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Simulation Study of Elbow Characteristics at Various Operating Conditions

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Abstract: This study was conducted to compare the 90° elbow characteristics under several operating procedures. In this study, the pipeline and the elbow will be examined in three different size of wall thickness and tested with four different operating pressure which was 10, 12, 14, and 16 bars of pressure. Every specification of piping and fittings are retrieved from the code and standards of ASME B36.10 for piping and ASME B16.9 for long radius elbow. The pipe sizing that are chosen for this simulation study was 1.5 inch and the idea of pipeline selected are taken from Biodiesel Pilot Plant in UTHM, Parit Raja Campus which are from the outlet of fire-tube boiler to the steam header. The pipeline selected consist of two flanges, two 90° elbow and three different lengths of pipeline. The pipe material that used in Biodiesel Pilot Plant are A53 B carbon steel pipe and the working fluid was steams which the temperature design is 250℃, and the maximum operating pressure of fire tube boiler is 10 bar of pressure. This study also focused on the evaluation of the elbow performance by using simulation by using Ansys Fluent. The model of pipeline selected are designed by using Solid Work 2019 software which will be transfer to Ansys 2019 R3 software for simulation testing based on the objective that have been set. The entire model will be tested by using Ansys fluid flow (fluent) which the result will show the flow of steam within the pipeline and Static Structural test which is to determine the stress and structural behavior after tested with different operating pressure. At the end of this study, it was confirmed that the specification of the pipeline was not compatible to run for high operating pressure. This is because the operating conditions chosen for this study was 10 bars to 16 bars of pressure. The dimensions of the 90 degrees elbow were totally affected after going through the pressure conditions setup and the size of wall thicknesses was not play the role of decreasing the value of stress and strain of the elbow. From the analysis, it was also confirmed that the elbow pipe was the highest-pressure point located for flow distribution along the pipeline. The simulation study proved as the best way to examine the specification of material and pressure than experimental method which caused safety effect if failed.

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Keywords: Corrosion, Elbow, Ansys, Simulation

1. Introduction

Elbows are commonly utilized in industrial installations to guide flow and offer flexibility to the system. Steel pipe elbows are used to alter the direction of fluid flow in a pressure piping system. It's used to join two pipes of the same or different nominal diameters and turn the pipe, and hence the fluid path, in a 45-degree or 90-degree direction. Due to collision, friction, and reacceleration, this shift in fluid flow direction causes pressure losses in the system.

Pipe elbows (bends) are considered critical pressurized components in the piping systems and pipelines due to their stress intensification and the effect of bend curvature [1]. This is because they are more susceptible to various corrosion failure types than straight pipes. Late discovery of elbow damage can result in a variety of hazardous and emergency circumstances, including environmental disasters, pollution, significant consumer losses, and a serious threat to human life. Pipes in working condition will be affected by internal pressure, thermal shock, and a variety of complex loads [2]. Ratcheting deformation of elbow pipe will occur because of these complex stresses and the pipes will stop working when the elbow reaches its limit.

Pipe elbow is one of the necessary parts to build the integrated piping system which is considered as a linking point between different parts of the transport systems [3]. Given the liquid nature of the effluent, as well as the surrounding pressure and temperature, the pipe elbows will become sensitive to corrosion difficulties due to its functional role and complicated shapes depending mostly on welding operation. Erosion-corrosion of pipelines is a significant problem affecting many industries, including oil and gas, and involves electrochemical, mechanical and synergistic processes [4]. This is because the presence of carbon dioxide (〖CO〗 _2) and sand particles in the resulting slurry creates a highly aggressive wear environment for pipes, especially those made of carbon steel. Hydrodynamic circumstances, which are influenced to some extent by flow geometry, can have a big impact on erosion-corrosion rates. The flow field influences the trajectories and velocities of sand particles impinging on the interior walls of a system, and the hydrodynamic regime can impact corrosion kinetics by boosting mass transfer events.

The importance of this study is to understand the effectiveness of elbow while operating under different operating condition of pressure which the range are from ten to sixteen bar by using simulation software. Besides, this study also is to understand on what happen inside the elbow while the process is conducted. This is because pressure drops through the pipelines and fittings are the common problem that faced while conducting any operation process including in Biodiesel Plant in UTHM.

