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Analysis of the Performance of a Pressure Vessel Structure: A Numerical Method Approach

Noor Fasya Fashihah Khalid[1], Zuliazura Mohd Salleh[1,*], Izuan Amin Ishak[2], Rais Hanizam Madon[1], Ishkrizat Taib[1], Mohd Fairuz Marian[3]

[1] Department of Mechanical Technology, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia
[2] Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, Malaysia
[3] Department of Technology Studies, Faculty of Technical and Vocational Education, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia

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ABSTRACT

A pressure vessel is a closed container that stores a gas or liquid at a pressure that significantly differs from the ambient pressure. Biodiesel plants are most common applications of pressure vessels. Because of the pressure vessel's varying operating conditions, it is potentially dangerous and could result in fatal accidents. This knowledge can help not only determine longevity but also determine how to care for and maintain them properly. Therefore, this study involved the investigation of the distribution of deformation and stress in the pressure vessel structure located at the UTHM biodiesel pilot plant using four different initial temperatures which are 35℃, 83℃, 120℃, and 350℃. The dimensions of the pressure vessel were obtained from the actual geometry of the pressure vessel VE203 in the UTHM biodiesel pilot plant. There were four variables for the different materials used in this simulation: stainless steel, carbon steel, titanium alloy, and super duplex 2507. The analysis results were used to establish a risk assessment to predict the performance of the pressure vessel structure. Analysis was performed using the Fluid-Structure Interaction (FSI) method. The constructed risk indicators aid in predicting risks for pressure vessels during the operating process, and for the safety of workers in the plant. The results indicated that carbon steel can withstand high deformation of the structure when the inlet temperature exceeds the allowable operating temperature, 350℃which is 0.03816 m. Meanwhile, stainless steel can withstand high-stress distribution because the lowest value recorded at an inlet temperature of 350°C is 3687 MPa.

1. Introduction

A plant is an important aspect of the oil and gas sector that processes products. In the plant, major equipment such as boilers, cooling towers, air compressors, and pressure vessels are used depending on the process involved. Pressure vessels are among the most widely used equipment in

[*] *Corresponding author.*
E-mail address: zulia@uthm.edu.my

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the industry, but their use depends on the process operation required. There are a few main parts of a pressure vessel, including the end closure, nozzle, shell, saddle, and manhole. Many parameters can affect the performance of a pressure vessel, such as the pressure, temperature, corrosion, and material selection. According to ASME [1], pressure vessels are designed to carry, receive, and store fluids, liquids, and gases at specific temperatures and pressures. The condition of the fluid in a pressure vessel changes due to variations in operating pressure [2].

The pressure vessel has a minimum and maximum allowable temperature according to the process being performed. When the temperature in the pressure vessel increases, it will weaken the metal used [3]. Therefore, the pressure vessel cannot operate at temperatures higher than the allowable temperature. There is also a minimum temperature at which the pressure vessel operates safely. Metals may become brittle at very low temperatures [4]. The selection of materials is an important factor in the structure of pressure vessels [5]. Pressure vessels consist of ductile and tough materials, such as stainless steel, carbon steel, and alloy steel, due to their high resistance to catastrophic failure. It is necessary to monitor and recognise the possible risks to all parameters regarding the overall performance of the pressure vessel structure. This is because a burst pressure vessel may be extremely dangerous, resulting in toxic gas leaks, fires, or explosions, all of which can cause significant human and property losses.

The pressure vessel structure and parameters used in this study were based on the University Tun Hussein Onn Malaysia (UTHM) biodiesel pilot plant located in Parit Raja, Batu Pahat, Johor. From this study, the effect of different initial temperatures on the deformation of the structure, as well as the effect of different materials on the stress distribution in the pressure vessel structure will be analysed and risk prediction performance will be established.

2. Methodology

2.1 3D Modelling of Pressure Vessel

The geometry of the pressure vessel model was taken and then drawn using SolidWorks, and the horizontal vessel was chosen as studied by previous researchers [6-11]. The pressure vessel model consisted of four parts: one body, a set of pipe nozzles, and saddle support. The pressure vessel model was constructed from the measured dimensions. Figure 1 shows the complete assembly modelling and the part names.

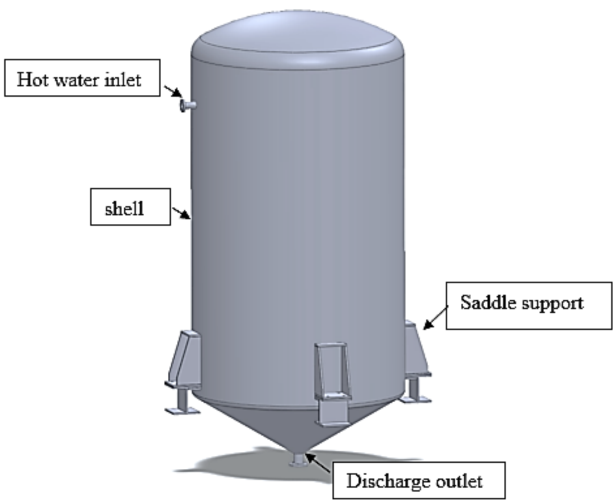

Fig. 1. 3D model of pressure vessel and part defined

2.2 Simulation Analysis

This study embeds the simulation method analysis to calculated and analysed all data from all cases. This method has been proven to be useful for studying and obtaining accurate results by previous researchers [12-15].

