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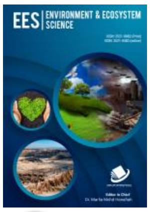

STRESS ANALYSIS ON PRESSURE VESSEL

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ABSTRACT

Researches done prior to this study focuses on designing of pressure vessel, theoretical studies on failure modes and catastrophic accidents of pressure vessel. This study intents to analyse stress effect based on ASME VIII Division I, PD 5500, and EN 13445 and design a storage tank using PVElite. This study is done for varying internal design temperature and internal design pressure. It is limited by tank capacity, size, type, shape and orientation of pressure vessel. The external design temperature, external design pressure, head type, joint efficiency, diameter, length, and corrosion allowance are restricted as well. The study is done by selecting type of pressure vessel, code of practices, materials and design parameters before performing analysis using PVElite. A LPG storage tank was designed using PVElite. A total of twelve simulation is done and the results are tabulated. It is seen that American standard is capable of simulating for internal temperature less than external temperature which is not possible than the other two counterparts. Here, the external temperature is set at 250C and the internal temperature varies from 00C - 600C with increment of 200C. British and European standard had an error while performing simulation for 00C and 200C The American standard also has the highest value for required thickness for external thickness for head and shell with 3.36518mm and 5.45026mm for head and shell respectively. The internal thickness for American standard is also the highest with 2.5mm, 2.65822mm, 4.01886mm and 6.14440mm for head thickness at 00C, 200C, 400C and 600C respectively while shell thickness is 2.5mm, 2.66606mm, 4.03766m and 6.18855mm for 00C, 200C, 400C and 600C respectively. Stress computed for head and shell for American standard was also the highest with 19.074 MPa, 38.148 MPa, 64.429 MPa and 118.258 MPa at 00C, 200C, 400C and 600C respectively for head and 15.525 MPa, 25.772 MPa, 60.151 MPa and 102.455 MPa for 00C, 200C, 400C and 600C respectively at shell. It is concluded that American standard is the better option of the three.

KEYWORDS

Pressure vessel, stress, ASME VIII Division 1, PD 5500, EN 13445, PVElite.

1. INTRODUCTION

Corrosion Developments in pressure vessels during the nineteenth and early twentieth centuries were accompanied by all-too-frequent terrible pressure vessel explosions. Tragic accidents such as the SS Sultana of United States (1865) and the Grover Shoe Factory explosion at Brockton, Massachusetts (1904) led to the development of basic standards for manufacturing and operation of pressure vessels. Further advances in metallurgy, welding technology and non-destructive testing helped, but an actual understanding of the science and mechanics of pressure vessel failure did not finally arrive until late twentieth century. Even in the twenty-first century, the catastrophic failure of a boiler pressure vessel in the SS Norway in Miami harbour in 2003, which killed eight crew, was a reminder that pressure vessels remain hazardous unless carefully designed, operated and inspected [1]. Pressure vessels works under certain pressure and temperature along with fatal substances that are risky for both human and environment. Considering this, safety implications and hazards arising from the operation of pressure vessels, there's a clear need to standardize engineering and fabrication practices. To assure minimum safety standards, many design codes have prepared and developed. In the united states and Canada, the most widely used Standards are the ASME Boiler and Pressure Vessel Code, published by American Society of Mechanical Engineers (ASME) [2]. Pressure vessels fail when the stress state somewhere in the wall material exceeds some failure criterion. It is thus necessary to be able to understand and quantify (resolve) stresses in solids [3]. Vessels failure may be sorted into four major classes, which describe why a vessel failure happens. Failures additionally classified into sorts of failures, that describe how the failure happens mean each failure contains its failure history, why and how it occurs. There are several reasons of vessels failure; (1) improper material choice, defected material; incorrect design information, (2) incorrect or inaccurate design technique or process, inadequate shop testing, (3) improper fabrication technique, poor quality control, insufficient fabrication process including welding, heat treatment and forming methods [1].
The ever-increasing use of vessel has given special emphasis to analytical and experimental ways for determining their operating stresses. Of equal importance is the appraising the significance of those stresses. This appraisal necessitates the means that of determining the values and extent of the stresses and strains, establishing the behaviour of the material concerned, and evaluating the compatibility of these two factors in the media or environment to which they're subjected. Knowledge of material behaviour is needed not solely to avoid failures, but also equally to allow maximum economy of material selection and amount used [4]. Although several national and international standard might exist, most studies are done pressure vessel designing by standard and analysis, theoretical studies on failure modes of pressure vessel and analysis on catastrophic accidents of pressure vessel. It is additionally noted that almost all studies referred to ASME VII Division I. Thus, study on stress analysis for variable on code of practices; ASME VII Division I, PD 5500 and EN 13445 is conducted. A proposition for possible and economical style accepted by chosen code of practices is created.