This study also could increase the understanding of the theoretical of pressure loss in pipeline and fittings that learnt and implement it in real-life applications. Besides, in future, this study also could be a platform for students to strengthen their knowledge on pressure loss problems in the real-life situation and compared it to the theoretical and actual results obtained.

2. Materials and Methods

2.1 Materials

According to Tawancy & Al-hadhrami, (2013)[5], despite its relatively low corrosion resistance, carbon steel is commonly used as a structural material for piping systems used on these ships due to its low cost and availability. Carbon steel can develop a passivation layer of iron oxide, and invasion of aggressive environments such as chloride leads to deterioration of the passivation layer, accelerating corrosion of unprotected surfaces and ultimately. May lead to the formation of hydrated iron oxide. Carbon steel is a durable material made from carbon steel, which is a steel alloy containing iron and carbon. Due to its strength and elasticity, carbon steel pipes are used in a variety of heavy-duty industries such as infrastructure, ships, distilleries, and fertilizer plants.

Carbon steel is often recognized as a cheaper alternative to stainless steel. However, due to its advantages and disadvantages, in some cases this material deserves the first choice, not the second option when choosing a plumbing system. Table 1 shows the advantages and disadvantages of carbon steel material for fittings and piping system. Carbon steel is the ideal product for economical and rapid installation of petroleum and diesel fuel lines. There are two types of carbon steel pipes that normally used in plant industry which is ASTM A53B and ASTM 106B Seamless. ASTM A53B pipes are ideal for high pressure applications. It can be welded into any shape and is mainly used for steam, water, gas, and air piping. Meanwhile, ASTM A106B Seamless Pipe is a seamless pressure pipe used to transport liquids and gases at high temperatures and pressures. This carbon steel grade is widely used in power plants, oil and gas refineries and other high temperature applications.

Table 1 The advantages and disadvantages of carbon steel (Engineering Department, 2022)

Advantages	**Disadvantages**
Simple smelting process	Poor hardenability
Low cost	High temperature strength, low carbon steel, red hardness difference
Good pressure processing performance	Weak comprehensive performance
Good cutting performance	Poor corrosion resistance
Good mechanical properties	Rusty

2.2 Methods

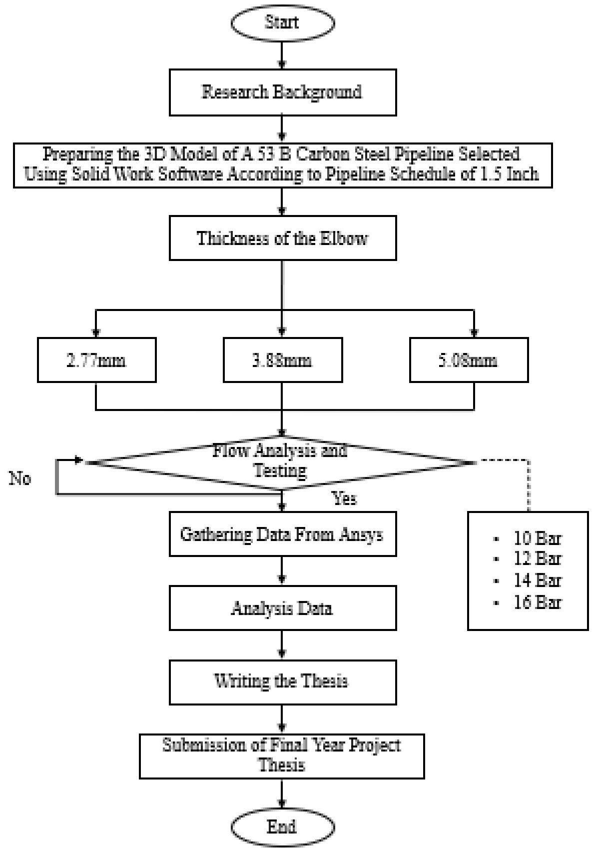

Figure 1 Project Flowchart

A flowchart is a diagram that shows all of the individual phases of a process laid out in the correct sequence. It is a general tool that can be used for a broad range of purposes, and it may be used to describe numerous processes, such as a manufacturing process, an administrative or service process, or a project plan. This project aims to do a simulation study on elbow characteristic which will be designed with three different wall thickness and tested with four different pressures. Figure 1 shows the process flowchart of completing this project starting from title selection with supervisor until the end which submitting full report thesis.

