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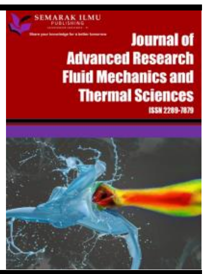

Computational Fluid Dynamic Analysis on Carbon Fibre Reinforced Polymer Wrapped on Defected Oil and Gas Piping System Using Solidwork Flow Simulation

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ABSTRACT

Utilising Carbon Fibre Reinforced Polymer (CFRP) as a wrapping structure on defected piping system is not a very new approach in maintaining the defected pipe structure. But simulating the entire approach using computational simulation technique makes this research to be unique. This composite material was regarded as a one-of-a-kind wrapping material since it might have the combined properties of the element or significantly different properties than the constituents individually. Computational Fluid Dynamic (CFD) analysis is needed to make sure that the proposed wrapping structure doesn’t disrupt the fluid flow after the repair is done. The research is keen to fully utilise Solidwork flow simulation in evaluating the capability of proposed CFRP wrapping structure without any leaks or opening. Based on simulated data, this technique provides a preliminary analysis and visual deformations in selecting the suitable optimised lamination orientation of CFRP in real-world applications. Furthermore, the flow simulation study in SolidWorks has identified areas where possible fluid accumulation could occur after the repair has been done. This approach may prevent two primary failure modes by achieving the right lamination orientation and thickness which is CFRP overloading due to excessive thickness and CFRP delamination of the composite laminate from the substrate.

1. Introduction

Pipeline systems are considered as critical infrastructure (CI) among today's infrastructural facilities, especially in the oil and gas industry and other industries that are related to it [1]. Safety is given the top priority in these sectors since the risk exposure is so high. Design, material, and operating procedures all work together to prevent pipe failures. Natural occurrences and exposure to essential components can both induce pipeline system failure. Leaks can occur for a variety of reasons, including pipe damage, manufacturing flaws, poor workmanship, rapid pressure changes, cracking, internal and exterior corrosion, and improper pipe maintenance [26]. To avoid such breakdowns and maintain uninterrupted product flow in the pipe, the pipe structure's strength and

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integrity gets the highest degree of attention and maintenance. Pipe insulation ensures the pipe structure's endurance by providing excellent mechanical strength and flexibility in a variety of applications.

Pipelines are commonly used to transport combustible and non-flammable liquids over millions of kilometres throughout the world. In such a case, the pipeline system's safety should always take precedence, as the pipeline system is designed to resist a variety of changing environmental conditions to provide a safe and effective distribution from one place to the next. However, the pipeline's life cycle creates certain issues in terms of its long-term capacity to withstand varied environments [2].

Wrapping materials for defective pipes or pipes that are going to fail are commercially available. The wrapping procedure is used to keep the pipe's strength, durability, reliability, and longer life span. The difficult element is determining the proper wrapping structure orientation and thickness. If a composite wrapping structure is not oriented properly, it can lead to two possible failures. When the composite wrap is overloaded, the first mode of failure occurs. In some circumstances, the substrate will break before the composite wrap, causing enhanced stress transfer and composite burst failure [3].

Delamination of the composite laminate from the substrate owing to a loss in bonding strength is the second failure mode [3]. As a result, this research is optimistic in designing the suitable Carbon Fibre Reinforced Polymer (CFRP) wrapping structure that could withstand the minimum and maximum pressure by maintaining the steady fluid flow solely through SolidWorks Flow simulation with proper parameter set-up to ensure that the composite laminate is not overloaded, stays attached to the substrate and do not interrupt the fluid flow after the repair [4]. Throughout the years, the SolidWork design software has been utilized sparingly to investigate the performance of wrapping structures including composites in earlier analyses. Using the validated finite element (FE) simulation in SolidWorks, mechanical responses, and failure of fiber-reinforced polymer (FRP) composite laminates can be predicted. The unidirectional lamina's properties, particularly those discovered through tension tests, served as the basis for the material constitutive and damage models used in the simulation [25]. To analyse the fluid flow in composite repaired pipe various software like ABAQUS, ALTAIR, ANSYS are necessary, to get the entire preventive maintenance data and simulation analysis. However, this research will lay the groundwork for evaluating the composite performance in making sure the fluid flow is uninterrupted solely using SolidWork flow simulation. Since widely mechanical engineers across the world are more familiar and comfortable with this CAD Software, this study is hopeful that it will be able to provide all associated analyses, including CFD analysis, totally using SolidWorks [5]. Flow simulation in Solidwork is capable to provide cut plots, surface plots and flow trajectories. All three features able provide the temperature, velocity, and pressure transmission across the enclosed system either exactly at the node with FEM analysis or providing the range of the readings. Cut plots will provide the internal parameter readings while surface plots will provide information on the properties that are exposed to the surface of the pipe. Besides, the flow trajectories will provide visual information on fluid particle flow in pipe. This distinguishes the study since it can be determined whether the applied wrapping is adequate, capable of withstanding fluid pressure, and does not generate any overload or excessive stress on the repaired pipe during simulation itself. Eventually such simulations will provide adequate data to consider such wrapping solutions for preventive maintenance in piping system.

