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Optimization thickness of head type for horizontal LPG pressure vessels according to ASME

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Abstract
Liquefied Petroleum Gas (LPG) are commonly used in many practical applications as a storage container for gasses under pressure such as oil refinery, production and fuel stations. Design of LPG vessels must meet strict requirements to insure safety and prevent environmental hazard ASME codes for pressure vessel are a general roles for design and testing for all the available vessels ranging from huge nuclear to small fuel tanks. For specified vessel the designer must has a spatial experience to involve the right criteria. In ASME codes there existed many types of end heads for pressure vessels such as; Torispherical, Elliptical 2:1 and Hemispherical. Selection of head type is left as an option for the designer. In this work an attempt is made to investigate the effect of using three types of end heads on the design of in- service horizontal. Moderate pressure vessel using ASME codes. The studied model represents a practical case in which a horizontal (18 bar) LPG vessel fabricated in Heavy Engineering Equipment State Company (HEESC) - Dura Refinery -Baghdad - Iraq. The design is based on ASME: SEC.VIII div.1 which is suitable for moderate pressure as classified by ASME The results are compared with two commercial design software namely; COMPRESS and PV Elite. It is found that using of hemispherical head can reduce design thickness up to 51.5% as compared with other heads which results economic and light weight vessel, so it is recommended in to be used at HEESC and using the commercial software lead to higher design thickness for all head types.

Keywords: LPG; Pressure Vessel; ASME code; COMPRESS; PV Elite.

1. Introduction
LPG pressure vessels are storage container widely used for petroleum gasses under pressure. The design pressure of this type of vessels is ranged from (1-206) bar. For the safety purposes the design must insure strict requirement to avoid severe damage. Many design criteria are suggested [1]. However ASME codes is the most acceptable design criteria for practical applications due to the elaborated improvements via addenda and longtime experience.
ASME codes are general roles for design of wide range of pressure vessels. To include the vast variety of pressure vessels and requirements ASME allocated many sections and divisions as below:
I. Power Boilers
II. Materials

III. Nuclear Facility Components
IV. Heating Boilers
V. Nondestructive Examination
VI. Care and Operation of Heating Boilers
VII. Care of Power Boilers
VIII. Pressure Vessels
VIII. DIV.1 Operating Pressure:1 to 206 bar
VIII. DIV.2 Operating Pressure:206 to 690 bar
VIII. DIV.3 Operating Pressure: above 690 bar
IX. Welding and Brazing Qualifications
X. Fiber-Reinforced Plastic Pressure Vessels
XI. Inspection of Nuclear Power Plant Components
XII. Transport Tanks

Many researchers investigated the design of pressure vessels capsule and its accessories. In this regard. Thakkar B.S and Thakkar S.A [2] investigated the high pressure rise in the pressure vessel. They carried out Hydrostatic tests to test the vessel at different pressures. ASME criteria was employed to design and manufacture the pressure vessel capsule and accessories Dhanaraj, A. and Mallikarjuna M.V. [3] studied the effect of stresses at the opening in the capsule of pressure vessel assuming round shape. Aluminum alloy is used for construction the vessel wall under the effect of internal pressure. Finite element method is used for analyzing stresses. A comparison between experiments and numerical analysis were made under the effects of many parameters related to the operation conditions. Kumar, V., and Kumar, P. [4] studied the effect of material properties such as safety factor for tensile and yield strength on the vessel design and operation. ASME section VIII is employed in design and testing, PV ELITE software is used in the theoretical analysis of horizontal pressure vessel containing opening and saddle supports The main factors investigated in this research are ; effect of internal and external pressure, geometry and weight, nozzle and saddle design. Dubal, S. V., et al [5] investigated the effect of high pressure in pressure vessel according to ASME codes namely; division 1 and division 2, section VIII, They investigated the effect of stresses on the design to maintain safe design and operation conditions Narale P., and Kachare P. S. [6] studies the effect of the opening size in vessel capsule especially for large opening such as manhole for ASME Sec. VIII Division 1 was followed in this study. Finite element analysis is used to evaluate the stresses developed at the vessel wall and opening the stress analysis is performed by ANSYS software. In this work a large exhaust opening located near to the filter sheet are considered. The effect of stresses in the large opening is treated as per ASME to validate the design. Sankara et al [7] investigated the shape and geometry of a manhole at the upper part of a cylindrical pressure vessel. Two opening types are investigated namely; circular and elliptical opening. The manhole is locate at the vertical position with respect to the cylindrical vessel. Many aspects related to the manhole walls are considered; such as major axes of the elliptical hole in case of parallel or perpendicularly to the axis of the vessel cylinder. They presented the results in many figures and tables for the design purposes. Lewiński, J. [8] studied the pressure vessels, nozzles required for inlet and outlet attachments. They considered the geometrical parameters of nozzle connections and the effect of a stress concentration around the opening at vessel capsule, they analyzed the model using Numerical analysis for stress analysis around the nozzle. Siva et al. [9] considered a steel LPG vessel containing fluid with partially liquid and vapor. The stresses due to pressure loading inside the cylinder and heads are investigated. The results of stresses are compared with the available solution in literature to check the theory and the mathematical model. PV Elite Pro is used to analyze the stresses in the vessel wall. Kumar, V., et al. [10] analyzed a horizontal vessel with saddle support. A solid model of the pressure vessel is employed by using ANSYS software. Then the stresses are obtained from the static analysis. It is found that; the higher localized stress is located at the junction of the pressure vessel and at the saddle support. A comparison between the numerical and theoretical of the allowable stress and safety of design are made in this study. Mukhtar, F. M., and Al-Gahtani, H. J. [11] considered a cylindrical pressure vessel with nozzle connection according to thin shell stress analysis. The analysis is perfumed numerically by using FE method, In order to validate the analysis the obtained results are compared with other models founded in the literature. It is concluded that; the results for the stresses in the vessels with moderate to large diameter nozzles are larger as compared with that for vessels having small diameter nozzles which is suggested in the research.

