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Simulation Analysis on The Effect of Different Pressure and Material of Pipe on Pipeline Lifespan in UTHM Biodiesel Plant

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Abstract: The purpose of this analysis is to analyse the durability of a pipe based on the pipe from esterification process to transesterification process at the UTHM biodiesel plant with on different pressure inlets and different materials. The main objective of this analysis is to analyse flow behavior and stress distribution with different pressure inlet and different material. Besides that, this analysis also will provide the risk indicator that can be a guideline for scheduled maintenance effects from different materials and different pressure inlets. The software that used in this analysis is Solidworks to design the model and Ansys 19.2 for run the simulation. Only three materials of pipe and two pressure inlets were variable in this simulation. The material is used in this analysis is Stainless Steel, Carbon Steel and Alloy Steel. While two pressure inlet that used in this analysis is minimum pressure inlet 150kPa and maximum pressure inlet 250 kPa. Ansys simulation will use a design model that has been designed in Solid Work and there are two types of analysis used in Ansys, namely Fluid Analysis for flow behavior and Structure Analysis for stress distribution. Ansys simulation will use a design model that has been designed in Solid Work and there are two types of analysis used in Ansys, namely Fluid Analysis for flow behavior and Structure Analysis for stress distribution. Result of flow behavior in this analysis proves that the relationship between pressure and velocity in the pipe is inversely proportional. In addition, the results for structure analysis show that the material with the lowest max von mises stress value is Stainless Steel which is 7.250Mpa at an inlet pressure of 150kPa. The conclusion that can be concluded in this analysis is that Stainless Steel material is more durable than the material used in this analysis. The maximum area of the Von Mises stress also was determined in this analysis and it can be as a risk indicator to maintenance of pipe in UTHM biodiesel plant.

Keywords: Pipe, Simulation, Flow Behaviour, Structural Analysis

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1. Introduction

The use of pipeline systems is very important in industries as a transportation system of fluid. Most of the plant industries in Malaysia have pipelines and the great condition of the pipeline is very important to ensure that plant can be operated properly. According to Anduin[1], the material used for the pipe is an important role to ensure the pipe has a good structure performance. Biodiesel plants are closely related to piping because piping is an important system in a plant. The function of piping is to transport fluids such as steam, chemicals, oil, and others. The maintenance of the pipeline in a plant is very important to ensure that the process in a plant is in good condition. This is because if the pipeline system in a plant does not function properly will cause the process in the plant will be disrupted and will cause losses in terms of production. Therefore, the purpose of this study is to study the durability of a pipe based on different pressure inlets and different materials. Data of flow behavior and stress distribution from the simulation is important to provide risk indicator for the schedule maintenance because the lifespan of a pipe is affected by the flow process in the pipe. To provide a risk indicator for scheduled maintenance this research must find out the effect of flow in the pipe if we change the inlet pressure and different types of material.

Therefore, the purpose of this analysis is to investigate the durability of a pipe based on different pressure inlets and different materials. The pipe used in this analysis is pipeline from esterification process to transesterification process at the UTHM biodiesel plant and fluid that use in this analysis is biodiesel B100. The main objective of this analysis is to analyse flow behavior and stress distribution with different pressure inlet and different material. Besides that, this analysis also will provide the risk indicator that can be a guideline for scheduled maintenance effects from different materials and different pressure inlets. The software used in this analysis is Solid Works for designing the model and Ansys 19.2 for the simulation. Results obtained from the simulation also will be able to identify and analyze problems on a pipeline that occur in the UTHM biodiesel plant. This can also help to improve the safety at UTHM biodiesel by detecting hazards on the pipes earlier.

1.1 Previous study

To obtain the detail information for this analysis, some information was obtained from previous studies. Table 1 show the summarized of the previous study.

Table 1: Summary of the previous study

Author	Year	Finding
Mora-Rodríguez [2]	2014	The types of failures were determined based on the pipe's surroundings, pipe material, and mechanisms, and the stresses that support the pipes
Jorge Solorio [3]	2018	Pressure loss is the difference in fluid pressure between two points in the system caused by pressure or heat loss, and pressure drop is the difference in fluid pressure between two points in the system caused by pressure or heat loss.
Dey [4]	2020	The fluid viscosity is less important in a "turbulent" flow, and the velocity profile takes on a much more uniform shape
Wei Luo, Jon Pelletier [5]	2016	Students gain a sense of control and ownership over their exploration and discovery through interactive computer simulations, which improves their understanding and retention of information.