The aims of the study are; (1) to analyse stress effect based on standard code of practices using PVElite, (2) to design a pressure vessel using PV Elite and propose the better standard.

The scopes of the study are; (1) variation in the code of practices selected for designing of pressure vessel, (2) variation in the internal design pressure and internal design temperature

The study is limited by; (1) limitation in tank capacity and size, (2) limitation in type of pressure vessel, (3) limitation in shape and orientation of pressure vessel, (4) limitation in external design pressure and external design temperature, (5) limitation in type of head selected for pressure vessel, (6) limitation to single joint efficiency, (7) limitation to fixed diameter, length and corrosion allowance, (8) limitation to single type of material.

2. METHODOLOGY

This study is done in a systematic approach. First, pressure vessel selection is done. Next, code of practices are selected. Then, materials are selected. The design parameters are fixed before proceeding into calculation and analysis. The result from the calculation and analysis are compared to make the proposition of design. PVElite is used to design the LPG storage tank.

2.1 Pressure Vessel Selection

There are many application of pressure vessel in the industry, LPG Tank was selected as the benchmark here. The design requirement are prepared. LPG storage tanks can be categorized into bulk storage and cylinders. LPG bulk storage tanks can be installed either underground or aboveground. For safety and risk prevention cause, the LPG storage tank for above ground should be located in the open air outside of the buildings. According to Gas Supply Act, the storage system is designed by engineers in accordance to gas consumption and safety distance. The installations of storage system shall be fenced and locked to prevent unauthorized access and tempering [5]. There should be a minimum distance (called the separation distance) between the tank and any building, boundary line or fixed source of ignition. For this study, the LPG aboveground storage tank is chosen [6].

2.2 Code of practice selection

There are many engineering standards which gives information on the design, construction and fittings of an LPG Tank. The MS 830 is normally followed in Malaysia, but other national or international standards may also be used [7]. For this study, ASME VIII (Division 1) "Construction of Pressure Vessel Codes", PD 5500 "Specification for Unfired, Fusion Welded Pressure Vessels" and EN 13445 “Unfired Pressure Vessels” are selected for the analysis.

2.3 Material Selection

Several materials are used in pressure vessel fabrication. The selection of material is based on the appropriateness of the design requirement [8,9]. All the materials used in the manufacturing of LPG Tank shall comply with the requirements of the relevant design code, and be identifiable with mill sheets. The selection of materials of the shell shall take into account the suitability of the materials with the maximum working pressure and fabrication process.

Table 1: Part material

Element		Code		
		ASME VIII	PD 5500	EN 13445
Head		ASTM A516 Grade 70	BS1501-224-490A	EN10028 P355GH
Saddle				
Shell				
Nozzle	(Liquid Withdrawal 1)			
	(Liquid Fill)			
	(Relief)			
	(Vapor Withdrawal)			
	(Manway)			