In dealing with the ASME codes for pressure vessels many head types are suggested for design, however selecting the head type is left as an option for the designer. So it is interest to investigate the effect of changing of head type on the vessel design and applying the idea on a real practical pressure vessel case to serve a recommendation for future improving.

2. Theory

Vessel capsule includes; vessel cylindrical shell which is formed from rolling of sheet metals plate, two end heads and flanges made from pressing and flanging. The required thicknesses, Maximum Allowable Working Pressure (MAWP) and Maximum Allowable Pressure (MAP) for the cylindrical shell as the follows [1];

$$t_{sh} = \frac{PR_i}{2SE+0.6P} \quad (1)$$

$$MAWP = \frac{\mathrm{SEt}}{\mathrm{R+0.6t}} \quad (2)$$

$$MAP = \frac{\mathrm{SEt}}{(\mathrm{R+0.6t})-\mathrm{Ps}} \quad (3)$$

All shells of the pressure vessel must be closed by heads at the ends. Head are normally curved rather than flat Curved shapes are stronger and allow the head to be lighter, thinner, and less expensive that the flat heads. The following three types of heads are commonly used by ASME codes [1];

A. Hemisphere head

Thickness and pressure design equations based on internal diameter are as the follows [2];

$$t = \frac{PR_i}{2SE-0.2P} \quad (4)$$

$$P = \frac{2SEt}{R_i+0.2t} \quad (5)$$

B. Ellipsoidal head

Thickness and pressure are as the follows [2];

$$t = \frac{PD_iK}{2SE-0.2P} \quad (6)$$

$$P = \frac{2SEt}{KD_i+0.2t} \quad (7)$$

Where k is a shape factor for ellipse.

C. Torispherical head

Thickness and pressure are as the follows [2]:

$$t = \frac{0.885PL_i}{SE-0.1P} \quad (8)$$

$$P = \frac{SEt}{0.885L_i+0.1t} \quad (9)$$

3. Design as Per ASME Codes

Figure 1 shows block diagram for the design steps of pressure vessels. The pressure vessel must be met the requirements of safe design fabrication and testing. Also meets the standard of ASME codes.

4. Design using compress and PV elite software

In order to compare the results of design of the various parts of the model which are made by hand as per ASME codes, two commercial software were attempted which are COMPRESS and PV Elite which are widely used in factories. Before using of these programs many trains are made to design simple cases such as solid vessel and other built in examples which are supplied with these programs. The same studied model is built in COMPRESS program as shown in Figures (2 and 3) and PV Elite programs as shown in Figures (4 and 5) workspace and wizard windows respectively. The same materials properties and design requirements are employed. Following the programs wizard complete design reports are gotten.

