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Analysis of Vibration in Pipe: Effect from Different Pipe Sizes and Pressure Inlet

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Abstract

Pipe vibration is a common problem in industries, causing damage and safety concerns. This study investigates how pressure loss in pipes leads to vibrations. When fluid flows through pipes, friction causes pressure to drop and speed to increase, resulting in damaging vibrations. The research focuses on the UTHM Biodiesel Plant's pipeline, analysing the pressure drop from the air compressor to the reservoir tank. The study examines the impact of different pipe sizes (Model 1: 65 mm, Model 2: 80 mm, Model 3: 105 mm) and pressure levels (6 bar, 8 bar, 10 bar) on the pressure drop. Using SOLIDWORKS and ANSYS software for design and simulation, a 3D model of the pipes serves as a reference. The objective is to identify the model with the least pressure drop, aiming to minimise vibrations in the pipeline. By understanding how varying diameter sizes and pressure levels affect pressure drop, this research seeks to provide insights for mitigating pipe vibrations. This study aims to bring about improvements in pipeline systems that positively impact both structural integrity and overall operational effectiveness. The larger diameter pipe is observed to potentially contribute to reduced vibrations in the pipeline. The larger the diameter of the pipes, the lower the pressure drop in the pipeline. This is because pipes with larger diameters have lower pressure drops, higher velocities, and increased temperatures. In other words, the larger the diameter of the pipe, the lower the pressure drop in the pipeline.

1. Introduction

An air compressor was vital for pressing and compressing air, producing kinetic energy. Higher air pressure in pipelines could cause vibrations, which had the potential to result in pipe bursts and sudden stops in plant operations [1]. Pipeline vibration involved calibrated movements around equilibrium conditions and posed a significant threat to the integrity of the entire operating plant [2].

Plant pipelines were often located close to high vibration levels, exposing them to possible cracking. Various factors contributed to machinery vibration, including bent shafts, worn or bent gears, unbalanced rotating parts, misaligned couplings or bearings, damaged bearings, electromagnetic forces, and others [3]. Imbalance in rotating components and irregular aerodynamic forces were common factors that led to compressor damage [4]. High levels of vibration in the piping system could affect the reliability and safety of the compressor infrastructure.

Research on pipe vibration and control usually focuses on vibration simulation and its engineering applications [4]. Previous studies have emphasised techniques for measuring vibration, simulation methods, vibration analysis, and piping system design [5]. These studies laid a solid foundation for checking and controlling pipe oscillations in compressor piping systems.

This study focused on exploring the relationship between the vibration effect of different diameter pipe holes and pressure inlets, aiming to minimise pipeline vibrations. Given the excessive vibration experienced in the inlet pipeline at the air compressor station, the paper evaluated variations in diameter pipe holes and pressure inlets to reduce vibration. Furthermore, the researcher conducted data analysis on pipe vibrations to identify the amount of pressure loss of vibration occurring with different diameter pipe holes and pressure inlets. The research utilised a Computational Fluid Dynamics (CFD) model to simulate the fluent fluid resulting from fluid flow inside the pipeline [6]. The research aimed to evaluate the impact of various parameters, including varied diameter pipe holes and pressure inlets, focusing on reducing pipe vibration during pressure loss or drop. The study specifically addressed the role of these parameters in mitigating vibration, thus improving pipeline safety and efficiency.

2. Methodology

This section demonstrates the specific approach used for the study, including the design, data analysis procedures, and overall methodological framework. In this investigation, SolidWorks was used to visualise the pipe structure, followed by simulation using ANSYS software, with the pipe geometry modelled based on the UTHM Biodiesel plant. The methodology consists of initial data collection, pipeline visualisation, flow characterisation, and structural properties at the three models' pipe diameters and pressure inlets.

2.1 3D Modelling of the Pipeline System

The pipeline model taken as a reference for this study is from the compressor room of the UTHM Biodiesel plant (Fig. 1) and is represented using SolidWorks software for visualisation. After designing the pipe structure in SolidWorks, relevant data, such as inlet and outlet pressure and density, were imported into Ansys for simulation. The objective is to analyse the characteristic behaviour of velocity, temperature, and pressure to obtain results related to pressure drop and minimise vibration in the pipeline.

(a)

(b)

Fig. 1 *(a) Pipeline from Air Compressor (b) Air Pipeline to Reservoir Tank*

2.1.1 Pipeline Models Design

In this part, three design models of pipelines with varying diameter sizes are presented, and they were sketched using SolidWorks software (Fig. 2) . It is essential to emphasise that all dimensions in these drawings are in millimetres (mm). This aims to analyse the impact of using pipes with different diameters to minimise pipeline vibration.