2.4 Design data fixation

The parameters used for the study are fixed and are tabulated

Table 2: Design Input

<table>
<tr><td>Code preference</td><td colspan="2">ASME VIII</td><td colspan="2">PD 5500</td><td colspan="2">EN 13445</td></tr>
<tr><td>Head Type</td><td colspan="6">Ellipsoidal</td></tr>
<tr><td>Major to minor axis ratio</td><td colspan="6">2</td></tr>
<tr><td>Material</td><td colspan="2">SA-516 Grade 70</td><td colspan="2">BS1501 - 224 - 490A</td><td colspan="2">EN 10028 P355GH</td></tr>
<tr><td>Tank Type</td><td colspan="6">Aboveground</td></tr>
<tr><td>Internal Design Temperature, ^{0}C</td><td>0</td><td colspan="2">20</td><td colspan="2">40</td><td>60</td></tr>
<tr><td>Internal Design Pressure, kPa</td><td>250</td><td colspan="2">500</td><td colspan="2">910</td><td>1550</td></tr>
<tr><td>External Design Temperature, ^{0}C</td><td colspan="6">25.0</td></tr>
<tr><td>External Design Pressure, kPa</td><td colspan="6">100.0</td></tr>
<tr><td>Diameter, mm</td><td colspan="6">915.0</td></tr>
<tr><td>Vessel Design Length, Tangent to Tangent, mm</td><td colspan="6">2350.0</td></tr>
<tr><td>Corrosion Allowance, mm</td><td colspan="6">1.0</td></tr>
<tr><td>Joint Efficiency, E (Longitudinal/Circumferential)</td><td colspan="6">1.0/1.0</td></tr>
</table>

2.5 Design Calculation and Analysis

This study uses the simulation using PVElite for computation of stress analysis. Prior to using the software, the design input or parameter had to be prepared first. The design inputs are tabulated in Table 2 the software comes up with necessary calculation for analysis.

The initiation is followed by launching the software. Next, the input parameter for head, shell and nozzle is entered. Then, material is chosen. Calculation is run for thickness on head, shell and nozzle. Later, the saddle parameters are entered. Calculation on saddle is performed. Following that, results for internal design pressure and external design pressure is obtained before terminating the sequence.

2.6 Designing of LPG tank

The tank is designed using PVElite by using the design parameters for 0.5kl storage tank.