1.1 Carbon Fibre Reinforced Polymer Wrapping Structure

In general, composite material was chosen as the wrapping material over other materials because of its capacity to alter characteristics depending on the requirements. As it adheres to international technical standards and provides a developed, proven, and long-lasting solution to both metallic and non-metallic repair work, this composite material wrapping technique is gaining popularity and acceptance across the world [6,7]. Depending on how the components are blended, the resultant composite material may have the combined attributes of the constituents or properties that are very different from the separate elements [8]. In general, CFRP is regarded as one of the most distinctive materials in the composite category, owing to its low density, high tensile strength, and lightweight.

In comparison to other fibre reinforced polymer materials, the CFRP is thought to be one of the most distinctive materials in the composite category, with low density, high tensile strength, low thermal expansion, high rigidity, high stiffness, and corrosion resistance [9,10]. Carbon fibres are ultra-thin filaments that have a diameter of 5–10μm and are hardly visible to the human eye [11]. The presence of such a tiny element did not prevent those fibres from exhibiting superior qualities to those of other materials. Though CFRP is theoretically a sophisticated and useful material, it is also somewhat costly. To evaluate CFRP as a wrapping material for a defective pipe, sufficient evidence is required to demonstrate its efficacy for justifying the reason to choose it as a wrapping material.

1.2 Computational Analysis on CFRP Wrapping Structure

The research is keen to provide computational simulation approach during CFRP pipe wrapping. This research will give a guideline for simulating the failure mechanism of composites and the use of composites solely on pipe structures. Eventually this approach may alleviate the “trial and error method” when repairing the defected piping system. CFD Analysis in SolidWork will provide visual simulated illustrations on the performance of CFRP during in service which can be considered real-world application. This method will save time and cost on providing justification when considering the possible wrapping structure for real-world scenarios, that could also provide possible failure visualisations on the pipe before it is wrapped.

As Solidwork software is capable to run static analysis, flow simulations, and failure simulations in general, it is expected that it will be able to provide deformed visual illustrations and numerical analytical data for persuasive suggestions. These three basic pillars can generate preliminary analysis for further consideration when for selecting the appropriate CFRP lamination orientations, which will serve as a point of reference for experimental techniques soon. Even though simulation tools such as ABAQUS and ANSYS are often used to investigate CFD analysis and composite simulation, this study is optimistic in modelling the defected pipe and CFRP analysing them using SolidWorks simulation. The 'Flow Simulation' add-in in SolidWorks was used to monitor fluid flows through the model after modelling the pipe structure based on standards and codes. This method aids in identifying the problematic section of a pipe and may help to enhance the model before it is manufactured. Flow simulation specifically addresses the fluid flow in a fully closed volume as illustrated in Figure 1.

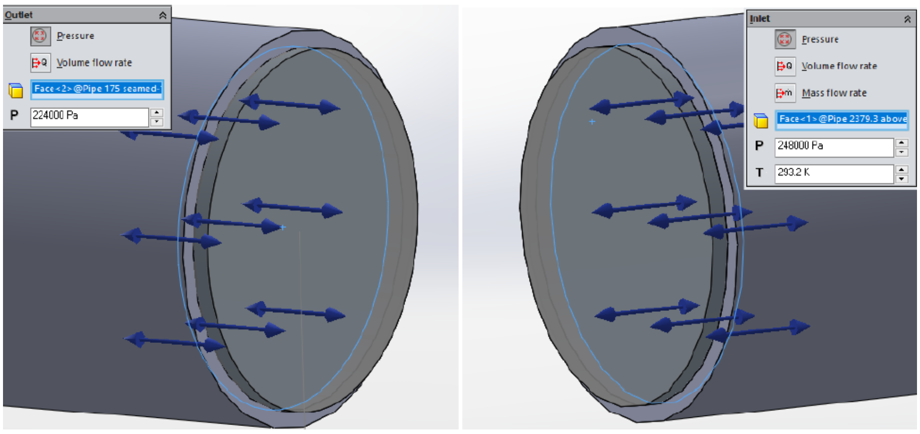
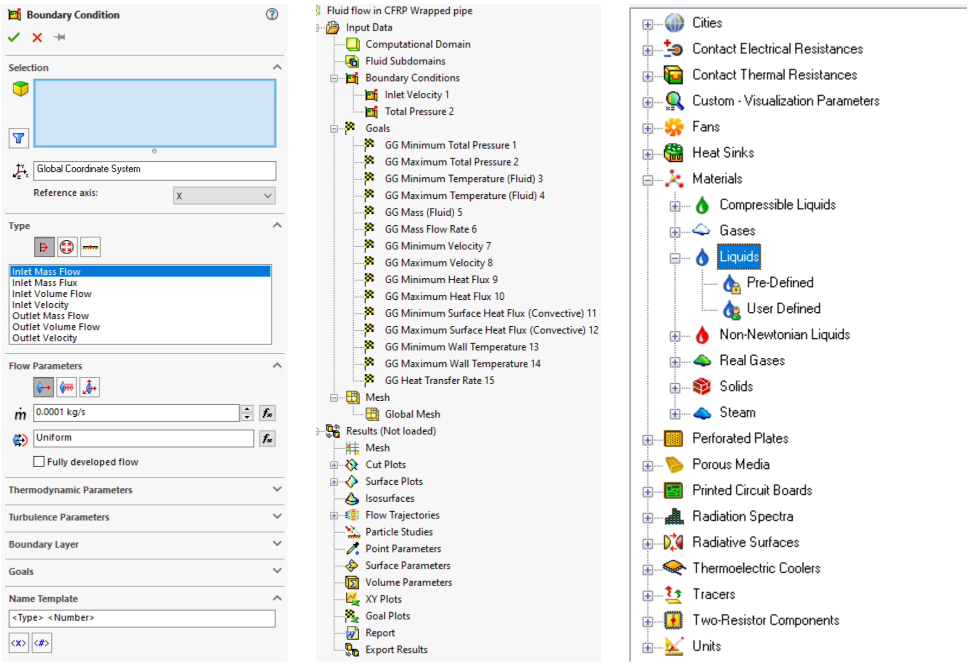