2.2.1 Thermal analysis and boundary condition

The ANSYS steady-state thermal model was used to analyse the effect of four different initial temperatures on structure behaviour. The initial temperature is a variable that will change in this simulation. The first law of thermodynamics states that thermal energy is conserved. The law of conservation of energy (Fourier's law) can be represented by a differential equation. The equation is written as:

$$\rho c \frac{\partial T}{\partial t} - \left(\frac{\partial}{\partial t}\left(kx\frac{\partial T}{\partial t}\right) + \frac{\partial}{\partial t}\left(ky\frac{\partial T}{\partial t}\right) + \frac{\partial}{\partial t}\left(kz\frac{\partial T}{\partial t}\right) \right) - \dot{q} = 0 \tag{1}$$

The boundary conditions required to complete the input data (in addition to the 3D geometric model and properties of the material) for heat transfer to the surface are as follows:

Specified temperature

$$T = T_s \tag{2}$$

Specified heat flux

$$q = -q_s \tag{3}$$

Convection heat transfer

$$q = h(T_s - T_\infty) \tag{4}$$

The boundary condition parameters used in this simulation was tabulated in Table 1.

Table 1
Parameter used in thermal analysis setting

Temperature	(°C)			
Initial	35	83	120	350
Ambient	27			

2.2.2 Structural analysis and boundary conditions

The pressure vessel structural behaviour was studied using steady-state thermal and static structural in ANSYS Mechanical in a one-way FSI technique. The analysis aims to study the deformation of the structure and the stress distribution of the pressure vessel structure of four different materials.
The Young's modulus (E), also known as the elastic modulus, which defines the relationship between stress (σ) and strain (ε) in a linear elastic material, can be calculated using the following Eq. 5. The boundary condition parameters used in this simulation was tabulated in Table 2.

$$E = \frac{\sigma}{\varepsilon} \quad (5)$$

Table 2
Materials properties of the structural components

Material	Young's modulus, E (GPa)	Density, p (kg/m^3)	Poisson's ratio, v
Stainless steel	193	77500	0.31
Carbon steel	210	7850	0.29
Titanium alloy	96	4620	0.36
Super duplex 2507	200	7800	0.30

3. Results

The analysis was carried out by connecting two systems in ANSYS Mechanical, steady-state thermal and static structural, as a one-way FSI method to increase the accuracy of the final results. The analysis results show the effects on the deformation of the pressure vessel structure and stress distribution using different initial temperatures and pressure vessel materials.

3.1 Effect of Structure Deformation at Different Initial Temperatures and on Different Materials

Temperature analysis was performed to investigate the deformation of the structure in different materials of the pressure vessel. This analysis will be carried out at four different initial temperatures, 35˚C, 83˚C, 120˚C and 350˚C, and four different materials for each temperature: stainless steel, carbon steel, titanium alloy, and super duplex 2507. The materials offer good corrosion resistance, apart from the structural rigidity and stiffness required for high-performance applications. The discussion will be compared at different initial temperatures using different types of materials to fabricate the pressure vessel.

3.1.1 Deformation distribution in 35°C initial temperature

All models for four materials of the 35°C initial temperature of the pressure vessel was analysed to obtain the deformation distribution shown in Figure 2. The highest deformation recorded for the titanium alloy was 0.06738 m due to its material properties, magnitude, and direction of application. Titanium has a low elastic modulus, which makes it flexible and easily deformable. The other materials recorded maximum deformations of (a) 0.03384, (b) 0.03127 m, and (d) 0.03274 m, respectively. The material deforms when a load is applied to the pressure vessel. When the elastic moduli of the four materials is compared, carbon steel is shown to be stronger because it had the lowest deformation value.

3.1.2 Deformation distribution in 83˚C initial temperature

Figure 3 shows the deformation distribution for all materials at 83°C initial temperature of the pressure vessel. All materials showed an increase in deformation upon high-temperature application. Deformation began to occur at the hemispherical head section for stainless steel, carbon steel, and super duplex due to the material properties as well as the initial temperature increase. The deformation at the hemispherical head sections showed by stainless steel and titanium, shows no deformation in any part. The titanium alloy remained constant with the maximum deformation at the inlet nozzle of 0.06931 m. Meanwhile, a lower deformation value of 0.03212 m was recorded for carbon steel due to the high strength of the material. The stainless steel and super duplex 2507 specimens exhibited deformation values of 0.03446 and 0.03343 m, respectively.

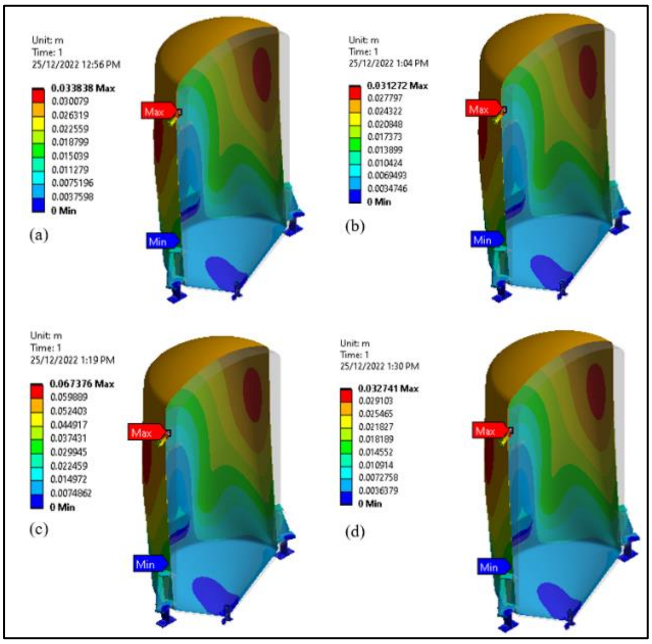

Fig. 2. 35˚C initial temperature (a) Stainless steel (b) Carbon steel (c) Titanium alloy (d) Super duplex 2507