Dmitri [6]	2012	Carbon steels are divided into three main categories, according to the steel classification.
Chris Burnett [7]	2014	The percentages of alloying elements used might range from 1 to 50%. Low alloy steel and high alloy steel are the two types of alloy steel.
Papavinasam [8]	2014	The percentages of alloying elements used might range from 1 to 50%. Low alloy steel and high alloy steel are the two types of alloy steel.

2. Methodology

In this analysis, all pipe measurements and boundary condition data are based on the UTHM biodiesel plant. The model of the pipe was constructed using the Solidwork software and the simulation was run using Ansys software. There are two methods of simulation used in Ansys software, namely Fluid Flow Fluent and Static Structure. Fluid Flow Fluent method is used to obtain the result of flow behavior and Static Structure method is used to obtain the result of stress distribution. The variable is used in the simulation of flow behavior and stress distribution is inlet pressure and different material.

2.1 3D Model

The measurement of the pipe model used in this study is based on a part of the pipe from esterification to transesterification in the UTHM Biodiesel plant. The pipe model was constructed with using the Solidworks software. 3D piping model was shown in Figure 1.

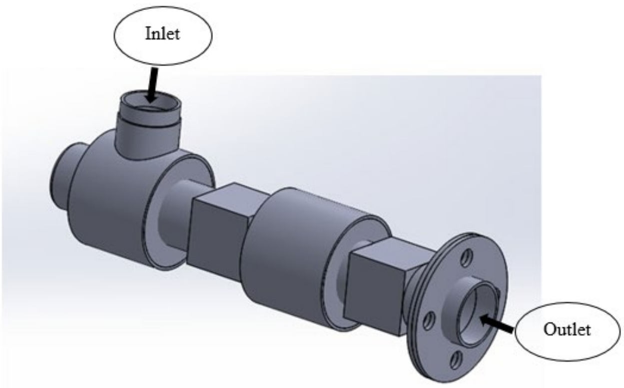


Figure 1: 3D model of pipe geometry

2.2 Grip Independent Test

Before the run the simulation, grip independent test was conducted to determine the best meshing for the simulation in this analysis. A better grid design is very important for increasing the accuracy of the CFD analysis. The shape type, quality, and several grids all must be taken into consideration when developing an optimal grid [9]. And, once a certain level of fineness is reached, vast computational resources are wasted on a negligible refinement effect. The mesh with the medium level of fineness must be selected to save computational resources[10]. In general, a denser mesh is preferable and more desirable for capturing variations in flow properties. A very fine mesh or dense mesh necessitates much more computational resources and time.

The first simulation was run is to select the most appropriate meshing size and the number of meshing and nodes. Table 2 shows the size of the element and the total number of nodes and elements obtained.

Table 2: Detail of element size

Element Size (m)	Number of elements	Number of nodes
0.009	53820	20855
0.008	62390	24065
0.007	80482	30339

Data obtained from the simulation were compared to choose the most relevant element size as shown in Figure 2. Based on Figure 2, all three numbers of elements do not show a significant change that occurred. If the number of elements increases, the use of space in the hard disk drive increases and requires a lot of time to run the simulation. Therefore, for the simulation in this analysis the number of elements used is approximately 62000.

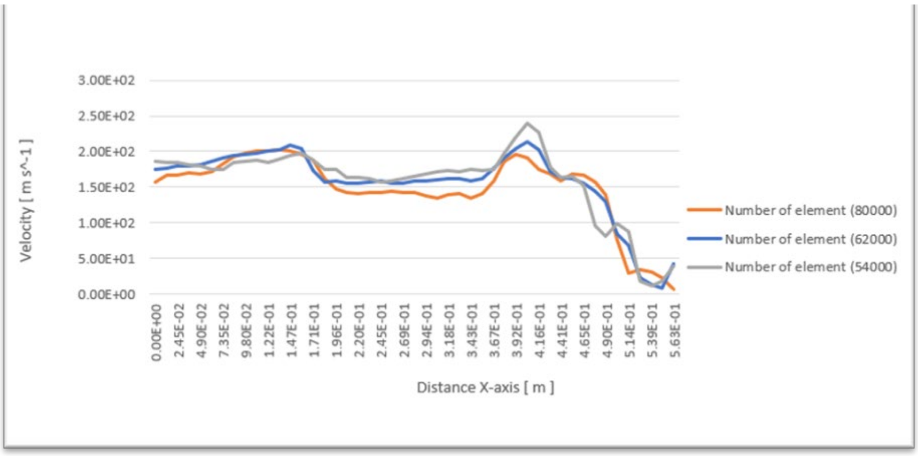


Figure 2: Velocity vs distance at the centre of the pipeline

Before running this simulation, meshing is created first, and inflation has been applied for meshing to fluent fluid flow as shown in Figure 3. This inflation is to achieve element stacking in the normal direction to the boundary. Inflation layer meshing to accurately capture the boundary layer region for any wall-bounded turbulent streams. This will provide a more accurate resolution of the border layer.