Fig. 1. Inlet pressure and outlet pressure assigned at lid [12]

The flow simulation add-in requires at least one inlet and one outlet flow, which has been used in this simulation concept. To execute a simulation, the lids were built to seal the pipes. SolidWorks Flow Simulation can model pipe performance with varied fluid characteristics using the principles of extrusion with appropriate parameters or boundary conditions [13]. Figure 2(a) shows the boundary conditions that must be configured to conduct the flow simulations, including inlet pressure, outlet pressure, operating temperature, and fluid velocity while Figure 2(b) shows the numerous outcomes approaches that could be used to examine the data. Figure 2(c) demonstrates that the SolidWorks Flow Simulation that includes several inflow substances from its directory [14].



(a) (b) (c)

Fig. 2. (a) Boundary Conditions for inlet substance, (b) Goals or results that could be achieved, (c) Various inlet substance

2. Methodology

The first part of the research was all about modelling the whole system, where the pipe with the defect, the CFRP wrapper with different lamination orientations, and the repaired pipe with the wrapping material were all designed and assembled as illustrated in Figure 3. The lamination orientation of CFRP that was configured in the Solidwork were designed and assembled with a sealer. The sealer acts as a temporary cover to enclose the whole system while the CFRP wrapping structure cure.

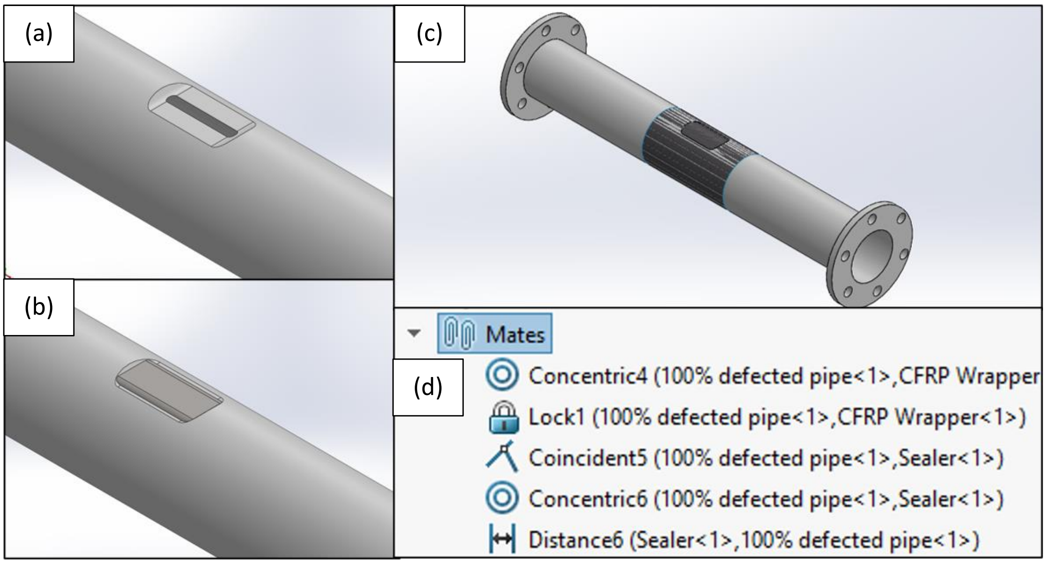


Fig. 3. (a) Insert Defected Pipe, (b) Assemble Sealer, (c) Assemble CFRP Wrapper, (d) Mates that are used to assemble

The CFD analysis in Solidwork Flow Simulation analyses the temperature, pressure in the pipe, and velocity along the pipe structure after the CFRP wrapped. The flow simulation is done to ensure that the CFRP can maintain fluid flow at maximum loading, especially in the repaired area. The goal of CFD analysis is considered since it will provide a better visualisation and study of fluid flow in a defective pipe and a pipe that has been repaired. The performance of the repaired pipe with CFRP lamination with variable lamination orientation was validated by simulating fluid flow in the repaired pipe. The flow simulation was chosen since it can only be performed if the entire structure is watertight, or if the leaks at the damaged zone are correctly fixed with CFRP. The simulation based on pressure, velocity, and temperature, as well as the parameter distribution along the pipe, could be assessed after setting up all the boundary conditions on the pipe and fluid.

This provides the ideal conditions for evaluating the CFRP wrapper as a wrapping structure. There would be three surface boundaries: an inlet for inflow, an outlet for outflow, and a wall. Some assumptions were made before, such as that the flow is steady isothermal, laminar, and have no turbulence or heat transfer models. The flow must be modelled with a constant pressure drop so that the simulation can forecast any changes in flow rate on the repaired pipe. The inclusion of a pressure boundary condition at the inlet allows the Flow Simulation analysis to impose the fully developed velocity profile at the inlet, ensuring that the flow is fully developed throughout the pipe and reducing the need for a lengthy pipe. A static pressure equal to the whole pressure drop along the pipe was specified at the input, with a zero-static pressure boundary condition at the exit [15]. Furthermore, because the flow simulation could only be executed when the entire geometry was enclosed, the flow simulation's lid function was used to seal all the holes, as shown in Figure 4.