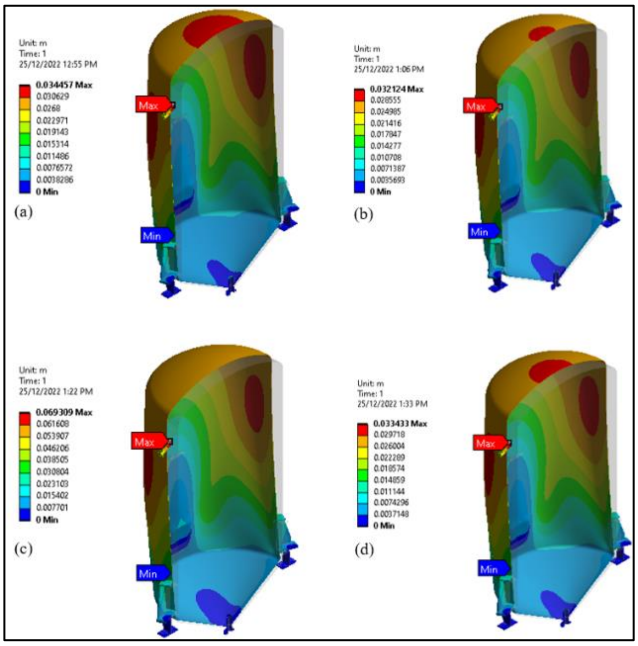

Fig. 3. 83˚C initial temperature (a) Stainless steel (b) carbon steel (c) Titanium alloy (d) Super duplex 2507

3.1.3 Deformation distribution in 120˚C initial temperature

A pressure vessel model with a pressure vessel initial temperature of 120˚C was analyzed as shown in Figure 4. This model represents the maximum allowable operating temperature for pressure vessel design at the UTHM biodiesel pilot plant. When the initial temperature was increased until the maximum temperature, the color deformation began to change for all materials. The maximum deformation of 0.07080 m for titanium alloy occurred near the inlet nozzle and the cylindrical shell of the vessel. Carbon steel has recorded the lowest deformation compared to other materials; 0.03279 m. Carbon steel is particularly effective in applications where strength is needed due to the high strength of modulus elasticity. However, the current material used for the pressure vessel at the UTHM biodiesel pilot plant, stainless steel recorded 0.03496 m of deformation value. Although a super duplex has excellent mechanical properties, this material only recorded 0.03398 m of the deformation value of the pressure vessel.

3.1.4 Deformation distribution in 350˚c initial temperature

This pressure vessel was operated beyond the allowable operating temperature range to analyze whether the pressure vessel is still safe to operate if a high initial temperature was applied as presented in Figure 5. Titanium alloy has shown the highest deformation value which is 0.08015 m at the inlet nozzle. The other three models, stainless steel, carbon steel, and super duplex 2507, have maximum deformation at the hemispherical head section and the cylindrical walls which is 0.04333 m, 0.03816 m, and 0.03981 m, respectively.

The highest deformation of the pressure vessel structure in this study does not potentially fail or break down and it is in the range of safe to operate if the initial temperature is beyond the allowable operating temperature. Although titanium has a high deformation, it is still safe to use and does not show a risk of danger because the data shows the deformation of the structure was below the maximum value and it still moves within the allowance range at the plant. This deformation occurs due to material properties where any material with a low modulus elasticity can easily deform the structure.

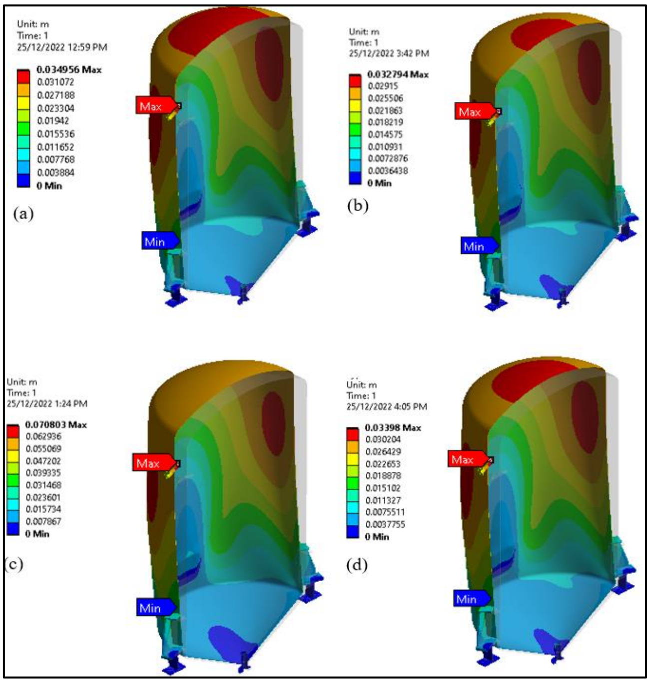

Fig. 4. 120˚C initial temperature (a) Stainless steel (b) Carbon steel (c) Titanium alloy (d) Super duplex 2507

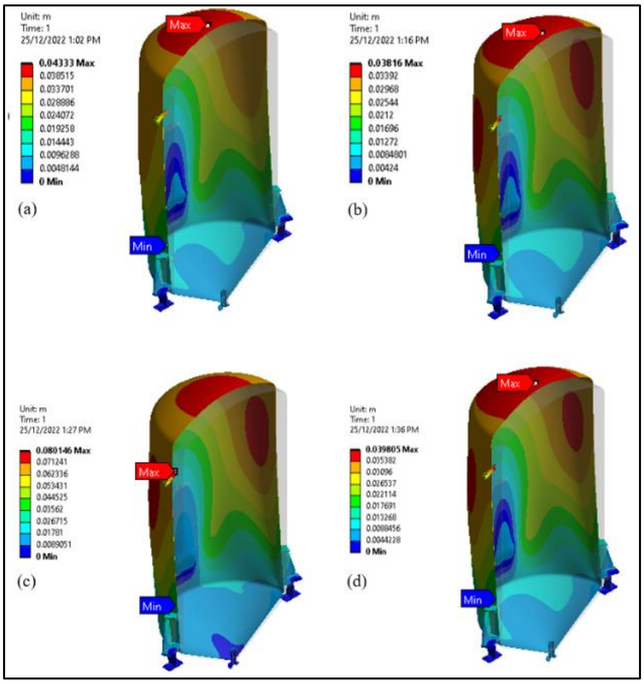

Fig. 5. 350˚C initial temperature (a) Stainless steel (b) Carbon steel (c) Titanium alloy (d) Super duplex 2507

3.2 Effect of Stress Distribution on the Performance of Pressure Vessel Structure

The stress distribution across the pressure vessel structure can be solved by stress simulation by properly applying boundary conditions such as pressure, temperature, and material properties [16,17]. Pressure vessel stress analysis determines how a pressure vessel behaves based on its material, pressure, body, temperature, fluid used, and saddle support. Pressure vessel stress analysis could better represent the pressure vessel lifespan, but it is a close approximation. Performing a pressure vessel analysis can also provide information on the probability of a risk involving a pressure vessel.