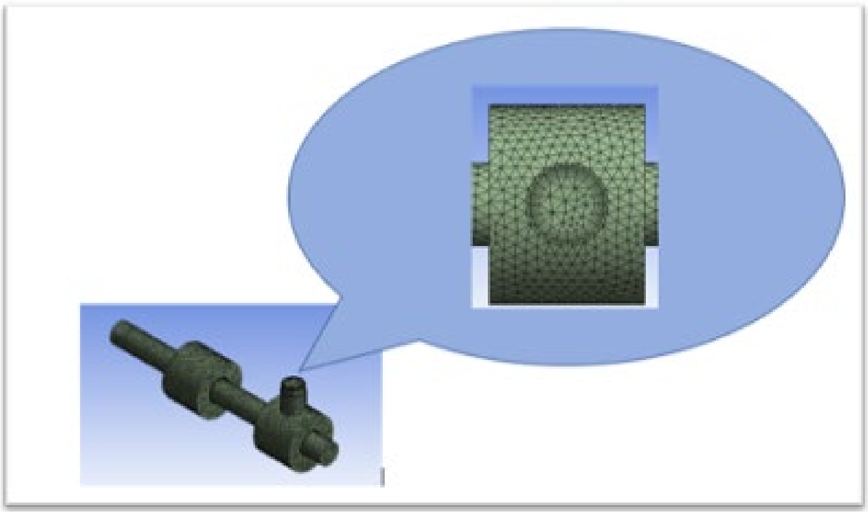


Figure 3: Inflation in the meshing of fluid flow (fluent)

2.3 Simulation Analysis

ANSYS is a finite element modelling package that can be used to solve a variety of mechanical problems numerically. This software can help save a lot of time while still providing accurate results. The Ansys software was chosen to simulate the flow behaviour and structure behavior from different materials and different pressure inlets. Flow behavior was simulated by fluid flow analysis and structure behavior simulate by static structure analysis using this software.

2.3.1 Fluid Flow Analysis

To analyzing all models used in this study, several software will be used. 3D Model was transferred from the Solidworks software into Ansys software. This is because the use of Solidworks is easier to create 3D models while Ansys is more accurate to run simulations. Ansys Fluent used to analyze the flow behavior effect from two different pressure inlet at Biodiesel plant. There are two different pressure inlets used in this Fluid Flow analysis which is 150 kPa and 250 kPa. 150 kPa is the minimum inlet pressure used in UTHM Biodiesel Plant while 250 kPa is the maximum inlet pressure that can be used.

(i) Bernoulli Flow Equation

Based on [11], Bernoulli's principle of fluid dynamics states that fluid speed increases when pressure or potential energy of the fluid decreases. The fluid speed in the pipe is not uniform throughout the section. P is the absolute pressure, ρ is the fluid density, v is the fluid velocity, h is the height above some reference point, and g is the gravity acceleration. While various quantities in the sum may change as we follow a small volume of fluid along its path, the total remains constant. The mean speed is used, and the steady flow continuity equation Eq.1 is used.

$$P + \frac{1}{2}\rho v^2 + \rho g h = constant \qquad Eq.1$$

(ii) Reynold Number

The Reynolds number is a dimensionless number that is used to classify fluid systems in which the effect of viscosity is important in controlling fluid velocities or flow patterns [12]. The Reynolds number is used to determine if fluid is moving in a laminar or turbulent flow. Mathematically, the Reynolds number, N_{Re}, is defined as Eq2.

$$N_{Re} = \frac{pvd}{\mu} \qquad Eq.2$$

(iii) Kinematic Velocity

The kinematic viscosity is an atmospheric variable defined as the ratio between the density ρ of the fluid and the dynamic viscosity μ. In this regard [13], viscosity (ASTM D445) is more important than surface tension, because it varies in magnitude more than the latter with different kerosene and temperature changes.

$$v = \frac{\mu}{\rho} \qquad Eq.3$$

Boundary conditions are constraints necessary for solving a boundary value problem. There are several types of biodiesels such as B100, B20 and B5 that have different properties of the fluid. For this analysis, the fluid used is biodiesel B100. Properties or boundary condition of B100 and boundary conditions for fluid simulation analysis were summarized in Table 3.