First stage of flowchart is research background which included finding the article related to this project in order to complete the first three chapter in thesis writing. Next stage is preparing the model of A53B Carbon Steel of pipeline selected which located at the outlet of boiler to the steam header at Biodiesel Pilot Plant UTHM. In this stage, Solid Work software will be used to create the full model of the pipeline and there will be three different design of pipeline which the wall thickness is 2.77mm, 3.88mm, and 5.08mm. Then, the model will be tested in Ansys 2019 R3 software which use Ansys fluid flow (fluent) to test the flow within the pipeline and static structural test which to determine the stress and strain of the elbow while going through the pressure.

After that, this project will proceed to most crucial part of the project which doing the flow analysis and testing on the elbows by using Ansys software. The testing will be carried out with four different operating procedures which is 10, 12, 14, 16 bar of pressure. After finished doing the flow analysis and testing, the project will be proceeded to collect and analyses the data from the testing that have been done for thesis writing before submitting the final year project thesis.

3. Results and Discussion

This simulation study was run using two type of method which is Ansys Flow (fluent) and Static Structural Test on elbow part. This 3D model is constructed by using SolidWorks software using actual dimension of piping that can be found in UTHM Biodiesel Pilot Plant which is from the boiler to the steam header and transferred to Ansys software to run the simulation testing.

3.1 Pressure Distribution

From this pressure distribution, it was confirmed that the difference of pressure was caused by the size of inner diameter. These three pipelines were designed by different size of wall thickness which according to ASME B16.10 code and standards for piping. The outer size for this specification was constant while the inner diameters changed which depends on the wall thickness set. So, the thicker the wall thickness, the smaller the size of inner diameter of the pipe. Besides, the medium used in this simulation is steam or vapor. The flow rate in the pipe governed by the pressure drop gradient along the pipe rather than the pressure in the pipe. As a result, the length of the pipe and the differential pressure at either end of the pipe must be specified to calculate the flow rate and lower the pressure of media passing through.

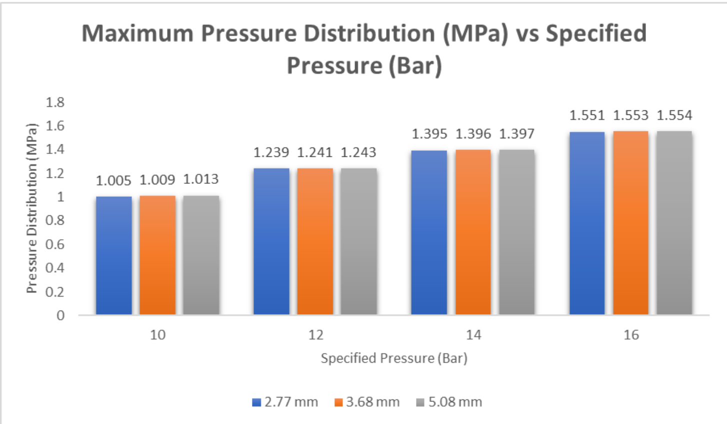

Figure 2 Graph of maximum pressure distribution (MPa) against specified pressure (Bar).

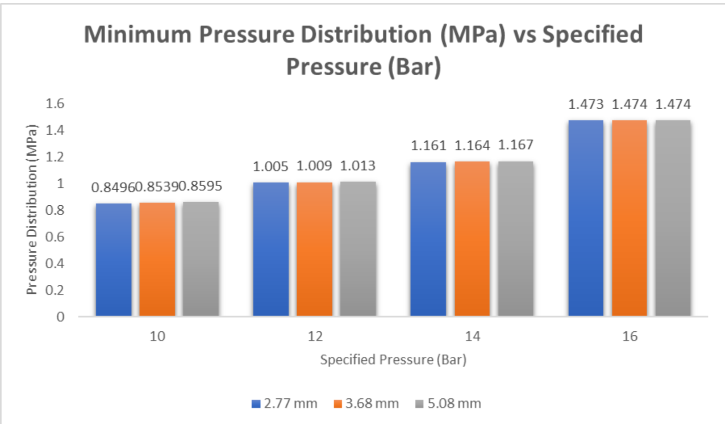

Figure 3 Graph of minimum pressure distribution (MPa) against specified pressure (Bar).