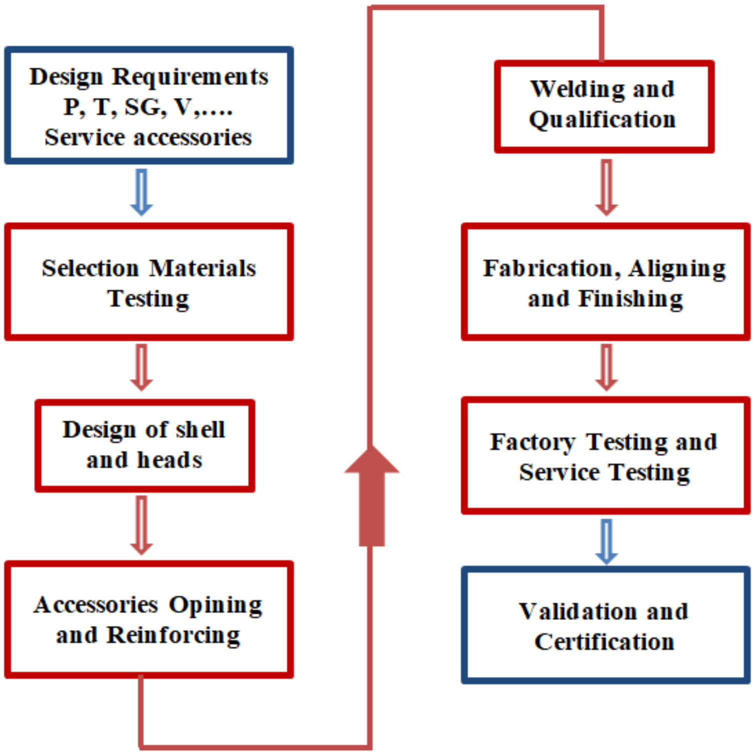


Figure 1. Design steps of pressure vessels.