3.2.1 Stress distribution in 35˚C initial temperature

The stress distribution results at the 35°C initial temperature for the different materials is shown in Figure 6. The highest stress was 3579 MPa for the titanium alloy. Other materials such as stainless steel, carbon steel, and super duplex 2507 exhibited stress values of 3474, 3441, and 3458 MPa, respectively. Stress occurs due to temperature gradients in materials. If the temperature increases, the stress distribution in the pressure vessel also increases. When the initial temperature is 35˚C, the high-stress area is at the support saddle on the pressure vessel. The support saddle is a critical point because it joins to the cylindrical wall and has a welding, bolt, and nut on it. Because of this, the support saddle holds the most pressure on the bottom compared to other parts of the pressure vessel. Other than that, stress occurs on the saddle as well as because of the weight it supports.

3.2.2 Stress distribution in 83˚C initial temperature

Figure 7 shows a view of the stress distribution at 83°C initial temperature. The results of the stress distribution were compared based on four materials. There was no significant difference in the stress distribution on the pressure vessel wall compared with the stress distribution at an initial temperature of 35˚C. The stress distribution increased by 3672 MPa for the titanium alloy and decreased for stainless steel, carbon steel, and super duplex 2507, which are 3506 MPa, 3499 MPa, and 3507 MPa, respectively. This occurred because of the material properties and affected the strength inside the pressure vessel. Due to the low strength of the material, titanium exhibited the highest maximum stress but also the lowest minimum stress in this case. Thus, titanium is still safe to operate at this temperature.

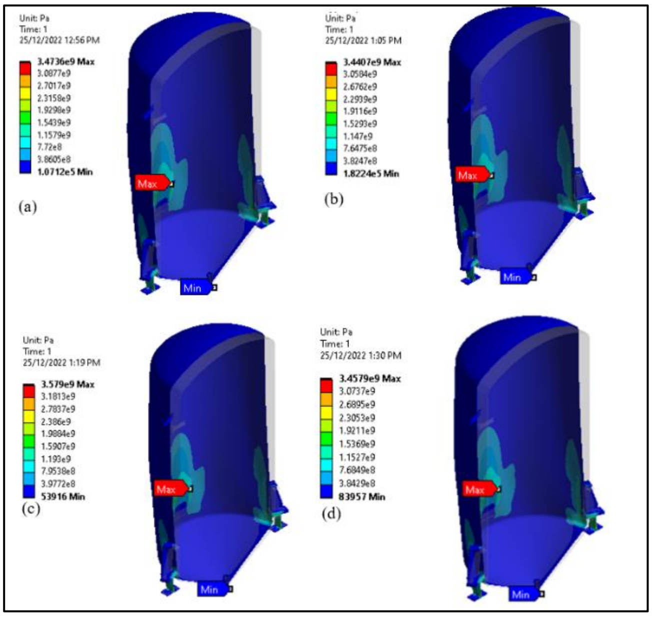

Fig. 6. 35˚C initial temperature (a) Stainless steel (b) Carbon steel (c) Titanium alloy (d) Super duplex 2507

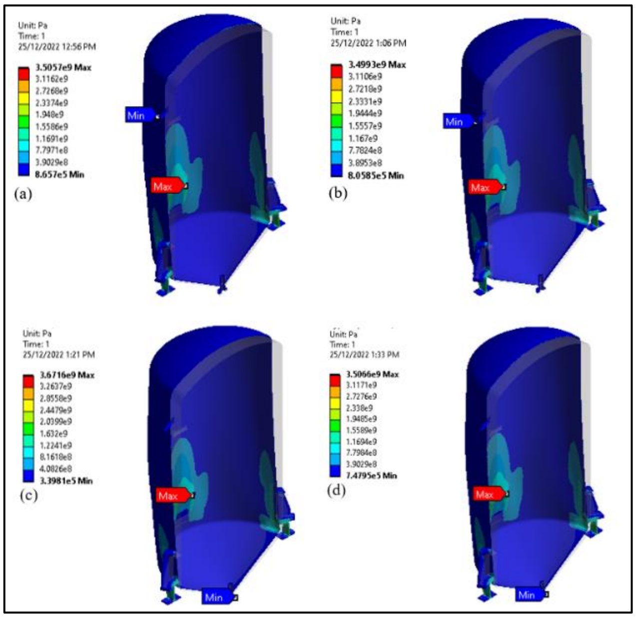

Fig. 7. 83˚C initial temperature (a) Stainless steel (b) Carbon steel (c) Titanium alloy (d) Super duplex 2507

3.2.3 Stress distribution in 120˚C initial temperature

The colour of the stress distribution began to increase on the cylinder walls and saddle support of the pressure vessel when the initial temperature was reached until the maximum allowable operating temperature, and this occurred for all the model materials, as shown in Figure 8. Stainless steel with high-strength material was recorded as the lowest stress distribution on the pressure vessel structure, at 3530 MPa at the 120°C of initial temperature. The minimum stress indicates the change in different parts for all materials in the pressure vessel models, where both stainless steel and super duplex 2507 exhibit a minimum stress at the outlet nozzle, titanium alloy at the inlet nozzle, and carbon steel at the hemispherical head of the pressure vessel. This result is due to the difference in the strength of each material to withstand the load according to temperature. However, the maximum stress was observed in the same part for all model materials at the saddle support. Meanwhile, the highest maximum stress recorded in this case was the titanium alloy at 3743 MPa, and the other two other materials recorded were (b) 3545 MPa and (d) 3544 MPa.

