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Design of a Hyperbaric Chamber for Pressure Testing

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Abstract. A hyperbaric chamber is an application of a pressure vessel to test the integrity of components and equipments subjected to high pressure. The chamber comprises of several main parts such as a shell, heads, instrumentation attachments, threaded fasteners and support. This paper describes the design of hyperbaric chamber for pressure testing that compiles to the ASME Boiler and Pressure Vessel code. The design approach adopted is the "design by formula" method. A structural analysis of the hyperbaric chamber with a cylindrical shell and a vertical orientation, based on an operating pressure of 34.5 MPa, was done. The analysis of the stress distribution shows that the normalized principal stresses acting on the chamber are within the yield envelop based on the maximum distortional energy criteria.

1 Introduction

A hyperbaric chamber is an application of a pressure vessel. These chambers were first developed in 18th century for medical purposes, such as for the treatment of decompression sickness. Today, hyperbaric chambers are used for pressure testing as well. A high pressure pump pumps fluid to the vessel, creating a high pressure environment in the chamber. The paper describes the design and structural analysis of a hyperbaric chamber for pressure testing of subsea components, such as pressure gauges, wellbore pressure/temperature sensors, proximity sensors and annular packing element for an annular blowout preventer. The aim is to develop a hyperbaric chamber [1] so that these components can be tested before installation in a high pressure environment. The hyperbaric chamber is designed to withstand a pressure of 38 MPa (110% of the maximum operating pressure) at 50 ºC (10 ºC above maximum operating temperature) as the pressure and temperature at deepwater depths of 3000 m is approximately 34.5 MPa and 40 ºC [2].

2 Methodology

The design approach adopted is the "design by formula" method, based on the American Society of Mechanical Engineers (ASME) Section VIII, Boiler and Pressure Vessel Code, Division 1: Rules for Construction of Pressure Vessel. The code has explicit rules for calculating wall thickness of heads, shells, reinforcement around openings, and other details of a vessel [3]. For the structural analysis, the ANSYS Static Structural software was used, to determine the maximum principal stresses and the corresponding critical regions. For this purpose, a 3D model of the hyperbaric chamber was created using CATIA V5. The various components of hyperbaric chamber models were simulated using

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ANSYS Static Structural software. All of the components of hyperbaric chamber are tested at a maximum design pressure and temperature of 37.4 MPa and 47.78ºC respectively. Numerical simulations are validated through calculations based on equations provided in the ASME code. The equations [4] used to determine the dimensions of hyperbaric chamber are as follows:

$$\text{Allowable stress, } S = 2/3(0.85\sigma_y) \tag{1}$$

$$\text{Shell thickness, } t_{shell} = PR/(SE-0.6P) \tag{2}$$

$$\text{Head thickness, } t_{head} = PR/(2SE-0.2P) \tag{3}$$

where P is the design pressure, R the internal radius and E the joint efficiency. The number of swing bolts used, n for the swing bolts closure was determined based on Equation 4.

$$\sigma_{bolt} d_{bolt} n \geq P\pi d^2/4 \tag{4}$$

The maximum principal stresses exerted in the system should not exceed the calculated allowable stress of the materials used to design the chamber [5]. The design is considered to have failed if the normalized (by yield stress) principal stresses exceeds the yield envelop based on the maximum distortional energy criteria.

3 Results and discussion

The chamber comprises of several main parts such as a main body, heads, instrumentation attachments, threaded fasteners and support. Among the design considerations were its orientation and ease of port accessibility. A cylindrical ellipsoidal head chamber with a vertical orientation was designed. A vertical orientation was chosen because it has a smaller footprint i.e. occupies less of space but more importantly facilitates the draining process, as well as making the ports accessible. The nominal diameter used is 406 mm or 16 inches based on ASME B36.10 for pipe design and a length of 500 mm. This diameter allows for testing of small subsea components and equipments. Figure 1 show an isometric view of the hyperbaric chamber while the dimensions of the chamber such as diameter, length, thickness, weight and capacity are shown in Table 1.