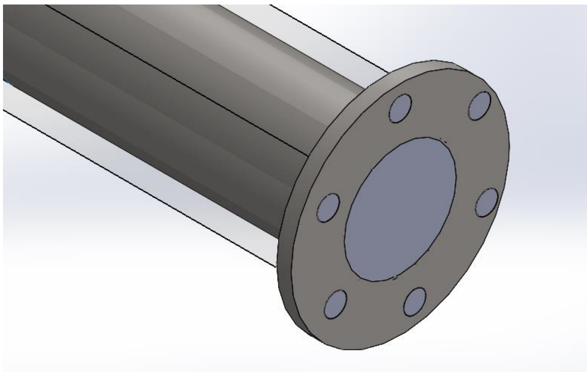


Fig. 4. Lid feature to enclose the piping system

The structure is deemed eligible to execute the analysis after it has been enclosed. The Fluid type that was used is normal fluid service which s hydrocarbon. The laminar flow was used to get the preliminary CFD simulation, and its characteristics should be added at first using the "Wizard" option.

As shown in Figure 5, all of the fluid parameters defined based on Table 1. The main reference for the simulation was based on ASME B31.3 where these standards give a clear guideline on the parameters that shall be considered before simulating the whole system.

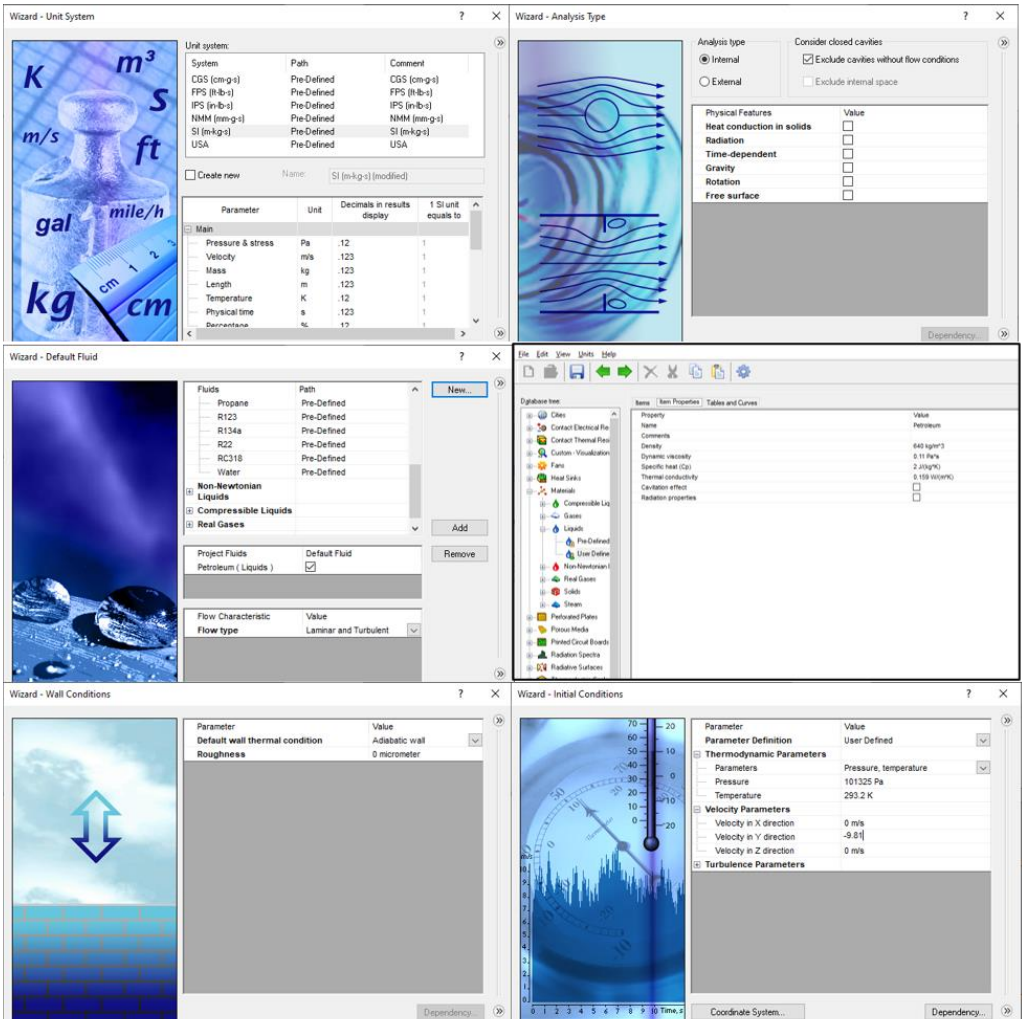


Fig. 5. The steps to input the fluid properties

Table 1
Parameter Set up for Pipe Specification

Parameters	Specimen Specifications	Parameter References
Type of pipeline	Crude oil pipeline, operating	NA
Outer Diameter (mm)	168.3	Minimum 150mm (ASME B36.10M)
Wall thickness (mm)	7.11	ASME B36.10M
Nominal Pipe Size (mm)	150	NPS range in between 1/8" – 12" (ASME B36.10M)
Pipe Schedule	40	(ASME B36.10M)
Internal Diameter (mm)	161.19	Sing [16]
Length (mm)	1200	Sing [16]
Seamless Pipe Minimum Yield Strength (MPa)	245	Table A-1 ASME B31.3
Seamless Pipe Tensile Strength (MPa)	415	Table A-1 ASME B31.3
Material grade	API 5L Grade B Carbon Steel Seamless	Rubio and Salas [17]
Fluid Service	Normal	
Fluid Velocity	2 to 10 m/s	NA
Pressure Rating	Class 150	ASME B36.10M
External Pressure Rating (MPa)	0.103421	ASME B36.10M
Corrosion Allowance (For 6-inch pipe)	0.063	0.00, 0.031, 0.063, 0.125 (ASME B36.10M)
Type of pipe thickness	Thin wall structure (23.67)	If ratio of pipe diameter to thickness is greater than 20 (D/t > 20) thin wall structure is considered [18]

Table 2 shows the range of Design Pressure and Design Temperature that are considered in flow modelling. The maximum and lowest test parameters were not considered because the final parameter is the test parameters.

Table 2
Fluid Boundary Condition [17]

Piping Specification		Corrosion Allowance (0.000, 0.031, 0.063, 0.125)						
Metric System	Design Pressure (MPa)	1.97	1.79	1.59	1.38	1.17	0.97	0.86
	Design Temperature (°C)	37.78	93.33	148.89	204.44	260.0	315.56	343.33
	Minimum Temperature (°C)	-6.67	-6.67	-6.67	-6.67	-6.67	-6.67	-6.67
	Minimum Test Pressure (MPa)	2.96	2.69	2.38	2.07	1.86	1.69	1.52