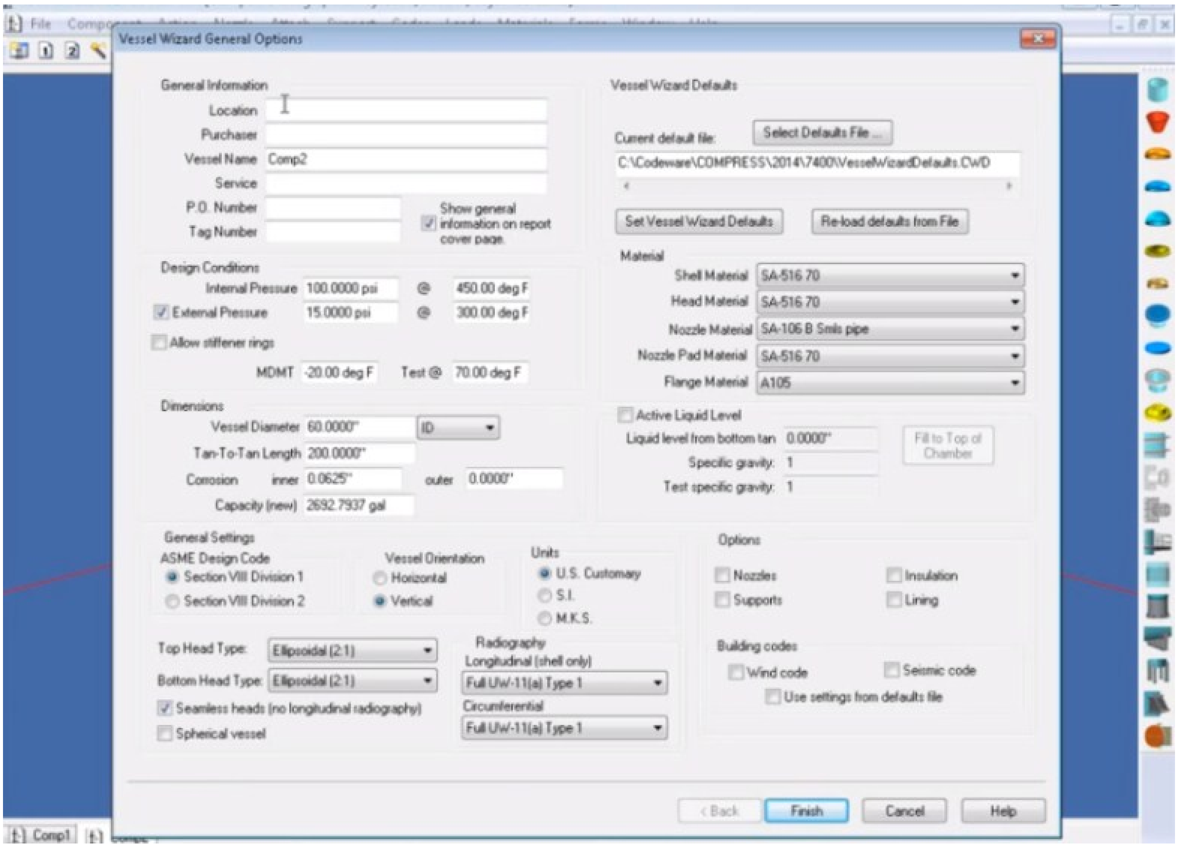


Figure 2. Software wizard window for COMPRESS.

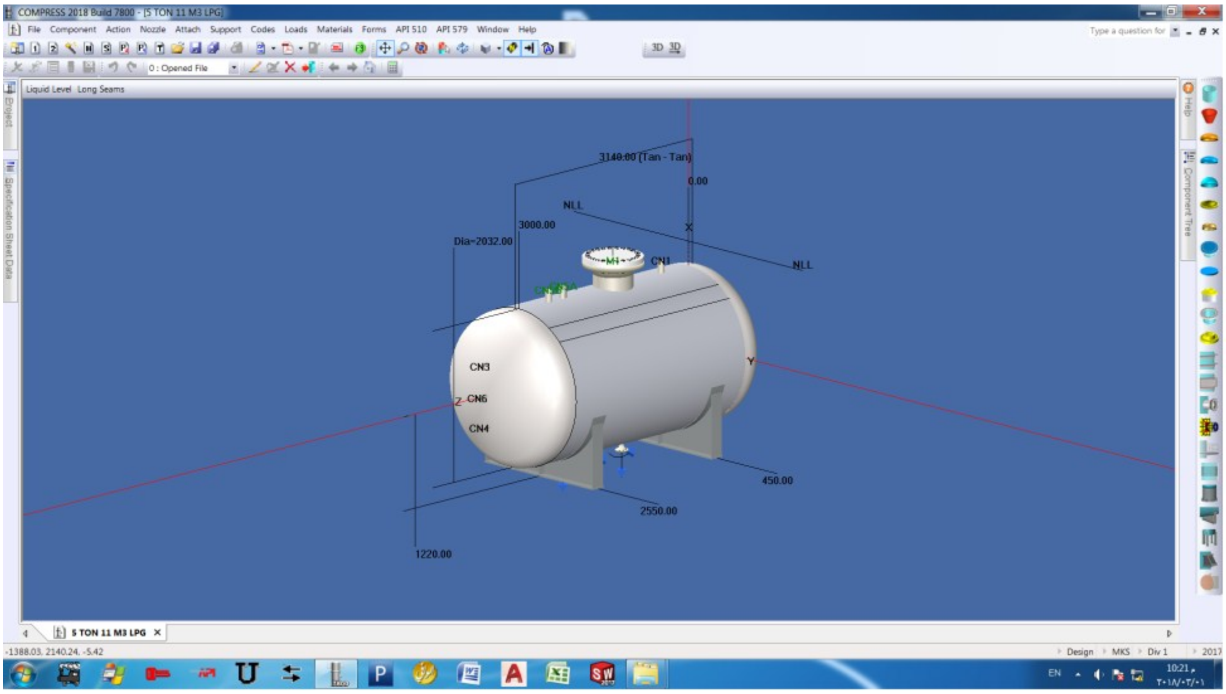


Figure 3. COMPRESS wizard window and model building.