Figure 2 and Figure 3 showed graph of maximum and minimum value for pressure distributions against specified pressure. From these two graphs, the value of pressure between the three different wall thickness increased. The bigger the size of wall thicknesses, the higher the pressure distribution in pipelines. Besides, the value between the specified pressure also increased which was from 10 bars to 16 bars. From this result also, it can be concluded that the higher the pressure applied, the higher the pressure distribution in pipelines. From this pressure distribution, it was confirmed that the difference of pressure was caused by the size of inner diameter. These three pipelines were designed by different size of wall thickness which according to ASME B16.10 code and standards for piping. The outer size for this specification was constant while the inner diameters changed which depends on the wall thickness set. So, the thicker the wall thickness, the smaller the size of inner diameter of the pipe. Besides, the medium used in this simulation is steam or vapor. The flow rate in the pipe governed by the pressure drop gradient along the pipe rather than the pressure in the pipe. As a result, the length of the pipe and the differential pressure at either end of the pipe must be specified in order to calculate the flow rate and lower the pressure of media passing through.

3.2 Velocity Distributions

This simulation also provide data for velocity distribution beside pressure. There was relationship among the pressure and velocity within the pipeline which occurred while going through the process.

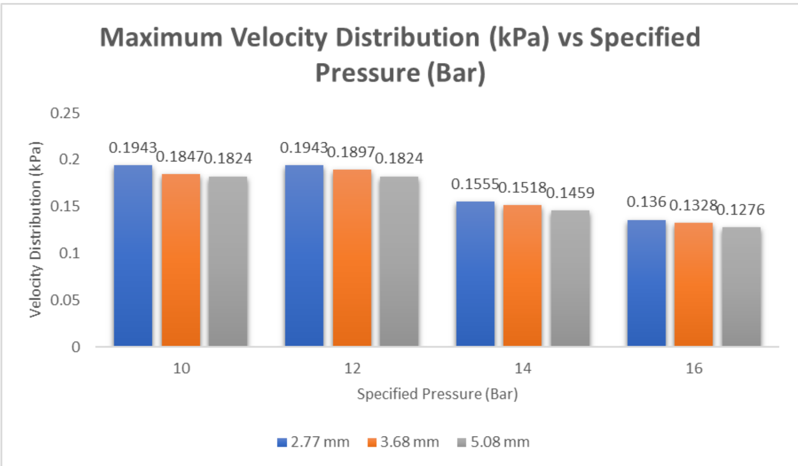

Figure 4 Graph of maximum velocity distributions (kPa) against specified pressure (Bar).

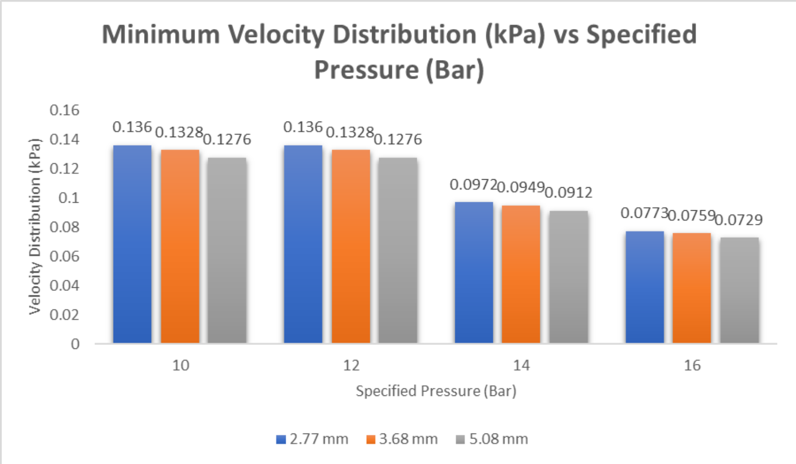

Figure 5 Graph of minimum velocity distributions (kPa) against specified pressure (Bar).