	Maximum Test Pressure (MPa)	5.65						

The SOLIDWORKS Flow Simulation was used to complete the flow simulation analysis, which is essentially a CFD analysis. The internal pressure was loaded as shown in Figure 6 when the intake and outflow velocity were both adjusted to 10 m/s, which is the maximum fluid velocity. Before conducting the simulation, certain boundary conditions must be set [28]. After all the boundary conditions have been set, various simulations can be used to perform several analyses. The procedure continues with the simulation boundary conditions being loaded. The flow simulation for this study includes cut plots, surface plots, and flow trajectories. The pressure, temperature, and fluid velocity will be the main parameters studied. The cut plot shows the findings in a specific area, whereas the flow trajectories show the fluid flow either throughout the pipe or in a specific area. The parameter transmission towards the surface is shown on the surface plot. It is more effective at analysing characteristics such as temperature and pressure transfer to the surface.

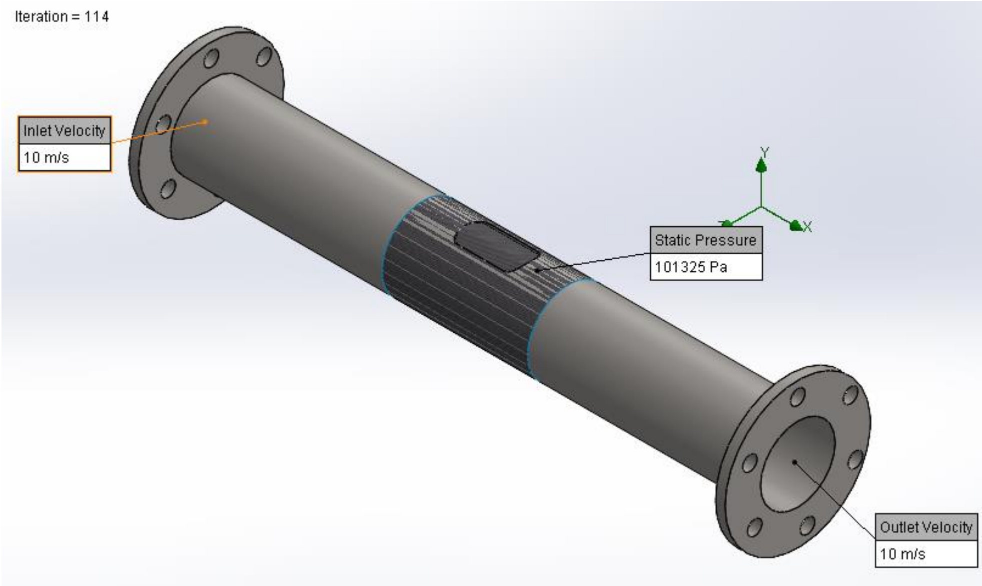


Fig. 6. The boundary conditions on CFRP wrapped pipe

3. Results and Discussions

To determine the flow studies in the pipe, cut plots, surface plots, and a few flow trajectories were performed. The pipe structure should be enclosed with lids to separate the solid and fluid regions after loading the fluid with varied parameters. The velocity input and outflow parameters were used, and the pressure type was static pressure. Instead of using ambient or total pressure, static pressure was used at this time. The total pressure refers to the sum of all the pressures in the system, whereas the ambient pressure simply refers to the pressure in the direct proximity. Since this analysis only involves fluid pressure then only the static pressure was chosen [19].

3.1 CFD Analysis: Cut Plots

Cut plots are used to examine attributes from a section perspective. This will ultimately enable for the analysis to be done on a cross-sectioned region and the plotting of maximum and lowest parameters [20]. It also provides an overview of attributes such as pressure, fluid velocity, and temperature as they flow through a pipe. Figure 7 shows the cut plot normal to the pipe's front plane.