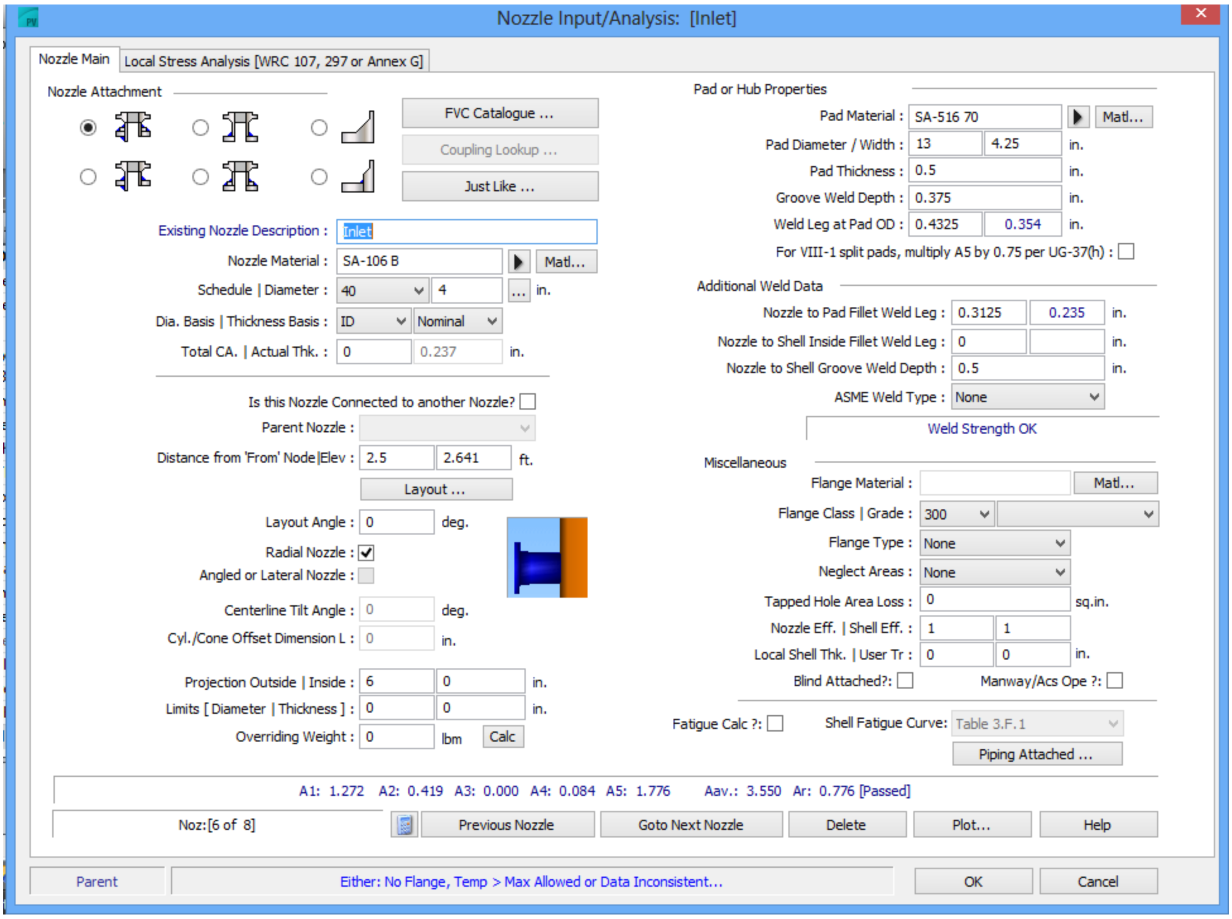


Figure 4. Design window for PV Elite.