Based on the graph shown in Figure 4 and Figure 5, the velocity distribution within the pipelines decreased from the thinner to the thickest wall thicknesses. Besides, the maximum and minimum value for each wall thickness also decreased after the specified pressure increase. This was because, the specified pressure that used was consider as a high steam pressure which operates above 10 bars of pressure. So, the velocity of steam is decreased from 10 bar to 16 bars of pressure and between the wall thickness of piping. The velocity distribution in this simulation was decreased when the pressure increase. This was because, the specified pressure that used was consider as a high steam pressure which operates above 10 bars of pressure. So, the velocity of steam is decreased from 10 bar to 16 bars of pressure and between the wall thickness of piping. As stated by Dan Holohan (2016), low pressure steam travels faster than high pressure steams. This was because high-pressure steam takes up less space than low-pressure steam. It was squeezed by the pressure. As a result, the steam does not have to flow as rapidly through the pipes to convey the same weight.

3.3 Static Structural Test on 90 Degree Elbow

After completing the simulation of fluid flow in pipeline system, the next procedure that carried out was static structural test on elbow parts. This test was done to achieve the value of strain and stress after going through the pressure tested which is 10, 12,14, and 16 bars of pressure.

3.3.1 Total Deformation

The built-up procedure used by the finite element approach separates all components into many tiny numbers of elements, which are subsequently analyzed while considering their relationships. This approach also attempts to resolve various polynomial approximation functions.

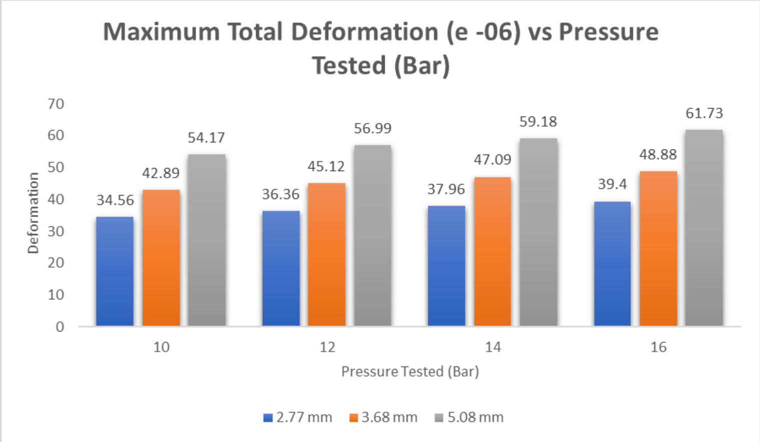

Figure 6 Graph of maximum total deformation (e -06) against specified pressure (Bar).

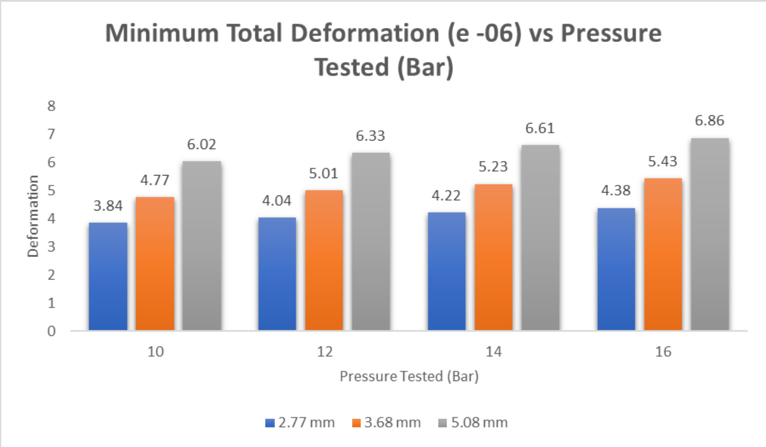

Figure 7 Graph of minimum total deformation (e -06) against specified pressure (Bar).

Figures 6 and Figure 7 shows the maximum and minimum value of total deformation of 90-degree elbow against the pressure tested. Both the maximum and minimum graph showed increased between the wall thicknesses which was from 2.77 mm to 5.08 mm. Besides, the value of maximum and minimum also increased against the specified pressure which was from 10 bars to 16 bars of pressure.

3.3.2 Strain Analysis

The analysis of strain was required in this project to achieve the readings of strain that contained in 90-degree elbow after going through the pressures conditions which is 10, 12, 14, and 16 bars of pressure. These testing will show the results of strain analysis of 90-degree elbow either could withstand the pressure applied or otherwise.