3. RESULTS AND DISCUSSION

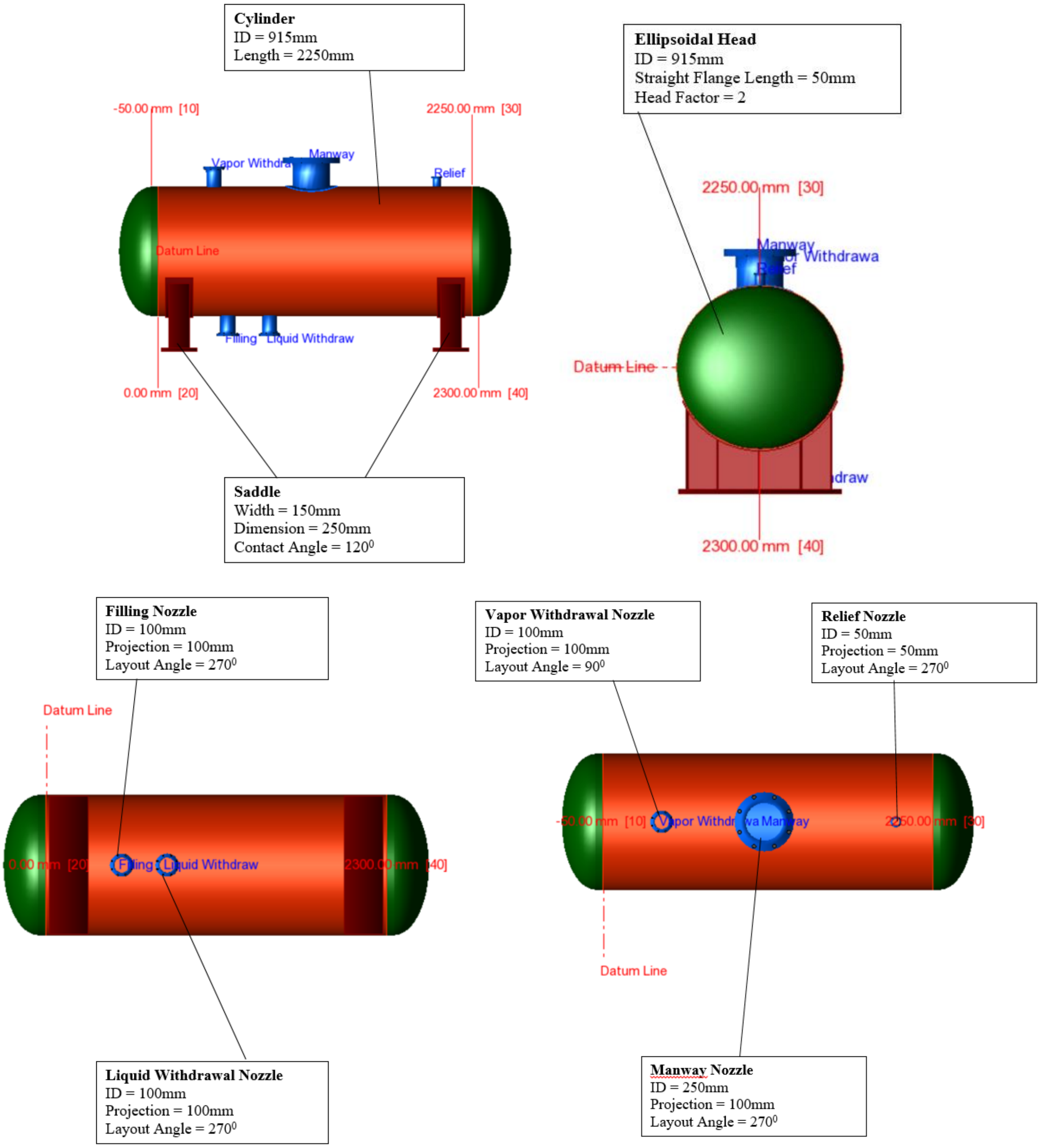

Figure 1: Design of LPG storage tank.

Figure 1 shows front layout, side layout, bottom layout and top layout of LPG storage tank. The cylinder is 2250mm long with an internal diameter or 915mm. The saddle supports the horizontal storage tank. Two saddle is placed at each end of the cylinder to hold the tank in position. The ellipsoidal head is used. The tank is designed with five nozzle. The refill nozzle, liquid withdrawal nozzle, vapor withdrawal nozzle, relief nozzle and manway nozzle. This tank is designed for 500kL capacity.

Table 3: Summary of simulation using PVElite.

Code	ASME VIII				PD 5500				EN 13445			
External Design Temperature (^{0}C)	25											
Internal Design Temperature (^{0}C)	0	20	40	60	0	20	40	60	0	20	40	60
Presence of error	No	No	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Type of error	-				Internal design temperature should be equal or more than external design temperature		-		Internal design temperature should be equal or more than external design temperature		-	

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PV Elite software was used to simulate the LPG storage tank. Simulation was done for three different code of practices; ASME VIII Division I, PD 5500 and EN 13445. The simulation was done for constant external condition and varying internal condition. Simulation for American standard was simulated with no error for all design condition. However, there was presence of error for British standard and European standard [10]. In both British and European standard, it is seen that error is present for internal design temperature of 00C and 200C. The simulation done for internal design temperature of 400C and 600C in both the British and European standard did not show any errors. For all the simulations let it be for British standard, American standard or European standard, the external design temperature is kept constant at 250C. Thus, it is evident that the internal design temperature should be equal or more than the external design temperature as the report that was produced by PVElite suggests.

Table 4: Stress for each element

Standard	ASME VIII				PD 5500				EN 13445			
Internal Design Temperature (^{0}C)	0	20	40	60	0	20	40	60	0	20	40	60
Head Stress (MPa)	19.074	38.148	69.429	118.258	4.78	9.55	17.38	21.97	-	-	63.126	79.959
Shell Stress (MPa)	16.525	25.772	60.151	102.455	22.92	45.85	83.45	105.46	16.500	33.000	60.060	75.900

PVElite provides the head actual stress and shell actual stress. Data obtained are for operating condition. Simulation on all three standards gave actual shell stress for every internal design temperature. However, for European standard, actual head stress was not computed for internal design temperature of 00C and 200C. This could be because the internal design temperature is below the external design temperature as was discussed earlier [11-13]. In general, the actual head stress and actual shell stress shows an increase for increasing internal design temperature for all three standards. It is seen that the head stress is slightly more than the shell stress for American and European standard. This is contradictory to the British standard which computes for higher shell stress than head stress. It is also noted that the American standard gives the highest head stress for a particular design condition than other counterparts. For instance, at internal design temperature of 600C, the American standard gives the highest head stress than the other two standards. On the other hand, both American and British standard gives higher value than European standard for shell stress.