3.2.4 Stress distribution in 350˚C initial temperature

Pressure vessels were operated beyond the maximum allowable operating pressure to study the effect of high temperature on the pressure vessel structure, as demonstrated in Figure 9. The colour shows that the stress slightly increased and changed the pattern for all materials. The high temperature applied to the pressure vessel causes the maximum load on the pressure vessel's wall to be increased. The stress distribution in the pressure vessel wall began to show at a fixed place or near the junction, such as saddle supports. An obvious stress distribution change occurs on the pressure vessel cylindrical wall in stainless steel.

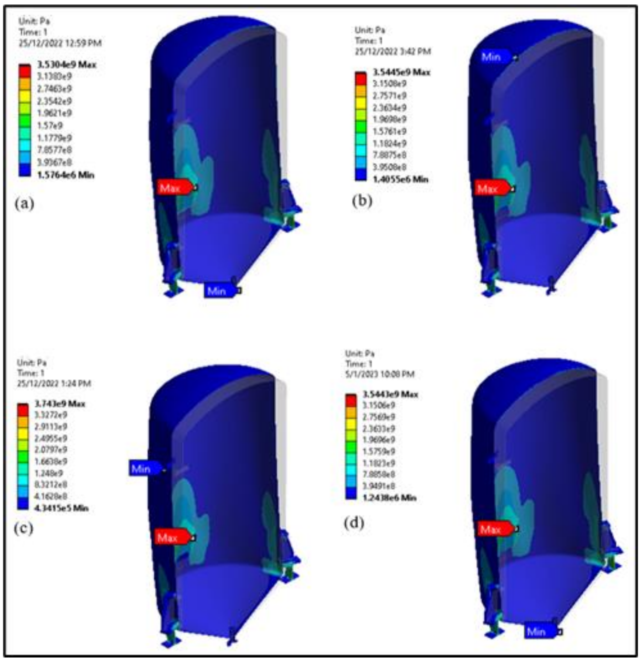

Fig. 8. 120℃ initial temperature (a) Stainless steel (b) Carbon steel (c) Titanium alloy (d) Super duplex 2507

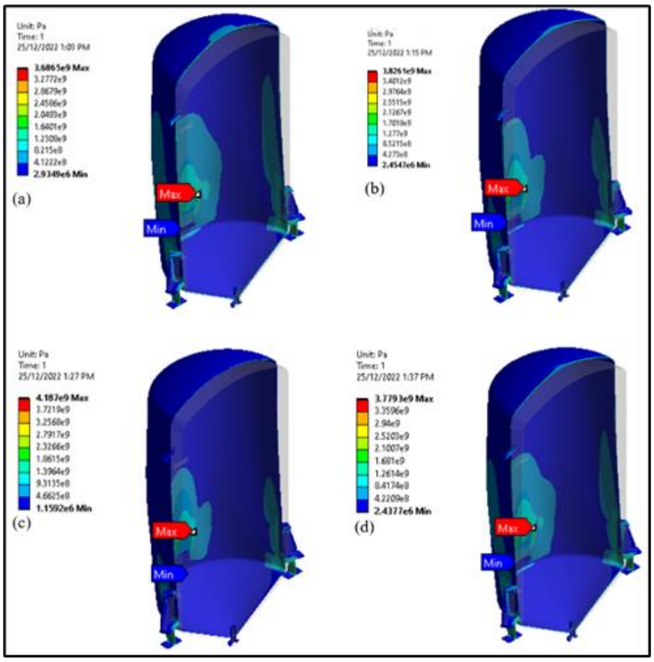

Fig. 9. 350℃ initial temperatures (a) Stainless steel (b) Carbon steel (c) Titanium alloy (d) Super duplex 2507

This material recorded the lowest maximum stress (3686 MPa) among the investigated materials and had the highest minimum stress (0.0293 MPa. The other three models (carbon steel, titanium alloy, and super duplex 2507) have maximum stress distributions at the saddle support of 3836, 4187, and 3779 MPa, respectively. The pressure vessel structure increases in the stress distribution due to the effect of a high initial temperature at 350°C applied to the pressure vessel. In this case, all the materials used have a high pressure on the saddle support, which connects to the wall body of the pressure vessel. This point is the most critical point for all temperature ranges of the pressure vessel model illustrated on the saddle support.

3.3 Risk Indicator

The risk indicator was constructed to predict the risk of the pressure vessel structure failure due to several factors, such as damage, cracking, or breaking, using different initial temperatures and materials during the operating process (Figures 10 to 13). This risk indicator will be compared with different materials to predict the risk and the performance of the pressure vessel. The results from all the simulation analyses performed previously were used to construct the risk indicator as a guideline for any plant in the industry and as a sample for an industry where the same method can be used to identify the possible risk at pressure vessels in terms of stress and deformation that the pressure vessel can withstand with the specific operation procedure.

Stainless steel is usually used for designing pressure vessels in the industry because it is highly resistant to corrosion, cost effective, and suitable for most work environments. By comparing stainless steel with other materials in this study, stainless steel is a better choice than carbon steel, titanium alloy, and super duplex 2507. However, in terms of cost, stainless steel is usually more expensive due to its alloy composition. In this study, stainless steel was used as the material for the VE203 pressure vessel in the UTHM biodiesel pilot plant. The pressure vessel is used in teaching and learning. Although the commonly used temperature is below the maximum allowed temperature, this is a precautionary measure that needs to be predicted because the probability of risk will occur if students tend to make mistakes up to a temperature of 350˚C. The data in this study show that the deformation of the structure and the stress distribution of stainless steel are not at high risk when the initial temperature increases. However, deformation at the greatest temperature, beyond the maximum allowable temperature, indicates a trend that is still below the maximum value and is still within the allowable range where the pressure vessel is installed in the plant. The stress distribution data for stainless steel reported the lowest stress at temperatures of 120˚C and 350˚C. So, this material is sufficient for the UTHM biodiesel pilot plant considering that the temperature limit is only at 120˚C and it is used for teaching and learning only. It also does not pose a high risk to the safety of students and workers at the plant.