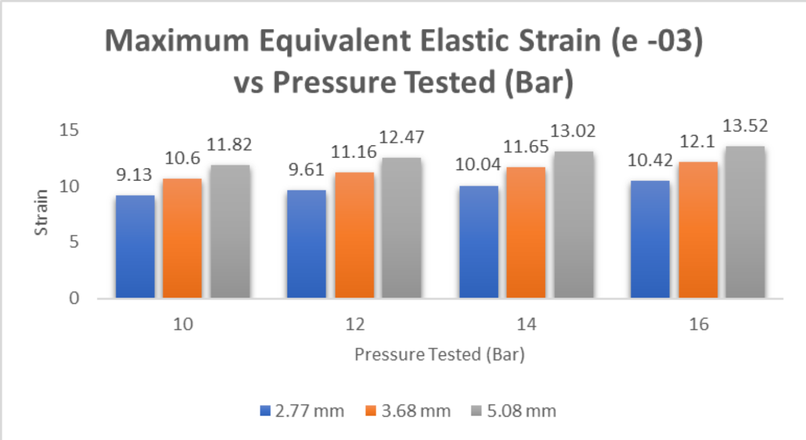

Figure 8 Graph of maximum equivalent elastic strain (e -03) against specified pressure (Bar).

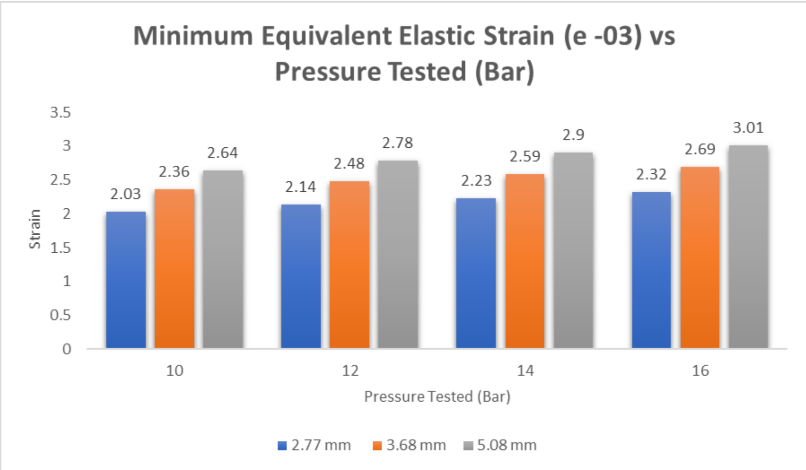

Figure 9 Graph of minimum equivalent elastic strain (e -03) against specified pressure (Bar).

Figure 8 and Figure 9 shows the graph of maximum and minimum value of equivalent elastic strain against the specified pressure. From this graph, it can be concluded that the equivalent elastic strain was increased from the thinner to the thickest of wall thickness. Besides, the strain value for each wall thicknesses also was increased from the lowest specified pressure to the highest.

3.3.3 Stress Analysis

A high level of confidence in the design and size of the components should be provided by the structural analysis. Incorporating analysis early in the design phase may save time and resources by reducing the need for structural verification testing and subsequent redesign. Finding design sensitivities and conducting trade studies are two useful outcomes of stress analysis.

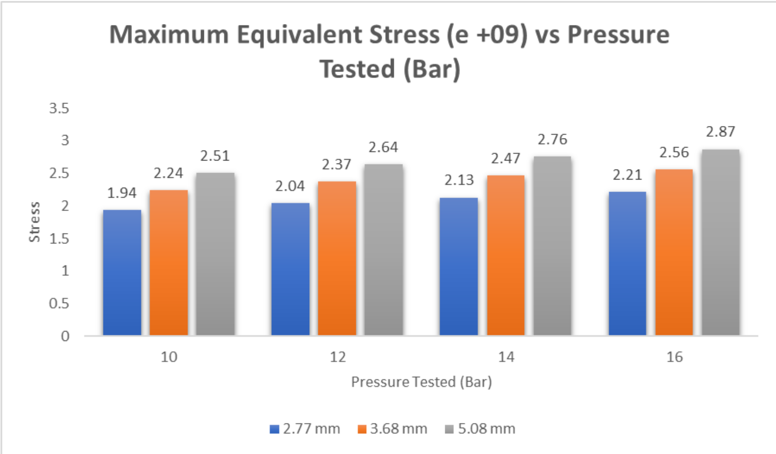

Figure 10 Graph of maximum equivalent stress (e +09) against specified pressure (Bar).