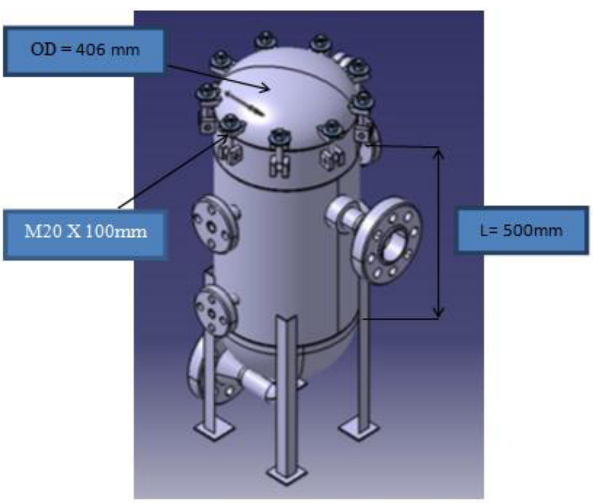

Figure 1. Isometric view of the hyperbaric chamber.

Table 1. Design Specification.

Design Code			ASME Section VIII Division 1 2002
Orientation			Vertical
Materials			API 5LX Grade 70, ASTM150, Allegheny Ludlum Martensitic Stainless Steel 410
Working fluid			Fresh water
Type of head			2:1 Ellipsoidal head
Number of bolts			9 X M20 swing bolts + 9 X M20 hexagonal nuts
Chamber dimension	**Cylinder body**		OD=406.4mm,ID=344.48mm, t=30.96mm, L=500mm
	Head	**Top**	OD=406.4mm, ID=356.4mm , t=25mm, SF=127mm, H=247.65mm
		Bottom	OD=406.4mm, ID=356.4mm , t=25mm, SF=25mm, H=178mm
Capacity			0.0704 m^3
Operating	**Pressure**		34 MPa
	Temperature		37.78 ^{o}C
Design	**Pressure**		37.4 MPa
	Temperature		47.78 ^{o}C
Design stress	**Head and body**		278.33 MPa
	Flanges		141.67 MPa
	Swing bolts		609.73 MPa
Corrosion allowance			2mm
Weight			877.13 kg

While a cylindrical vessel is somewhat less efficient, as wall stresses vary with direction (internal pressure is resisted by the hoop stress in an “arch action” with no axial stress), they are more convenient to fabricate, especially where seamless pipes for the shell are used, as this avoids many inspection and testing issues. However, a cylindrical vessel requires the use of additional local reinforcements, since it must be closed at the ends by end caps/heads. The top head is ellipsoidal rather than flat as curved configurations are stronger and allow heads to be thinner, lighter and less expensive [6]. For access, various closures have been utilized such as clamp type, clutch type, screw type and swing bolt [7]. A swing bolts closure, by CRALL Industries [8], was chosen it provides quick opening and sealing. For the instrument attachments, flanges based on ASME B16.5, Pipe Flange and Flange Fitting [9] were selected. Compensation pads for nozzle reinforcement were used but for the sake of brevity, the calculations are not shown here. The dimension of leg support was determined based on the weight and load applied on it.

Although material selection is an important consideration [3], as the emphasis is on the design itself, carbon steel was chosen as the material of choice for all parts. API 5L Grade 70 [10] carbon steel was selected for the design of the main part which is body, head and support. ASTM 150, which is also carbon steel, was used for the three types of flanges attached on the chamber i.e. a 2” weld-neck, a 1” and a ¾” lap joint flanges [11]. For critical parts i.e. threaded fastener, Allegheny Ludlum Martensitic Stainless Steel 410 [12] was selected, because of its high yield strength of 1076 MPa. The material specification for the hyperbaric chamber is summarized in Table 2.

Figure 2 and Figure 3 shows the maximum principal stresses on the main body and ellipsoidal top head of the chamber respectively while Table 3 summarizes the maximum principal stresses on all components. All components of the chamber are capable of withstanding the specified pressure based on the calculated allowable stress and maximum principle stress.

Table 2. Material Specification.