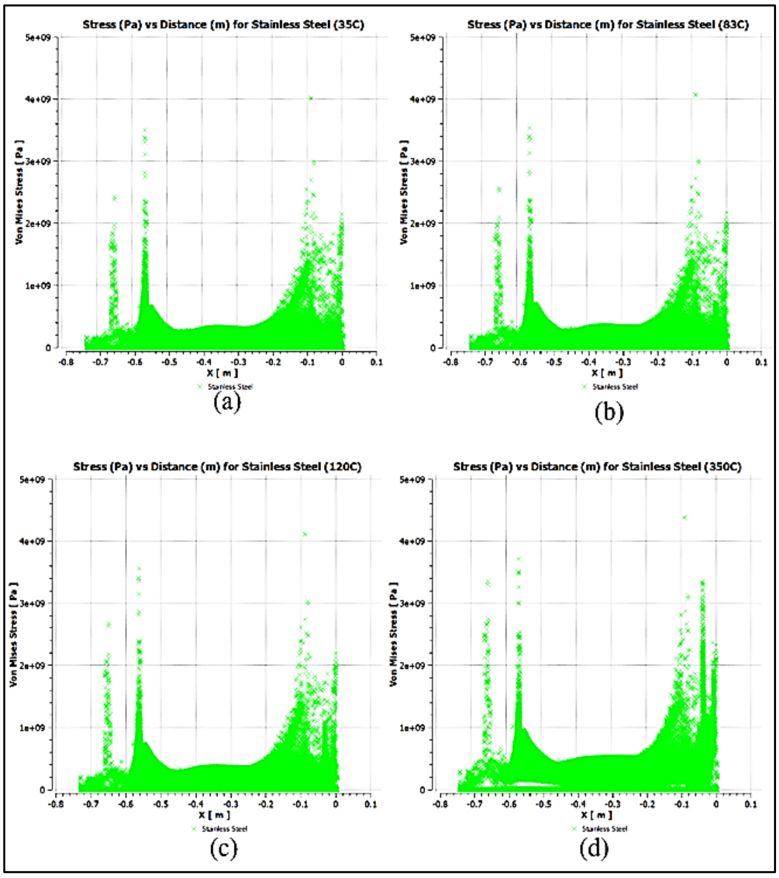

Fig. 10. Stress distribution effect from different temperatures for stainless steel (a) 35˚C (b) 83˚C (c) 120˚C (d) 350˚C

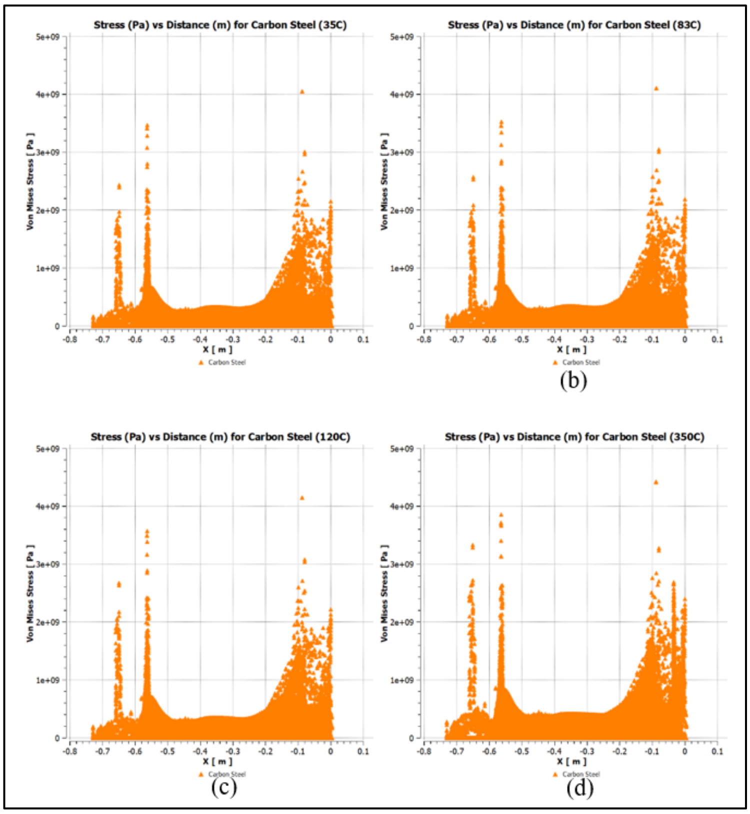

Fig. 11. Stress distribution effect from different temperatures for carbon steel (a) 35˚C (b) 83˚C (c) 120˚C (d) 350˚C