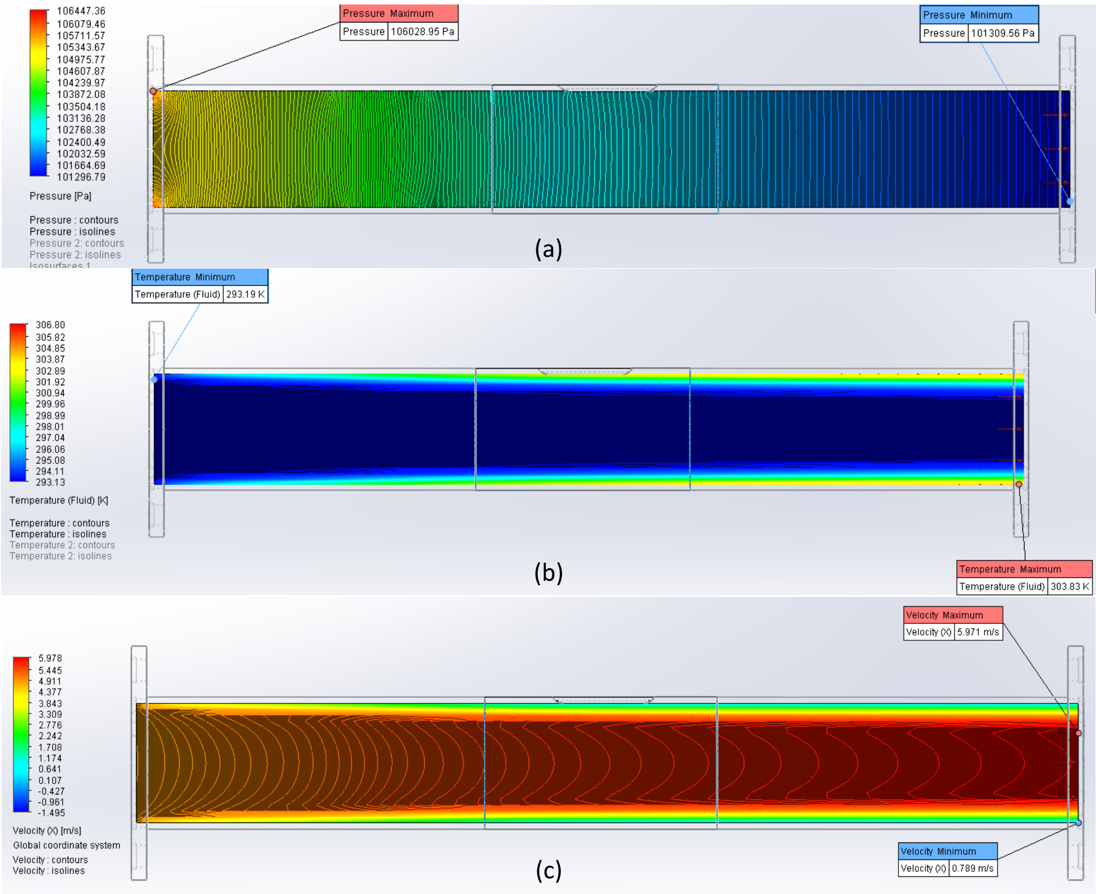


Fig. 7. The cut plot of the pipe: (a) Fluid Pressure, (b) Fluid Temperature, (c) Fluid Velocity

The maximum pressure was 160.3kPa and the minimum pressure was 101.309kPa at this location, according to the cut plot in Figure 7(a). Both the pressure and the opening were shown to be on the verge of opening, indicating that there will be a pressure reduction as the length increases. While the temperature seems to be increasing along the length based on Figure 7(b). The minimum temperature was 293.19K at the inlet while the maximum temperature was 303.83K at the outlet. It might be due to the pressure difference along the pipe, where a drop in pressure leads to a rise in temperature. The temperature is constant along the isothermal part of the pipe and is varying along the heat flux region. The temperature is high at the pipe wall and is gradually decreasing towards the centreline [27]. This situation could be related to Gay Loussac Law which gives $\frac{Pressure\ 1}{Temperature\ 1} = \frac{Pressure\ 1}{Temperature\ 2}$ [20]. By referring to Figure 7(a), Figure 7(b) and Figure 7(c) it could be all the properties has uniform flow without any disruption at the repaired region. The velocity of fluid seems to be very smooth where it indicates that the flow is undisrupted based on the maximum and minimum velocity region in the repaired pipe segment.

3.2 CFD Analysis: Surface Plots

Surface plots are another sort of analysis that can provide a clearer visual representation of the variations in attributes. Internal pressure and temperature inside the pipe were transferred to the pipe wall and subsequently to the pipe's external surface, giving an understanding of the properties exposed to the surface [21]. Figure 8 shows surface plots for pressure on the defective pipe towards the CFRP Wrapper, and Figure 9 shows surface plots for temperature. The surface plots could ideally show the range of temperature and pressure experienced by the external wrapper at the repaired region. In this case it shows that both properties are normal at the repaired region. Indeed, this range will indicate the CFRP could sustain the properties range in accordance with its mechanical properties. The clear indication from the surface plots will be useful if the repaired region has serious indications.