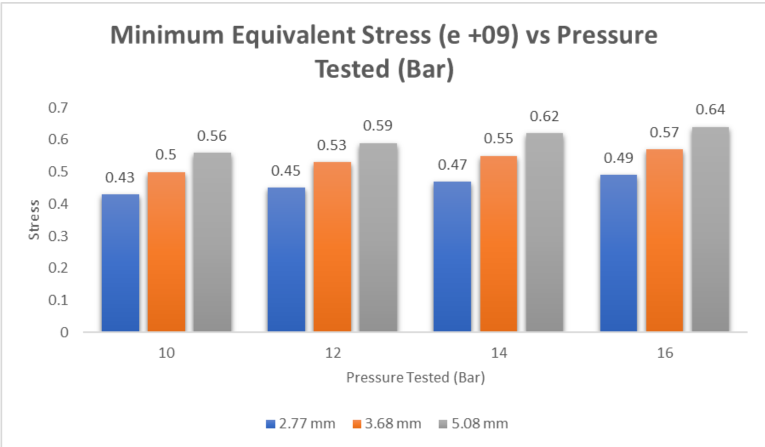

Figure 11 Graph of minimum equivalent stress (e +09) against specified pressure (Bar).

Figure 10 and Figure 11 shows the graph of maximum and minimum value for equivalent stress against specified pressure. From this graph, it can be concluded that the value for both maximum and minimum increase from the thinner of wall thickness to the thickest. Besides, the value between the wall thickness also increased when the pressure tested increase.

3.3.4 Summary of Static Structural Test

All the data have been taken and analyzed. This analysis was focused on determining the three outcomes which were total deformation of the 90-degree elbow, strain analysis of 90-degree elbow and lastly stress analysis of 90-degree elbow. From this analysis, it was confirmed that the specification of this elbow was not suitable for high operating conditions that used in this study which was 10 bars to

16 bars of pressure. This was because the result showed the elbows were expanded from its original dimension after going through the operating conditions.

Both stress and strain value also showed increases pattern between the wall thickness and the operating procedure. The result shows that thicker wall thickness does not give significant difference than the thinner wall thickness which was 2.77 mm of wall thickness. The correlation of wall thickness did not influence the deformation, strain analysis and stress analysis. Logically, as the wall thickness, the strength of the elbow will increase since the structural strength of material increases. As the analysis done, this theory does not apply due to inaccurate parameter when running simulation.

4. Conclusion

This study was conducted to compare the elbow characteristics under several operating conditions. Based on the results of this simulation that had been measured, it can be concluded that the thicker wall thickness of piping system, the higher-pressure value recorded while undergo the simulation procedures. Besides, in evaluating the elbow performance based on simulation, which was done by using Static Structural Analysis, work similar as Finite Element Analysis in SolidWorks used to define the total deformation, strain, and stress analysis. The simulation method used Ansys software was more efficient than using SolidWorks since Ansys provided more detail data and had many features. But for this project its only requires Fluid Flow (fluent) Static Structural Test.

As shown in the results, the pressure drops proved after hitting the first elbow from the fire tube boiler. This was because elbows were used to change the direction of piping which cause internal friction of fluid within the pipeline depends on the designed. Besides, material selection and piping specification also were important factor that needed to be considered in order to design piping systems. This was because to decrease cost on material and contribute to losses in term of profit due to the overdesign.

As mentioned by Liu (2018), the appropriate design safety factors should be prescribed to reach this target safety level and to avoid unnecessary conservatism. The selection of material and specification of piping in UTHM Biodiesel Pilot Plant were compatible and safe to operate. Meanwhile, the outcome of this study which the specification of piping selected were inaccurate for operating conditions parameters which were 10, 12, 14, and 16 bars of pressure. These operating pressures were too high for the specification of elbow tested.

Acknowledgement

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