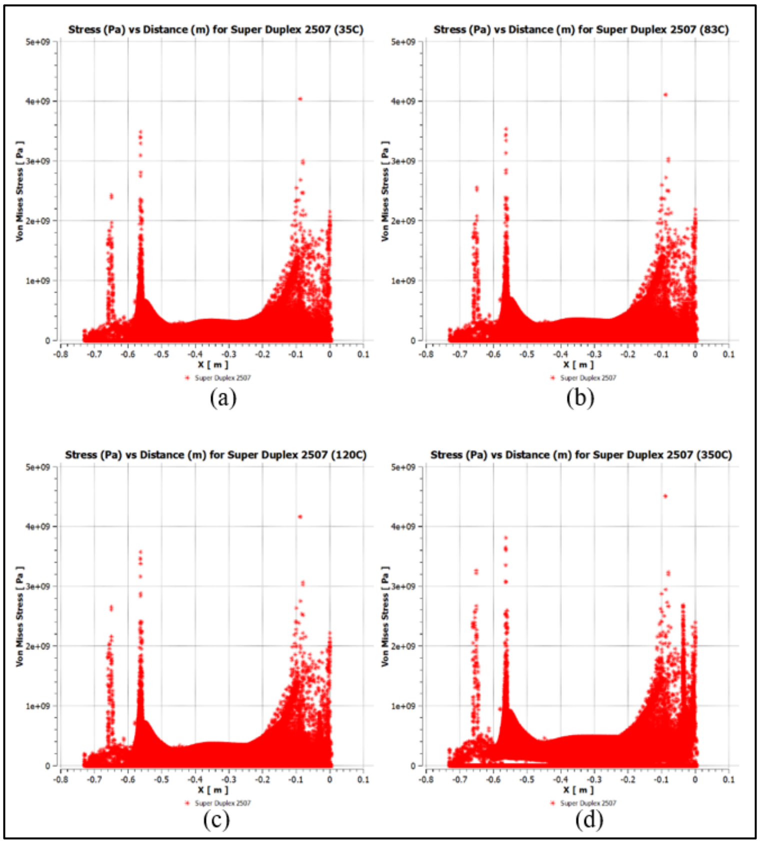

Fig. 12. Stress distribution effect from different temperatures for super duplex 2507 (a) 35˚C (b) 83˚C (c) 120˚C (d) 350˚C

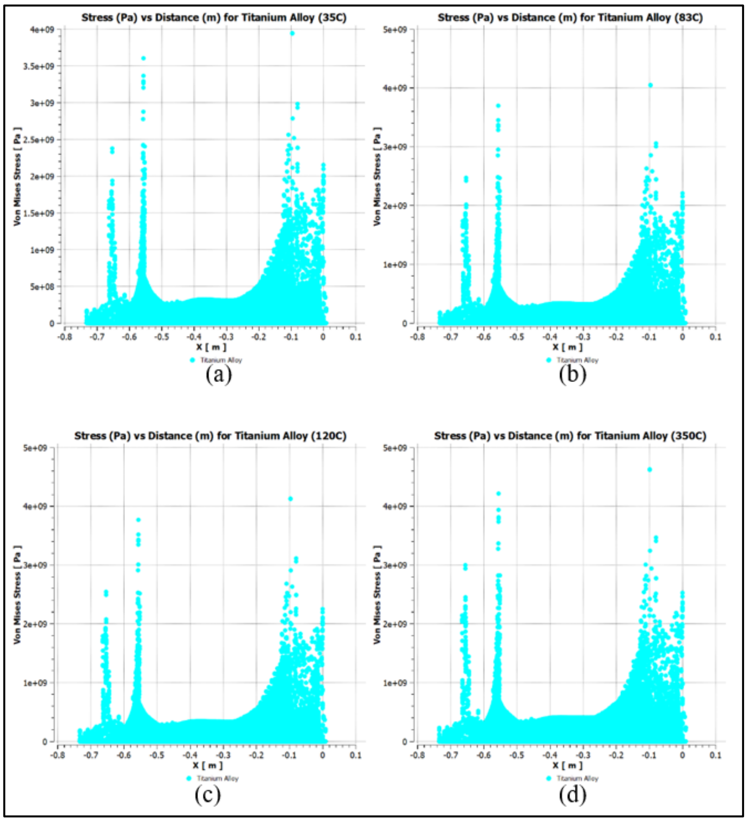

Fig. 13. Stress distribution effect from different temperatures for titanium alloy (a) 35˚C (b) 83˚C (c) 120˚C (d) 350˚C

Unlike in UTHM biodiesel pilot plants, pressure vessels made of carbon steel may be suitable for heavy-duty industrial use because of their excellent resistance to stress distribution and structural deformation. Carbon steel is more difficult to work with and exhibits a higher tensile strength. This material has a high operating safety range and a noncorrosive environment, making it ideal for heavy industry and plants. According to this assessment, when the initial temperature exceeded the maximum allowable temperature, pressure vessel carbon steel exhibited the lowest risk of stress and deformation. This is due to the material strength. As a result, the risk of pressure vessel failure due to bursting or cracking is low.

Super duplex 2507 is highly alloyed and exhibits corrosion comparable to high-performance stainless steel Super duplex 2507 is more expensive than stainless steel due to its high alloying content and is not readily available on the market. Because it is less commonly used than stainless steel, it must be specified and ordered. This material is resistant to stress corrosion cracking. Due to its high-strength material, super duplex 2507 presented a lower risk in this analysis. Similar to carbon steel, super-duplexes have lower deformation and stress values in pressure vessels. The excellent durability of super duplex 2507 gives it an advantage in large industries, but its use temperature is limited up to 316˚C. When the temperature exceeds this temperature, the super duplex 2507 will record high pressure, indirectly putting their application at high risk.

Pressure vessels containing titanium alloys exhibit the riskiest conditions in all indicators because the largest deformation and stress distributions are observed compared with those of other materials. Although titanium exhibited the highest stress and deformation values in this simulation, it is not considered a dangerous or risky material to use in the fabrication of pressure vessels. This material has low strength and is probably suitable for smaller applications at low temperatures to reduce the risk of failure. Although titanium alloy is light in weight and has extraordinary corrosion resistance, it may be suitable for different types of industries or plants. However, the high cost of raw materials and processing has limited its use for applications.

Lastly, risk assessment can be used to help designers design pressure vessels during material selection or as a guideline. This risk assessment is limited to temperatures up to 350°C only. However, the methods used to conduct risk assessments can also be used in any application containing heat, such as boilers or heat exchangers. It is important to understand the stress-deformation relationship of materials to assisst designers strategically select materials for pressure vessels that perform specific functions. In addition, risk assessment can also be used in maintenance or safety schedules for workers, and the lifespan of pressure vessels can be predicted.