Table 3: Boundary condition used in fluid flow analysis

Fluid Type	B100

Material	Alloy Steel		Carbon Steel		Stainless Steel	
Inlet Pressure (kPa)	150	250	150	250	150	250
Outlet Pressure (kPa)			88			
Temperature (K)			311			
Viscosity μ(P)			$5.68e^{-3}$			
Density (kg/m^3)			878			

2.3.2 Structure Analysis

When we check the failure using the Von-Mises Stress, we are applying the Von-Mises yield criterion to determine yielding. The von Mises yield criterion is mathematically expressed as Eq3:

$$\sigma_v = \sigma_y = \sqrt{3J_2} \qquad Eq. 4$$

The von Mises yield criteria is often expressed in terms of the von Mises stress or equivalent tensile stress in materials science and engineering σ_v. When the von Mises stress reaches a value known as yield strength, the material is considered to start yielding σ_y. It's a concept from plasticity theory that generally applies to ductile materials like metals. The magnitude of a shear yield stress in pure shear is $\sqrt{3}$ times smaller than the tensile yield stress in the case of simple tension [14].

For material selection, pipe exteriors must be able to withstand adverse environmental conditions such as severe pressure and temperature, differing levels of humidity, and some wear. Varying levels of pressure can also impact the pipes elasticity, fatigue resistance, and overall strength. These characteristics need to remain stable [15]. Therefore, to study the effect different from internal pressure, this study uses the same fluid and temperature. Besides that, the materials chosen to be used in this simulation are Stainless steel, Alloy Steel and Carbon Steel. Table 4 shows a summary of the structure characteristic used in this simulation.

Table 4: Boundary condition used in structural domain analysis

Type of Material	Stainless Steel	Alloy Steel	Carbon Steel
Young's Modulus E (Pa)	1.93×10^{11}	2.00×10^{11}	2.00×10^{11}
Density (kg/m^3)	7750	7850	7850
Tensile Yield Strength (Pa)	2.07×10^{8}	4.90×10^{8}	4.70×10^{8}
Tensile Ultimate Strength (Pa)	5.86×10^{8}	6.35×10^{8}	7.45×10^{8}
Poisson Ratio	0.310	0.285	0.285
Coefficient of Thermal Expansion (C^{-1})	1.7×10^{-5}	1.23×10^{-5}	1.17×10^{-5}

3. Results and Discussion

The pipe model used was modelled in Solid Works software and then simulated using ANSYS software. The fluid flow used in this analysis is to analyze the state of the fluid in the pipeline. This simulation analyzed the pressure and velocity conditions in the pipeline. Besides that, the data obtained in the fluid flow then transferred to static structure. Static structural is used to obtain the value of von mises stress found on the pipe after the insertion of a fluid that has a certain pressure inlet.

3.1 Flow behavior in pipe

In this analysis, the fluid we used was B100. Each run simulation carried out for fluent fluid flow has the same density and viscosity of B100. For the simulation of fluid flow, the boundary condition is the same and the thing that changes is the inlet pressure. The inlet pressure applied is the minimum pressure inlet and the maximum pressure inlet which is 150kPa and 250kPa. Once the fluid flow simulation is carried out, the result obtained from this fluid flow analysis is the velocity and pressure of fluid in the pipe.

3.1.1 Velocity of flow in pipe

There is a change in velocity in the fluid present in the pipe when a change in pressure inlet occurs based on Figure 4. The velocity of the fluid at Fluid 2 is greenish-yellow than that of fluid at Fluid 1. This means the velocity of fluid in Fluid 2 is higher than fluid in Fluid 1. Therefore, here can be conclude that when pressure inlet increase, velocity of fluid in pipe also increases. This occurs because Fluid 1 has a 150 kPa inlet pressure and Fluid 2 has a 250 kPa inlet pressure.

Based on Figure 4, the velocity of the fluid in the center of the pipe is higher than the fluid that has contact with the wall pipe. Based on M.Soladini [16] fluid velocity is zero at the wall and fastest at the center. This is because, the pipe wall has a rough surface. The amount of roughness influences the fluid's drag. The height of projections sticking up from the pipe wall is used to determine roughness. Furthermore, the drag between layers tears shears them apart, causing each layer to move at a different speed. As the distance from the wall increases, the shear rate decreases. This means that the fluid's central core exits the pipe first.