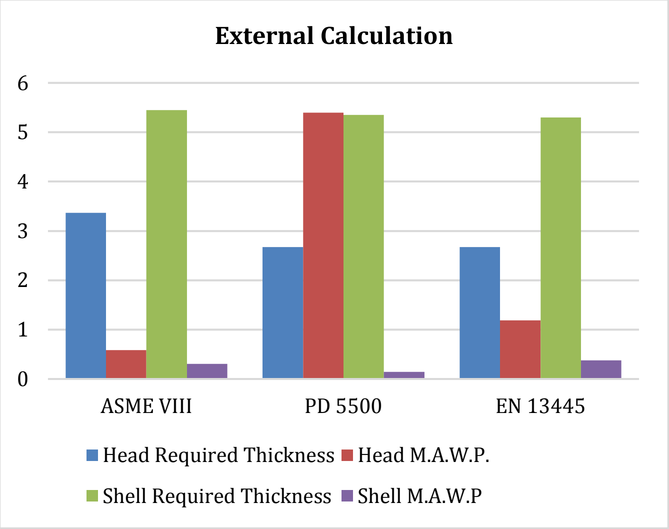

Figure 2: External calculation for head and shell.

From Figure 2, it is evident that the shell required thickness is far greater than the head required thickness for all three standards. This must be due to the saddle imposing load on shell and also due to the existence of nozzle. A point to be noted is that the tank is also horizontal, meaning the center of gravity is at the shell. It is also evident that the head maximum allowable working pressure is higher than the shell maximum allowable working pressure for all three standards. Head required thickness for American standard is higher than the other two standards but the British standard's head maximum allowable working pressure is higher than the other two standards.

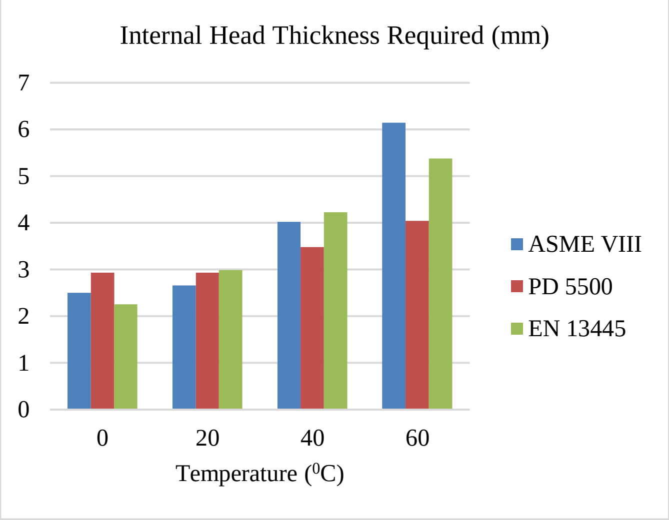

Figure 3: Internal head required thickness

From Figure 3, the thickness increases for increasing temperature in all three standards. The American standard requires higher thickness than the British standard and European standard. However, for the British standard, the required thickness for the first two temperature is the same probably due to the error stated earlier