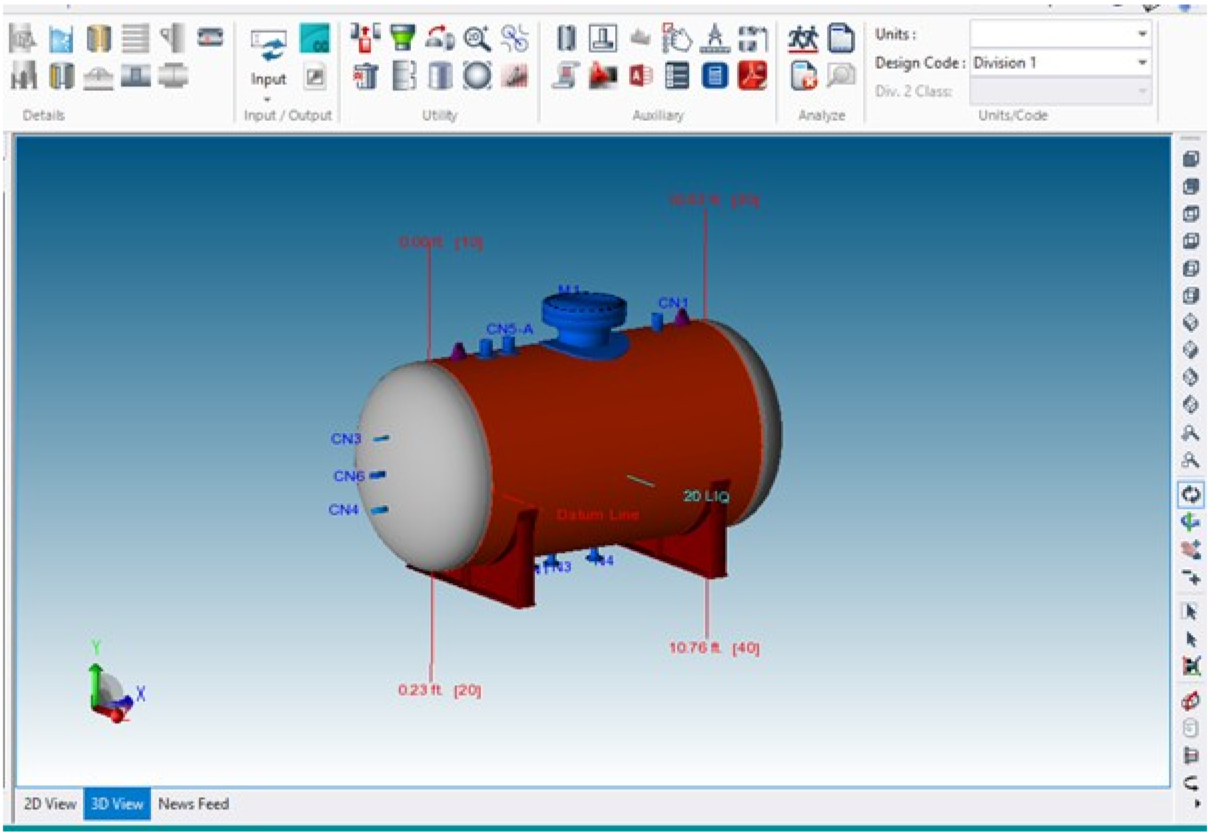


Figure 5. PV Elite wizard window and model building.

5. Results and discussions

For design calculation purpose the design data are selected from practical LPG vessel which is fabricated in HEESC. The vessel model is shown in Figure 6. The vessel is of cylindrical horizontal type with two torispherical head ends and supported over ground by two saddle supports it supplied with 12 nozzles to perform its requirement for service life. The detailed drawing and dimensions are shown in Figure 7.

The main required data for design such as fluid type, pressure, temperature and so on are given in Table 1. The associated mechanical properties of materials are as given in Table 2 [2]. While the required materials for the vessel various parts are shown in Table 3.

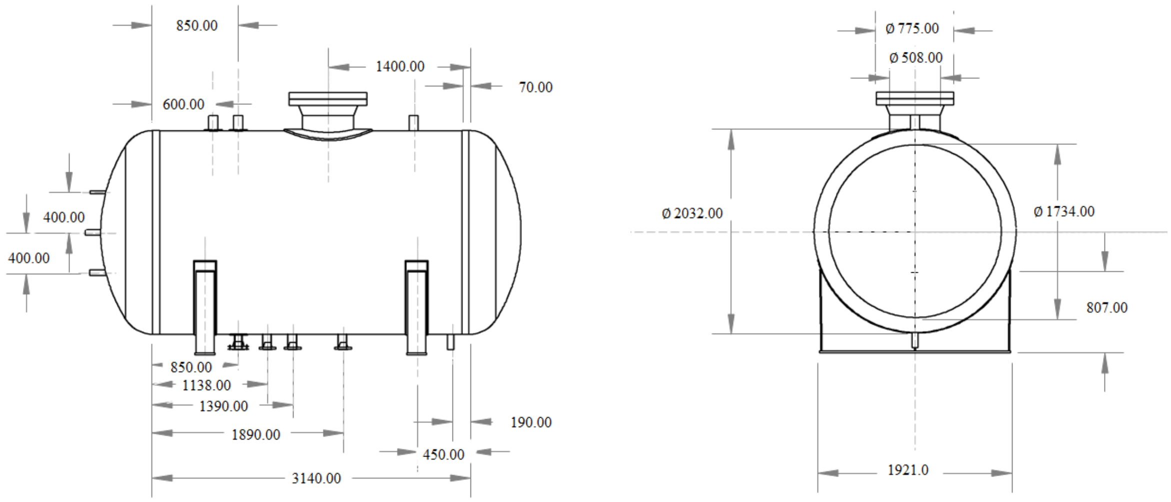
Since the operating internal pressure is within 18 bar and the outer pressure is zero so that ASME: SEC. VIII div.1 will be applied for the presented model.