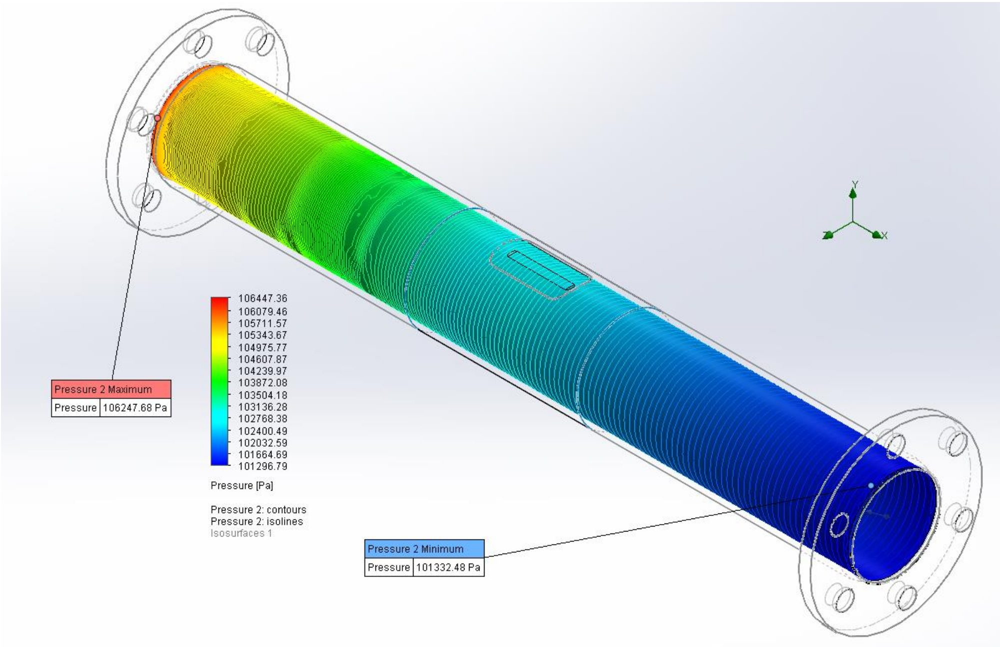


Fig. 8. The pressure surface plots

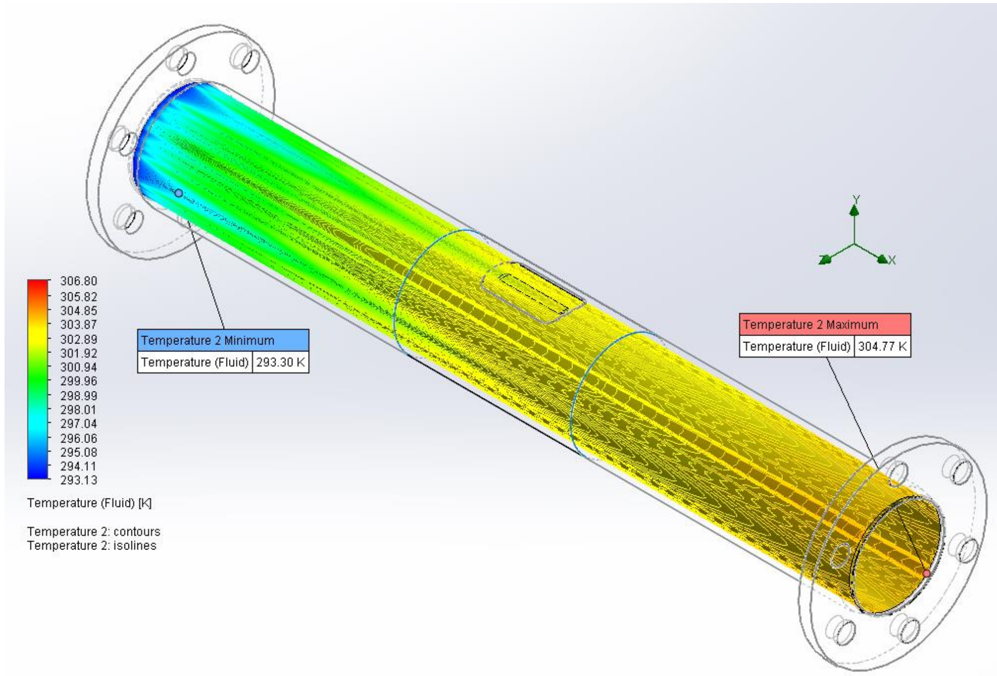
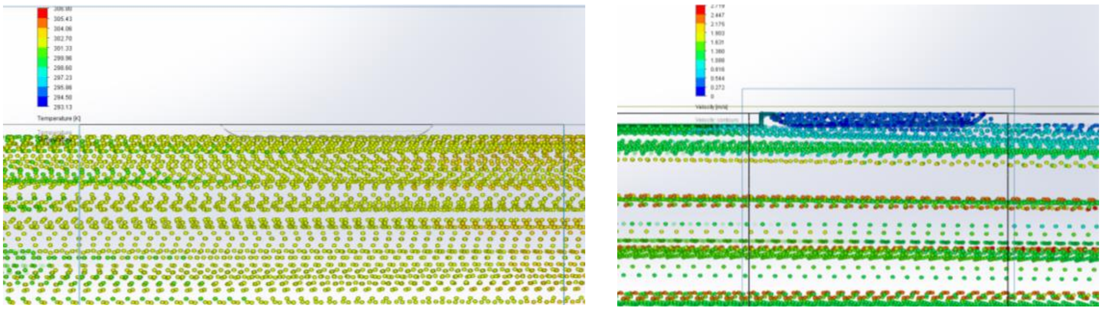