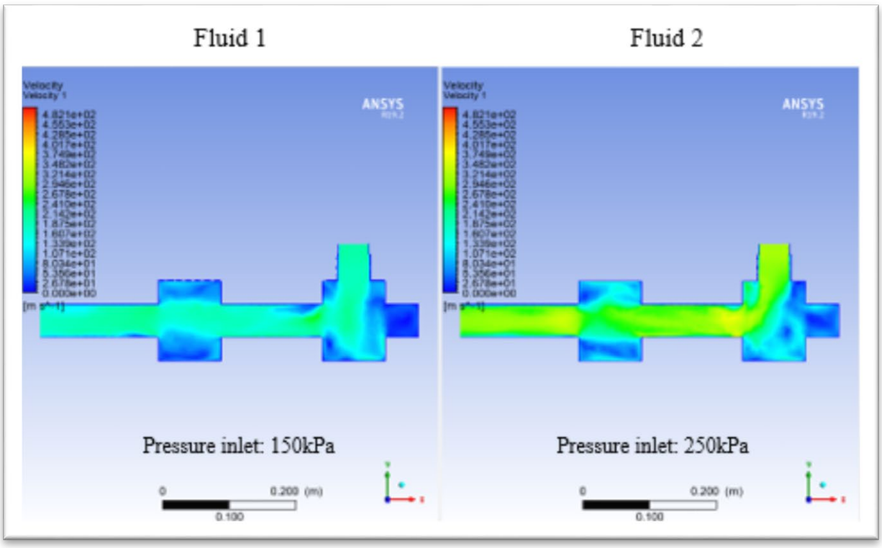


Figure 4: Velocity in pipeline with different pressure inlet

Figure 5 shows the velocity value at distance 0 which is at the outlet of pipe is 0.0175 ms^{-1}, for Fluid 1 and 0.0300 ms^{-1}, for Fluid 2. This is the most significant difference in velocity value which is 41.67 % found in the graph. Besides that, the highest velocity at the centre of the pipe obtained in Fluid 1 is 0.0223 ms^{-1}, whereas Fluid 2 obtains 0.0356 ms^{-1}. Both values occur at 0.40 m from the outlet of the pipe. It can be concluded that at 0.40 m from the outlet is the place with the highest velocity. Figure 5 extracted from this simulation of fluent fluid flow can further prove that the velocity in a pipeline will increase when the inlet pressure increases.

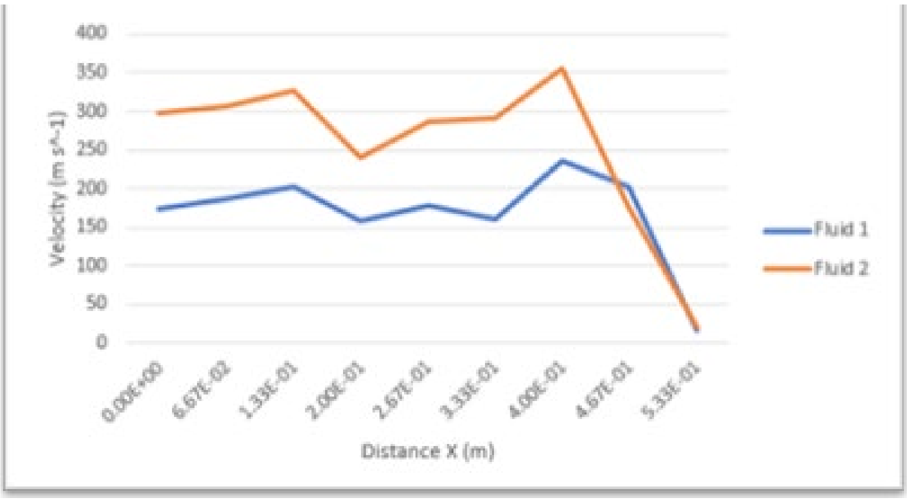


Figure 5: Velocity of fluid at centre of pipeline

3.1.2 Pressure of flow in pipe

The pressure of fluid in the pipeline is shown in Figure 6. Both above contour of pressure is the result pressure of fluid in pipeline with different pressure inlets. The contour colour of Fluid 2 is reddish than those of Fluid 1. That means that Fluid 2 has a higher pressure distribution in its pipeline than Fluid 1. This is attributed to the reason that Fluid 1 only has a 150kpa bar pressure inlet, while Fluid 2 has a 250kPa pressure inlet. Therefore, it can be concluded that this is proportional, if the inlet pressure increases then the pressure of fluid inside the pipeline will also increase. Compared Figure 6 with Figure 4, the highest velocity is in the center of fluid, while the highest pressure is in the fluid adjacent to the wall of pipe. This shows that the velocity and pressure of fluid in the pipe are inversely proportional.