First the results of capsule vessel model fabricated at HEESC is calculated using ASME code. The results are collected in Table 4. It is important to note that this pressure vessel is used Torispherical heads at the two ends.

(a) Front view

(b) Side view

Figure 6. LPG vessel case study.



(a) Front view (b) Side view

Figure 7. Detailed dimensions of vessel model.

Table 1. Design data.

Diameter	2000 mm
T-T length	3140 mm
Content Fluid (S.G)	LPG / 0.65
Design Pressure	18.15 kg/cm^2
Design Temperature	-20-70 C^o
Corrosion Allowance	1mm
Radiography	(Shell- Heads)
Hydro Test Pressure	Horizontal POS (23.5 kg/cm^2)
Geometric capacity	11m^3

Table 2. Material properties [2].

Property	Value
Density	7850 kg/m^3
Young's Modulus	2.00E+11 N/mm^2
Poisson's Ratio	0.3
Bulk Modulus	1.67E+11 pa
Shear Modulus	7.69E+10 pa

Table 3. Vessel required materials.

Shell	A-516 Gr. 70
Heads	A-516 Gr.70 Norm.
Sun Shade	Al 1.5 THK.
Compensation Plates	A516 GR. 70
Supports (Saddles)	A-283 Gr C
Plates and Ladder Clips	A-283 Gr C
External Branching Pipe Flange	A-106 Gr.B A-105
Internal Branches Pipe Fitting Flange	A-106 GR. B, A-234 WPB A-105
Manhole Pipe Flange	A-106 Gr.B A-105
External Bolting Nut	A-193 B7 A-194 2H
Coupling	A-105
Gasket	CAF

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Table 4. Summary of capsule design for HEESC vessel model.

Component	Mat.	ID mm	Len. mm	Design t mm	Nom t mm	MAWP bar	MAP bar
Head 1 (Torispherical)			516.36	15.23	16	18.98	20.4
Straight Flange on F&D Head 1			70	14.27	16	18.98	20.4
Cylinder	SA-516 70	2,000	3,000	14.27	15	20.35	21.87
Straight Flange on F&D Head 2			70	14.27	16	18.98	20.4
Head 2 (Torispherical)			516.36	15.23	16	18.98	20.4

To compare the effect of using other two types of heads which are; Ellipsoidal (2:1) and Hemispherical. The calculations are made using ASME (hand calculations), COMPRESS and PV Elite program. The results of head thicknesses are summarized in Table 5.

In order to investigate the effect of head type on the design thickness Figure 8 is plotted. As it is shown from this figure the minimum head thickness is obtained when using hemispherical type. The reduction in thickness is 46.8% and 51.5% as compared with the Ellipsoidal (2:1) and Torispherical head.

Figure 9 is plotted to compare the result of thicknesses calculated by ASME codes (hand calculations) and by using, COMPRESS and PV Elite programs.

As it can be seen from Figure 9 that the minimum design thickness values are obtained from using ASME codes for all head types while the higher values are obtained from using PV Elite program. This mean that such programs are used higher safety factors which are leading to non-economical design.

Table 5. Compression of heads thicknesses (mm).

Torispherical	Ellipsoidal (2:1)	Hemispherical
r_1=1000	r_1=1000	r_1 = 1000
r_2=300	r_2=340	r_2= 1000
t (by hand) =15.47	t (by hand) =14.1	t (by hand) =7.5
t (COMP.) = 16	t (COMP.) = 17	t (COMP.)= 8
t (PV Elite) = 17.5	t (PV Elite) = 20.63	t (PV Elite) = 14