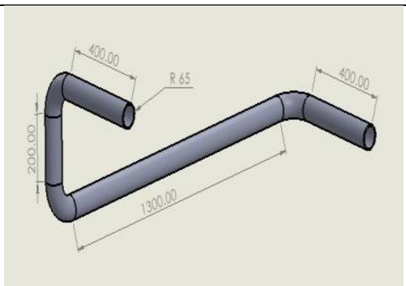
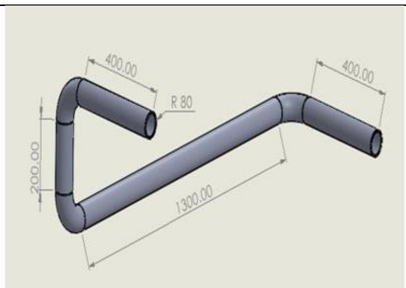
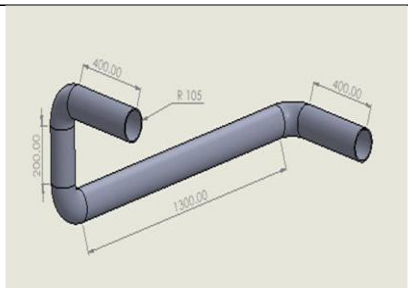
 Model 1 is a pipe with a diameter of 65 mm.	 Model 2 is a pipe with a diameter of 80 mm.	 Model 3 is a pipe with a diameter of 105 mm.

Fig. 2 *3D Model Pipeline*

The length of the pipe dimension in the model remains consistent with that of the Biodiesel Plant at UTHM. However, intentional changes were made to the inside diameter of each model's pipe hole. This modification investigates the potential impact of varying pipe diameters on the pipeline system. By altering the inside diameter, it aims to explore how fluid dynamics, pressure drop, and vibration characteristics may be influenced. The material chosen for these pipes is carbon steel.

3. Procedure

Grid Independence Test (GIT) is a process in Computational Fluid Dynamics (CFD) simulations that involves systematically varying the grid or mesh resolution to evaluate its impact on the simulation results [7]. The goal is to assess whether the solution obtained is insensitive to changes in the grid size or if it converges to a consistent solution as the mesh is refined [8]. The process typically involves performing the simulation with different grid resolutions while keeping other parameters constant.

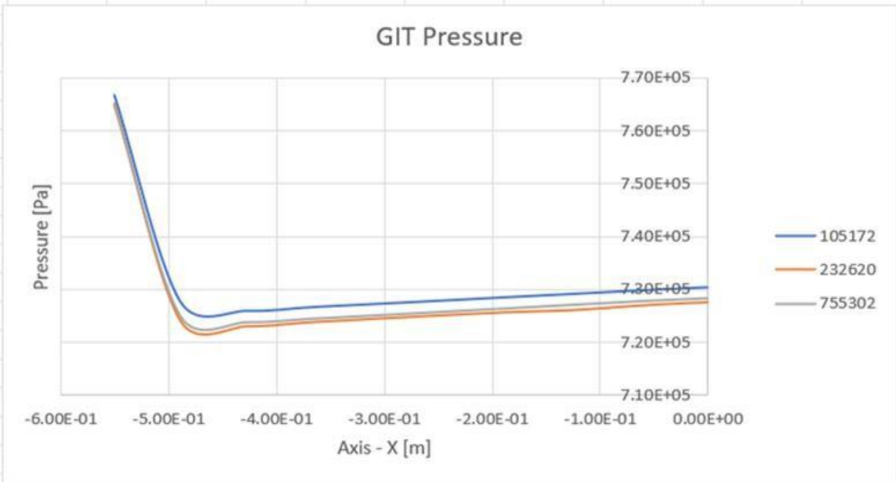


Fig. 3 *Grid Independence Test (GIT)*

Fig. 3 compared three meshing refinements for pipeline geometry with different element counts: Git 1 (105,172 elements), Git 2 (232,620 elements), and Git 3 (755,302 elements). The Graph Independence Test revealed that the configuration with 232,620 elements would be used in the study due to its suitability and distinctive pattern at point -4.28e-01 m. This choice was made for pressure drop simulation, as it had the lowest count among the three GIT elements, indicating its appropriateness.

3.1 Boundary Condition for Fluid

A computational fluid dynamics (CFD) simulation was conducted using Ansys Fluent to study the fluid flow behaviour of all pipeline models. This research mainly emphasises comprehending the fluid flow, focusing on the air from the compressor [9, 10]. The boundary conditions play a crucial role in ensuring the precision and significance of outcomes by specifying the fluid’s conduct. The properties of the fluid are outlined in Table 1.

Table 1 *Boundary Condition of Fluid*

Parameters	65 mm			80 mm			105 mm		
Pressure Inlet (bar)	6	8	10	6	8	10	6	8	10
Pressure Outlet (bar)	4.8	6.4	8	4.8	6.4	8	4.8	6.4	8
Temperature (°C)					58°C				

3.2 Boundary Condition for Pipe

The boundary conditions for the pipe simulation model involve selecting parameters for the diameter and pressure at the inlet. In this study, the pipe material is carbon steel, and Table 2 presents the properties of the piping model. Here is a summary of the characteristics related to the pipe model's boundary conditions:

Table 2 *Boundary Condition for Pipe*

Material Pipe	Density	Specific Heat, Cp	Thermal Conductivity
Carbon Steel	7870 (kg/m^3)	502.416 (J/kg K)	45 (W/m K)

4. Results and Discussion

This chapter intends to clarify the findings of the current study. The 3D model of the piping system was developed using SolidWorks and Ansys software, and all results were obtained through Ansys simulation analysis. The expected outcomes aim to comprehend the effects of different pipe diameters and pressure inlets on achieving a pressure drop to reduce vibrations. The validation of these findings will be conducted using Ansys Fluent simulation.