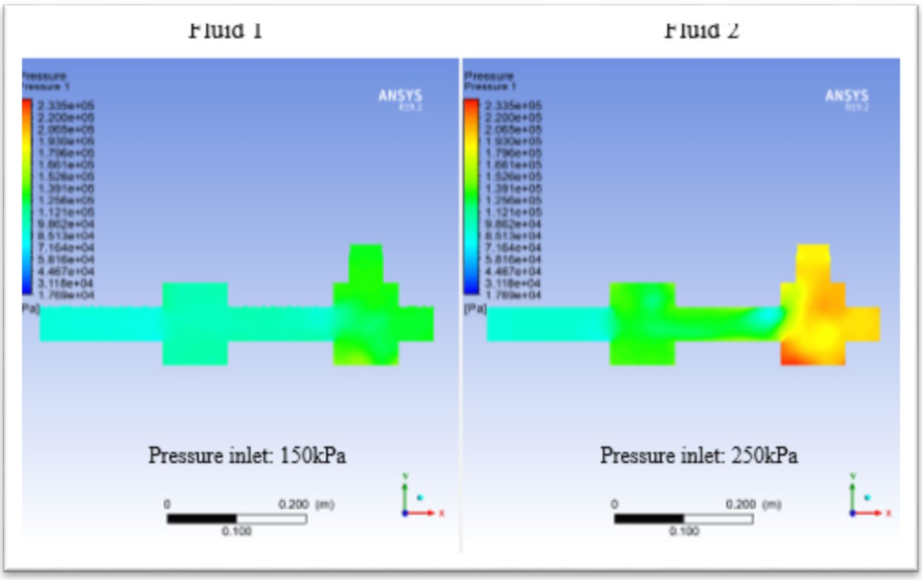


Figure 6: Pressure in pipeline with different pressure inlets

Based on the Figure 7, the most significant pressure difference is at the area of the inlet in the pipe because of different pressure inlets. At distance X = 0.00 m is pressure outlet while at distance X = 0.53 m it is the part adjacent to the pressure inlet. The highest value of pressure at Fluid 1 and Fluid 2 occurs at distance X = 0.53 m which is 125 kPa and 200 kPa. This occurs a slight reduction of pressure from the inlet pressure and this was related with pressure drop rules [17]. Based on the graph, the different pressure at this distance is the largest difference that occurs which is 37.50 %. Besides that, pressure of Fluid 1 and Fluid 2 start to obtain almost the same value at distance X = 0.13 m. The Figure 7 also shows the value of pressure being decrease from the inlet part to the outlet part. This can be interpreted as the occurrence of pressure drop in the pipe.

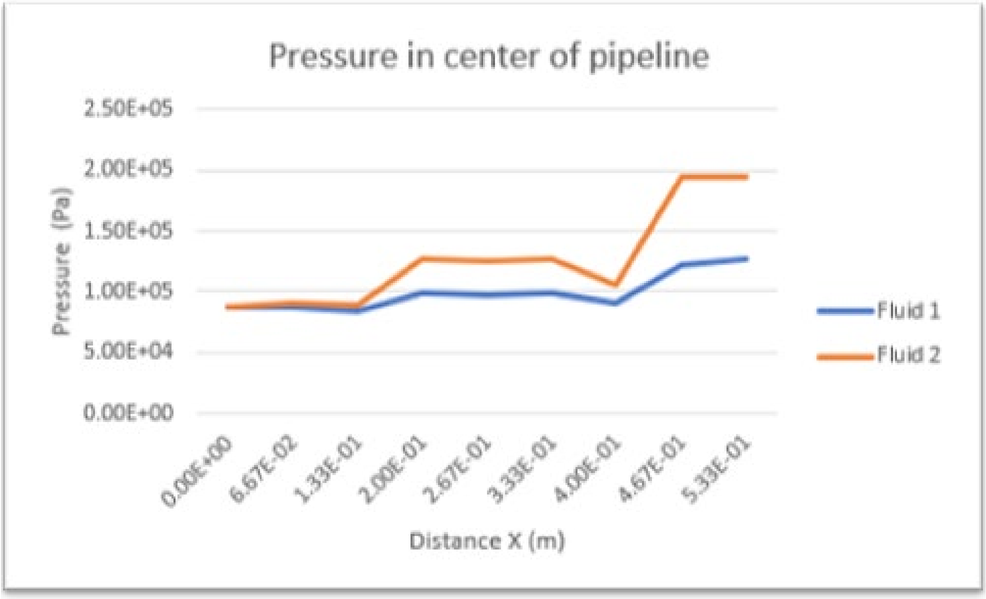


Figure 7: Pressure of fluid at centre of pipeline

Comparison of the on Figure 5 which is the velocity and Figure 7 which is the pressure, the trend of the velocity is increasing, while the trend of the pressure is decreasing. It can be concluded that if the pressure of fluid increases, the velocity of fluid is decrease. This result can be related to Bernoulli's Principle [18]. Bernoulli's Principle states that the higher a fluid moves, the slower pressure it exerts. The random motion of fluid molecules is what causes fluid pressure. When the fluid speeds up, some of the energy from the random motion is used to elevate the fluid to move faster in its direction.