No	Parts			Material
1	Cylindrical body	1.1	Compensation pad	API 5LX Plate. Grade 70, Seamless, ERW, Butt-Weld
		1.2	Two Inch Weld-neck Flange	2” NPS, PN 420, Class 2500, ASTM 105,Butt-weld, Seamless
		1.3	One inch lap join flanges	1” PN 420, Class 2500, ASTM 105,Butt-weld, Seamless
		1.4	Three quarter inch lap joint flanges	¾ “ PN 420, Class 2500, ASTM 105,Butt-weld, Seamless
2	Heads	2.1	Ellipsoidal head	API 5LX Plate. Grade 70, Seamless, ERW, Butt-Weld
		2.2	Swing bolts and nuts	Allegheny Ludlum Martensitic Stainless Steel 410
		2.3	Compensation pad	API 5LX Plate. Grade 70, Seamless, ERW, Butt-Weld
		2.4	Two inch elbow	2” NPS, 90 D, SR, PN 420, Class 2500, ASTM, Butt-weld Seamless
		2.5	Two inch weld-neck flange	PN 420, Class 2500, ASTM 105,Butt-weld, Seamless
3	Support	3.1	Leg support	API 5LX Plate, Grade 70, Seamless, ERW, Butt-Weld
		3.2	Compensation pad	API 5LX Plate. Grade 70, Seamless, ERW, Butt-Weld
		3.3	Base plate	API 5LX Plate. Grade 70, Seamless, ERW, Butt-Weld

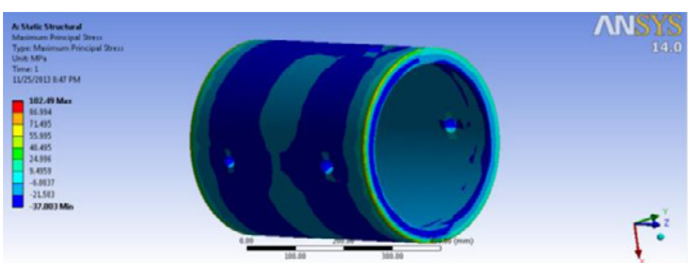

Figure 2. Maximum principal stresses on the main body of the chamber.

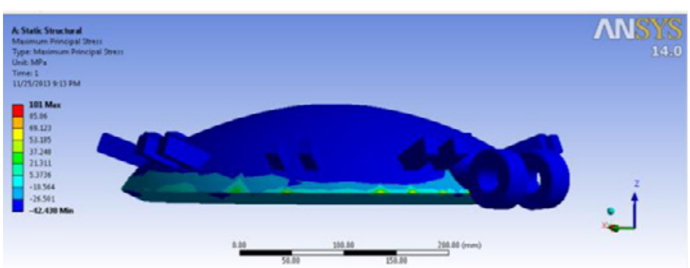

Figure 3. Maximum principal stresses the ellipsoidal top head of the chamber.

Table 3: Maximum Principal Stresses

API 5LX Grade 70 (Line Pipe / Plate), S = 278.3 MPa	
16” Cylindrical Body	102.5
16” Ellipsoidal bottom head	85.7
16” Ellipsoidal top head	101.0
16” Straight flange	75.0
Leg Support	15.6
2” Nozzle & reinforcement pad	112.0
1” Nozzle & reinforcement pad	106.3
3/4” Nozzle & reinforcement pad	90.8
Allegheny Ludlum Martensitic Stainless Steel 410, S = 609.7 MPa	
M20 swing bolts	35.0
M20 hexagonal nuts	28.1
ASTM 150, S = 141.7 MPa	
1” Lap joint flange	15.3
¾” Lap joint flange	15.3
2” Weld neck flange	35.7
2” Short elbow	80.9

4 Conclusions

The design and structural analysis of a hyperbaric chamber based on a design pressure of 34.5 MPa has been presented. The design is based on ASME standards and all design and materials specifications were determined by adhering to the ASME Section VIII codes. As the maximum principal stresses acting on the chamber are within the yield envelop based on the maximum distortional energy criteria, the chamber is capable of withstanding the design pressure.

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