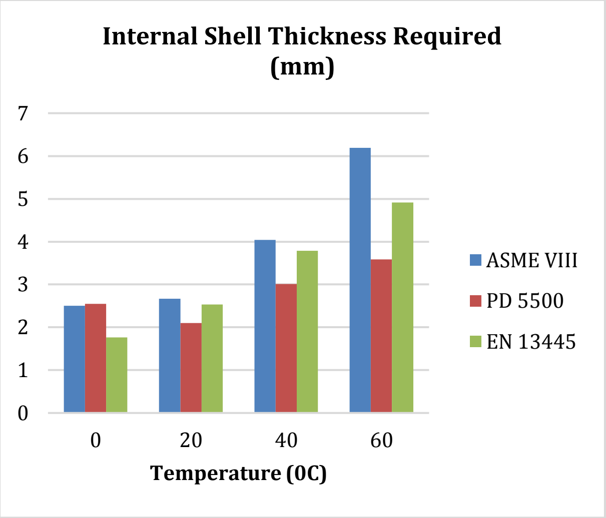

Figure 4: Internal shell required thickness

As for Figure 4, the thickness increases for increasing temperature in all three standards. The American standard requires higher thickness than the British standard and European standard. However, for the British standard, the required thickness for the first temperature is higher than the second temperature probably due to the error stated earlier.

4. CONCLUSION

In conclusion, the three standards are used to simulate and analyse stress effect using PVElite. Later, the PLG storage tank is designed using PVElite. The code of practice is varied along with the internal design condition; (1) pressure; (2) temperature. The simulation is limited to tank capacity, type, shape, external design condition and type of head. Here, the external temperature is set at 250C and the internal temperature varies from 00C-600C with increment of 200C. British and European standard had an error while performing simulation for 00C and 200C. The American standard also has the highest value for required thickness for external thickness with 3.36518mm and 5.45026mm for head and shell respectively. The internal thickness for American standard is also the highest with 2.5000mm, 2.65822mm, 4.01886mm and 6.14440mm for head thickness at 00C, 200C, 400C and 600C respectively while shell thickness is 2.5000mm, 2.66606mm, 4.03766m and 6.18855mm for 00C, 200C, 400C and 600C respectively. Stress computed for head and shell at operating condition for American standard was also the highest with 19.074 MPa, 38.148 MPa, 64.429 MPa and 118.258 MPa at 00C, 200C, 400C and 600C respectively for head and 15.525 MPa, 25.772 MPa, 60.151 MPa and 102.455 MPa for 00C, 200C, 400C and 600C respectively at shell. It is safe to say that the American standard which is ASME VIII is a better option. This is supported with the idea of it is better to assume more than to assume less. A point to be noted is also that not every internal design condition necessarily always higher than the external condition.

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REFERENCES

[1] Cholan, A.B.H. 2008. Design, Analysis and Fabrication of Pressure Vessel (Bachelor of Manufacturing Engineering (Manufacturing Process), Universiti Teknikal Malaysia Melaka.

[2] Kumar, V., Kumar, P. 2014. Mechanical design of pressure vessel by using PV-ELITE software International Journal of Scientific and Research Publications, 4 (4).

[3] Kaminski, D.C. 2005. Stress Analysis and Pressure Vessels.

[4] Joseph, M., Vishnu, V., Vijay. 2011. Design of Pressure Vessel.

[5] Gas Supply Act. 1993. Act 501 C.F.R.

[6] Gupta, S.R., Desai, A. 2014. Design of Horizontal Pressure Vessel using PVElite Software. International Journal for Innovative Research in Science and Technology, 1(1).

[7] Khattak, M.A., Mukhtar, A., Khan, K.A. 2016. Common Root Causes of Pressure Vessel Failures: A Review. Advanced Research in Applied Mechanics, 21 (1).

[8] Vyas, B.P., Tayade, R.M., Kumbhani, A.D. 2013. Design of Vertical Pressure using PVElite Software. International Journal of Engineering Research and Technology, 2 (3).

[9] ASME. 2013. Boiler & Pressure Vessel Code.
[10] Morris. 2011. Pressure Vessel doi:10.1615/AtoZ.p.pressure_vessels

[11] Megasy, F.E. 1983. Pressure Vessel Handbook: Pressure Vessel Handbook Pub.

[12] Nash, D.H. 2008. UK Rules for Unfired Pressure Vessels. In the Companion Guide to ASME Boiler and Pressure Vessel Code.

[13] Sulaiman, A.R. 2005. Interactive computer aided design of pressure vessels. (Bachelor of Mechanical Engineering), Universiti Teknologi Malaysia.