3.2 Stress distribution of pipe

The Von Mises Stress is a value used to determine if a given material will yield or fracture. According to the von mises yield criteria, a material will yield if its von Mises stress under load is equal to or greater than its yield limit under simple tension. According to the theory [19], a ductile material starts to yield at a point where the von Mises stress equals the stress limit. In this study, the results of a fluent fluid flow solution were used to run the simulation of this static structure. From this analysis of static structure von Mises stress of the pipe is obtained.

Figure 8 show Von Mises Stress from static structure simulation of pipe when data from the fluid flow that using pressure inlet 150 kPa. Based on data from Figure 8, the trend of contour obtained is almost the same although the material differences. In addition, the maximum value of von mises stress of stainless-steel material is 7.25 MPa. While the model with carbon steel and alloy steel material has a maximum value of Von Mises Stress is 7.80 MPa. The difference of maximum stress between stainless steel with carbon steel and alloy steel is 0.55 MPa.

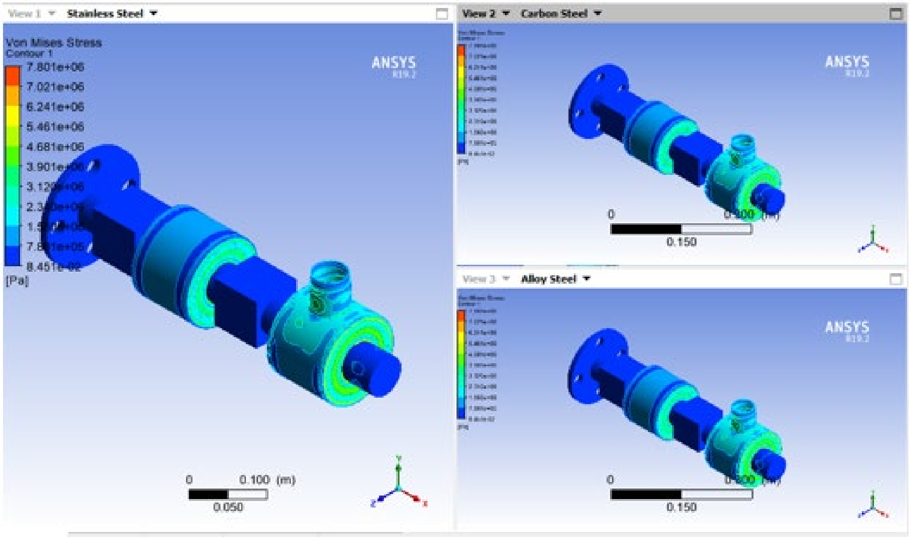


Figure 8: Von Mises Stress of different material with minimum pressure inlet

Figure 9 show Von Mises Stress from static structure simulation of pipe when data from the fluid flow that using pressure inlet 250 kPa. Different of the result of Von Mises Stress in Figure 8 and Figure 9 is different inlet pressure used. In stainless steel, the maximum Von Mises Stress obtained is 11.67 MPa. On models made from carbon steel and alloy steel, the value of Von Mises Stress is 12.55 MPa.

However, because the maximum von mises stress of Stainless Steel is lower than the maximum von mises stress of Carbon Steel and Alloy Steel, it can be concluded that the best material in this analysis is Stainless Steel compared to Carbon Steel and Alloy Steel. Both models that use carbon steel and alloy steel materials have the same value of Von Mises Stress. This happens because the material of carbon steel and alloy steel has a same young's modulus value, which is 200 GPa. While stainless steel has a value less than that which is 193 GPa. It can be stated that the different materials used in this study had a lower impact on Von Mises Stress.

There is an increase of the value of Von Mises Stress compared to the result using the inlet pressure value of 150 kPa in Figure 8. Therefore, the maximum value of Von Mises Stress will increase when the inlet pressure increase. The use of maximum inlet pressure is not recommended because it will produce a high maximum value of Von Mises Stress and a higher probability of failure.

