels and fully complied with standard code.

Other factors can be considered when conducting research. The development of selection materials with ASME standards is also possible. Future research on the behaviour of pressure pipes under varying loads could present difficult problems.

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