Fig. 9. The temperature surface plots

3.3 CFD Analysis: Flow Trajectories

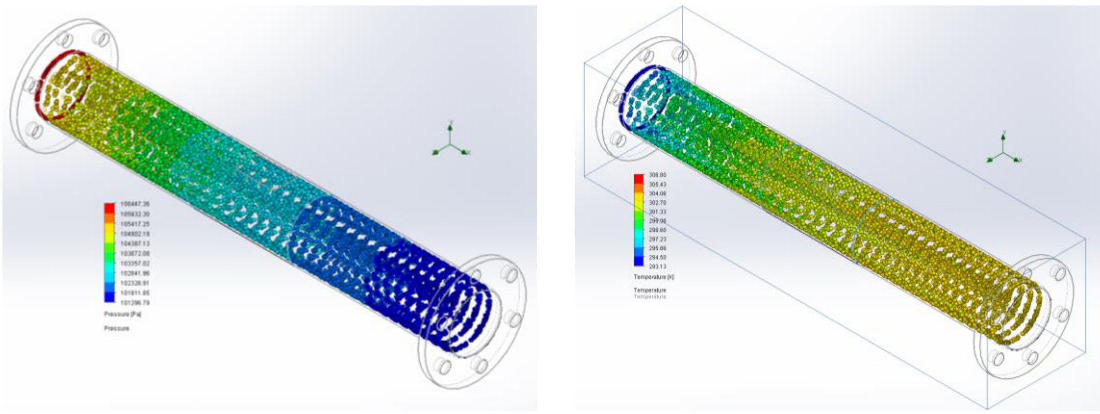
The flow paths show how fluid flows through the pipe. Flow trajectories, too, might offer a clearer understanding of fluid flow in a defective region [22]. The differences between a CFRP Wrapped Sealed Defected Pipe and a CFRP Wrapped Unsealed Defected Pipe are shown in Figures 10(a) and Figure 10(b).



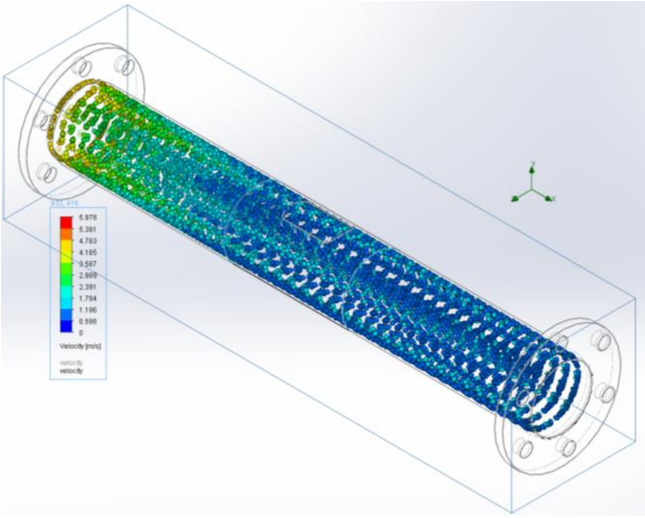
(a) (b)

Fig. 10. (a) The CFRP Wrapped Sealed Defected Pipe, (b) CFRP Wrapped Unsealed Defected Pipe

It is clear that the CFRP Wrapped Unsealed Defected Pipe collects some fluid flow, but the CFRP Wrapped Sealed Defected Pipe has a smooth flow. This was discovered when looking at flow paths. Furthermore, Figure 11(a) depicts pressure flow trajectories, whereas Figure 11(b) depicts temperature flow trajectories, followed by velocity flow trajectories Figure 11(c). All this simulation could be even animated for future analysis [23,24].



(a) (b)



(c)

Fig. 11. (a) Flow trajectories for pressure, (b) is the flow trajectories for temperature, (c) flow trajectories for velocity

4. Conclusions

Theoretically, the CFRP composite is the best material for pipe wrapping since its characteristics are at their best. Since this study is entirely based on simulation, the results may provide confidence in using CFRP with various lamination orientations as an effective wrapping material that could withstand high pressurized fluid flow. There have been no costs because this was totally modelled using SOLIDWORKS software, which could offer a clear static analysis and flow simulation for CFD studies. The research can completely simulate and assess the performance of the CFRP wrapper using correct meshing and material properties application. This distinguishes the study since it was feasible to determine whether the wrapper used was adequate and optimal, could sustain fluid pressure, and did not generate any overload or excessive stress on the repaired pipe during simulation. Furthermore, the flow simulation study in SolidWorks revealed that fluid flow was unaffected after the repair, and the wrapped region was fluid leakage resistant. Indeed, the CFD Analysis found that a sealer is needed to cover the defected region temporarily to prevent any sorts of fluid clog. It is critical to emphasise that this study is simply a preliminary analysis to support the lamination orientation and wrapping material that would be used in real-world situations. Because it is only a result of simulation, it is strongly recommended that an experimental technique be used to further confirm the results. This simulation will undoubtedly save money, time, and effort because exploratory tests may reveal the desirable lamination orientation for future consideration. By getting the proper lamination orientation and thickness, you may avoid two major failure modes: CFRP overloading owing to excessive thickness and CFRP delamination of the composite laminate from the substrate due to a drop in bonding strength. Instead of using a trial-and-error technique in the actual world, convincing simulation data will be used to consider the orientations.

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