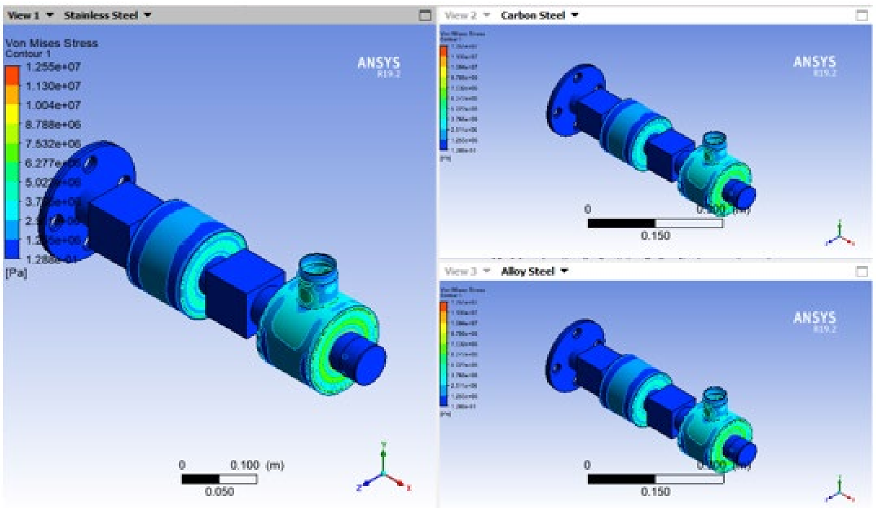
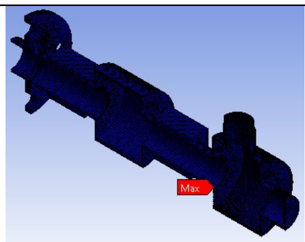
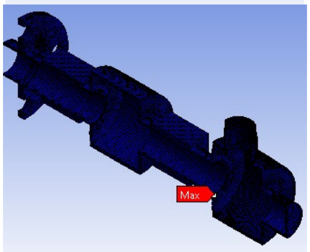
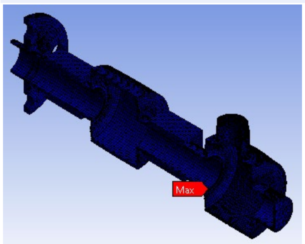


Figure 9: Von Mises Stress of different material with maximum pressure inlet

3.3 Risk indicator

The area of maximum stress on the pipeline under investigation is visualized in Table 4. The area of maximum stress is the same regardless of the pressure inlet or the material. This high-stress area is more likely to be damaged than other areas of the body. This is due to the force that is concentrated at a small area. Therefore, effect of maximum area of Von Mises Stress is the design of pipe. Uneven design of pipes will cause higher Von Mises Stress values in that area. The maintenance crew of Biodiesel Plant UTHM should give particular attention to this area because that area of this pipeline receives the most stress compared to other areas.

Table 4: Boundary condition used in structural domain analysis

Detail	Maximum area
D: Stainless Steel Equivalent Stress Type: Equivalent (von-Mises) Stress	
C: Carbon Steel Equivalent Stress Type: Equivalent (von-Mises) Stress	
E: Alloy Steel Equivalent Stress Type: Equivalent (von-Mises) Stress	

4. Conclusion

The main purpose of this analysis is to obtain the flow behavior and stress distribution of the pipe. The pipe segment that has been studied in this analysis is pipeline from the esterification to transesterification in the UTHM biodiesel plant and the pipe has been modeled using SolidWorks software. The 3D Model created in SolidWorks is transferred into the ANSYS Workbench for simulation. Simulation method that used in this study is Fluid Flow Fluent analysis for the fluid behavior and Static Structural analysis for the stress distribution. In this simulation, the meshing size used is 0.008m and the values of elements and nodes obtained are 62390 and 24065. The variables used to obtain fluid flow analysis are different pressure inlet which is minimum pressure inlet of 150kPa for and maximum pressure inlet of 250kPa. Besides that, the materials used in the structural analysis are Stainless Steel, Carbon Steel and Alloy Steel.

For the velocity at center of pipeline shows a downward trend occurring from distance X = 0 to X = 0.50 m. While, for the pressure at center of pipeline shows an upward trend occurring from distance X = 0 to X = 0.50m. Therefore, it can be concluded that the velocity and pressure in the pipe are inversely proportional, and the result obtained corresponds to the Bernoulli Principle. For the structure analysis, the simulation results obtained shown, if the value of the inlet pressure increases then the value of Von Mises Stress will also increase. Other than that, Stainless Steel has the lowest maximum value of Von Mises Stress compared to Carbon Steel and Alloy Steel. Area of the maximum Von Mises Stress at the pipeline also was determined from the simulation. This is used as a risk indicator to the maintenance crew of UTHM Biodiesel Plant as a precaution. For the conclusion, based on all result obtained in this analysis, all objectives of this analysis are achieved.

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