4. Conclusion

The objective of this study was to analyse the deformation of a structure from the effect of different initial temperatures inside a pressure vessel and to investigate the effect of pressure vessel performance on materials and temperature loads. This analysis was conducted at four different inlet temperatures, 35˚C, 83˚C, 120˚C and 350˚C, and four different materials for each temperature, which are stainless steel, carbon steel, titanium alloy, and super duplex 2507. Finally, a risk assessment of the performance of the pressure vessel structure was conducted for the safety of workers at the UTHM biodiesel pilot plant. Each model was analysed using the steady-state thermal and static structural models in ANSYS Mechanical were used to identify the structure behaviour for pressure vessels. The deformation results showed that the deformation increased for materials with a low elastic modulus at high inlet temperatures due to their specific strength. In terms of stress distribution, the stress that occurs on a pressure vessel affects its performance and lifespan because the pressure vessel cannot withstand the stress load.

The Fluid-Structural Interaction (FSI) method was used to evaluate the deformation of the pressure vessel structure and stress distribution at four different initial temperatures in the pressure vessel model using four different materials for each temperature. According to the results, the pressure vessel with the titanium alloy has the highest deformation and stress distribution, particularly at 350˚C initial temperature as high as 4187 MPa. Lastly, a risk indicator was established to serve as a guideline for any plant in the industry for predicting risks of the pressure vessel structure during the operating process and for safety workers in the plant. These risk indicators can also be used to help pressure vessel designers and as a guideline during material selection. The temperature and material of the pressure vessel affected both deformation and stress in the pressure vessel, as evaluated by both risk indicator results. The greater the inlet temperature inside the pressure vessel, the greater the deformation of the structure and stress deformation of materials with low yield strength, which affects the performance of the pressure vessel.

References

[1] Peters, Daniel, and Adam P. Maslowski. "Overview of revisions to the ASME boiler and pressure vessel code section VIII division 3 for the 2015 edition and near future." In *Pressure Vessels and Piping Conference*, vol. 56987, p. V005T05A012. American Society of Mechanical Engineers, 2015. https://doi.org/10.1115/PVP2015-45787

[2] Afkar, Amir, Majid Nouri Camari, and Amin Paykani. "Design and analysis of a spherical pressure vessel using finite element method." *World Journal of Modelling and Simulation* 10, no. 2 (2014): 126-135.

[3] Tripathi, Pradeep Mani, Satya Prakash, Rahul Singh, and Satish Kumar Dwivedi. "Thermal analysis on cylinder head of si engine using FEM." *International Journal of Scientific Engineering and Research (IJSER), ISSN* (2014): 2347-3878.

[4] Towler, Gavin, and Ray Sinnott. *Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design*. Butterworth-Heinemann, 2021.

[5] Jegatheesan, J., and Z. Zakaria. "Stress analysis on pressure vessel." *Environment & Ecosystem Science* 2, no. 2 (2018): 53-57. http://doi.org/10.26480/ees.02.2018.53.57

[6] Anandhu, P. D., and A. Avis. "Design and analysis of horizontal pressure vessel and thickness optimization." *international journal of innovative research in science, engineering and technology* 6, no. 5 (2017).

[7] Mali, Mr Amol, Mr Hemant Bhosale, Mr Dilpreet Singh Bedi, and Mr Akash Modasara. "A review paper on study of pressure vessel, design and analysis." *International Research Journal of Engineering and Technology* 4, no. 5 (2017): 1369-1374.

[8] Toudehdehghan, Abdolreza, and Tan Wai Hong. "A critical review and analysis of pressure vessel structures." In *IOP Conference series: materials science and engineering* 469, no. 1, p. 012009. IOP Publishing, 2019. https://doi.org/10.1088/1757-899x/469/1/012009

[9] Arunkumar, S., PR Eshwara Moorthy, and N. Karthik. "Design optimization of horizontal pressure vessel." *Materials Today: Proceedings* 26 (2020): 1526-1531. https://doi.org/10.1016/j.matpr.2020.02.314

[10] Gond, Sandeep, Akhilesh, Anoop Singh, Vinod Sharma, and Shyaam Bihari Lal. "Design and analysis of the pressure vessel." *International Journal of Scientific & Engineering Research* 5, no. 4 (2014): 939.

[11] Khorsand, Mohammad, Kunkun Fu, and Youhong Tang. "Multi-directional functionally graded materials for enhancing the durability of shell structures." *International Journal of Pressure Vessels and Piping* 175 (2019): 103926. https://doi.org/10.1016/j.ijpvp.2019.103926

[12] Niranjana, S. J., Smit Vishal Patel, and Ankur Kumar Dubey. "Design and analysis of vertical pressure vessel using ASME code and FEA technique." In *IOP Conference Series: Materials Science and Engineering* 376, no. 1, p. 012135. IOP Publishing, 2018. https://doi.org/10.1088/1757-899X/376/1/012135

[13] Devaraju, A., and K. Pazhanivel. "A study on stress analysis for design of pressure vessel." *Int. J. Mech. Prod. Eng* 3, no. 11 (2015): 98-101.

[14] Vijay, Mallela, and Rajashakar Reddy. "Design and Stress Analysis of Multilayer High Pressure Vessel by Using FEM." *International Journal of Innovative Research in Science and Engineering* 2, no. 1 (2016): 191-197.

[15] Hernandez-Perez, Valente, Mukhtar Abdulkadir, and B. J. Azzopardi. "Grid generation issues in the CFD modelling of two-phase flow in a pipe." *The Journal of Computational Multiphase Flows* 3, no. 1 (2011): 13-26. https://doi.org/10.1260/1757-482X.3.1.13

[16] Moss, Dennis R. *Pressure vessel design manual*. United Kingdom: Elsevier, 2004

[17] Cerit, Muhammet. "Corrosion pit-induced stress concentration in spherical pressure vessel." *Thin-Walled Structures* 136 (2019): 106-112. https://doi.org/10.1016/j.tws.2018.12.014