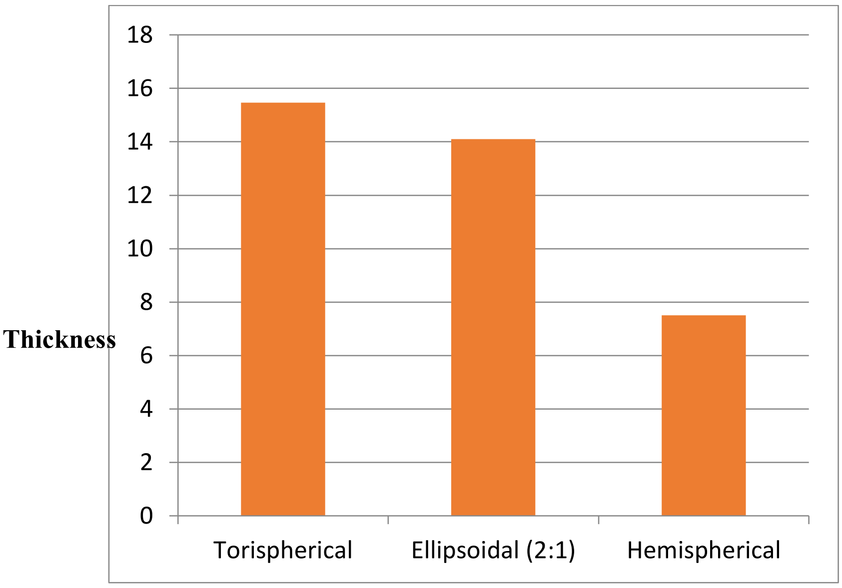

Figure 8. Design thickness of the three head types.

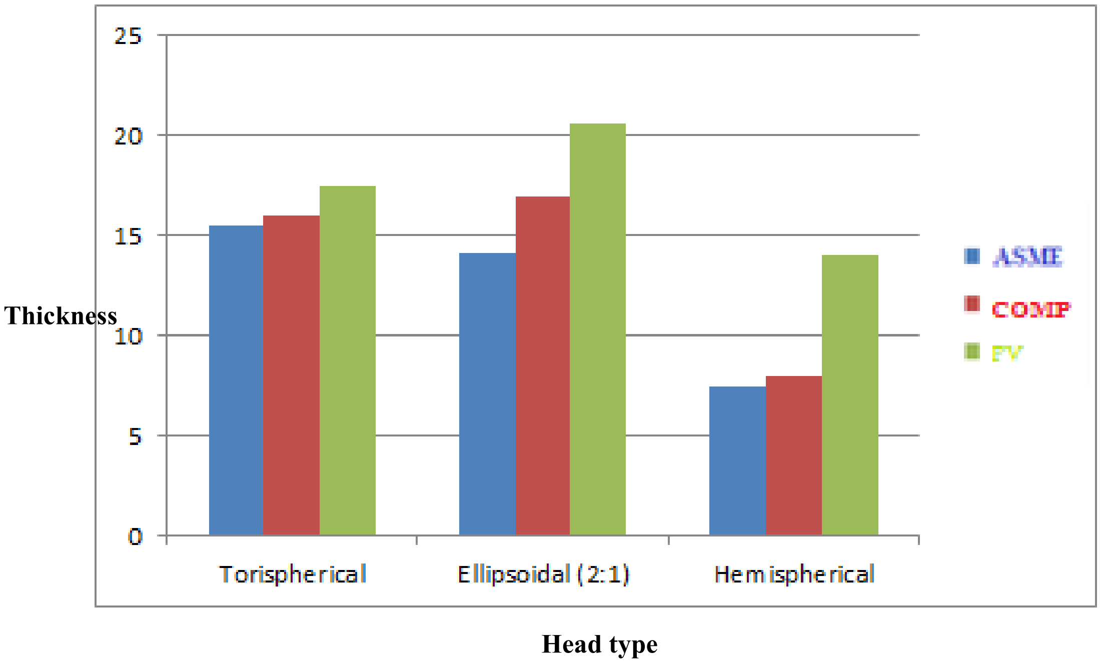

Figure 9. Compression of thicknesses of head obtained by ASME and commercial software.

6. Conclusion

The following conclusions can be derived from the numerical results of the studied model

1- Using hemispherical head can reduce the design thickness up to 51.5%
2- Using of commercial design software such COMPRESS and PV Elite lead to higher design thickness regardless of head type.
3- It is recommended for HEESC to fabricate pressure vessels with hemispherical head rather than deep tori head to achieve economical design.

List of symbols

A	Cross sectional area m^2	r_s	Diameter of the cylindrical shell /2, mm.
E	Elasticity modulus N/m^2	r_s	Inside radius of the shell to the base metal, mm.
ID	Internal shell diameter mm	S	The allowable stress, N/mm^2
r_i,	Inside/outside radius, mm.	t	Thickness of head, mm
r_m	Vessel Mean Radius, mm.	t_s	Shell thickness, mm
r_n	Inside radius of the nozzle to the base metal, mm	v	Poisson Ratio

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