4.1 Analysis of Fluid Behaviour

The analysis of fluid behaviour involved conducting simulations using Ansys software, with a specific focus on investigating vibrations within a piping system. Factors such as high pressure, high velocity, and high temperature were considered [11].

4.2 Effect from Different Inlet Diameters

This research included the analysis of various pipe diameters at the inlet, designated as Model 1 (65 mm), Model 2 (80 mm), and Model 3 (105 mm). The simulations were carried out to analyse the impact on velocity, temperature, and pressure distribution under three different inlet pressures: P1 (6 bar) (Fig. 4), P2 (8 bar) (Fig. 5), and P3 (10 bar) (Fig. 6).

4.2.1 Velocity Distribution

The analysis focuses on examining the velocity distribution in pipes with varying diameters under three different pressure inlets: P1 (6 bar), P2 (8 bar), and P3 (10 bar). This suggests a comprehensive investigation into how different pressure levels influence the velocity within pipes of different sizes. Including multiple pressure conditions enhances the study's depth and allows for a more nuanced understanding of the relationship between pressure, pipe diameter, and velocity distribution.

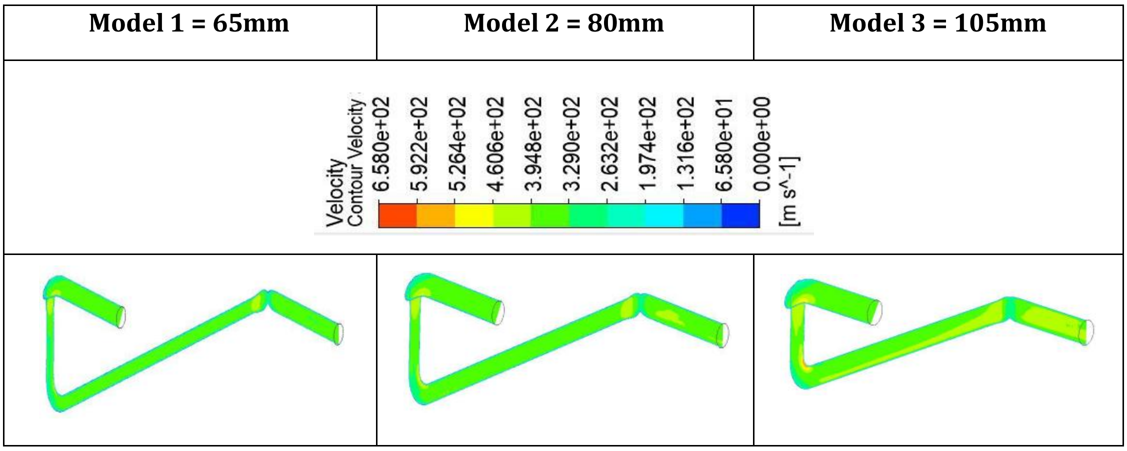


Fig. 4 *Velocity Distribution for Pressure Inlet 1 = 6 bar*

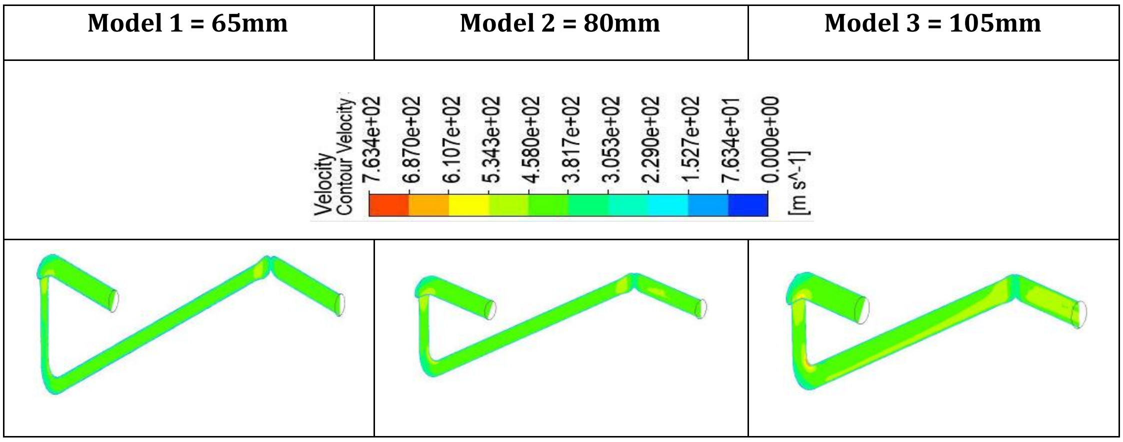


Fig. 5 *Velocity Distribution for Pressure Inlet 2 = 8 bar*

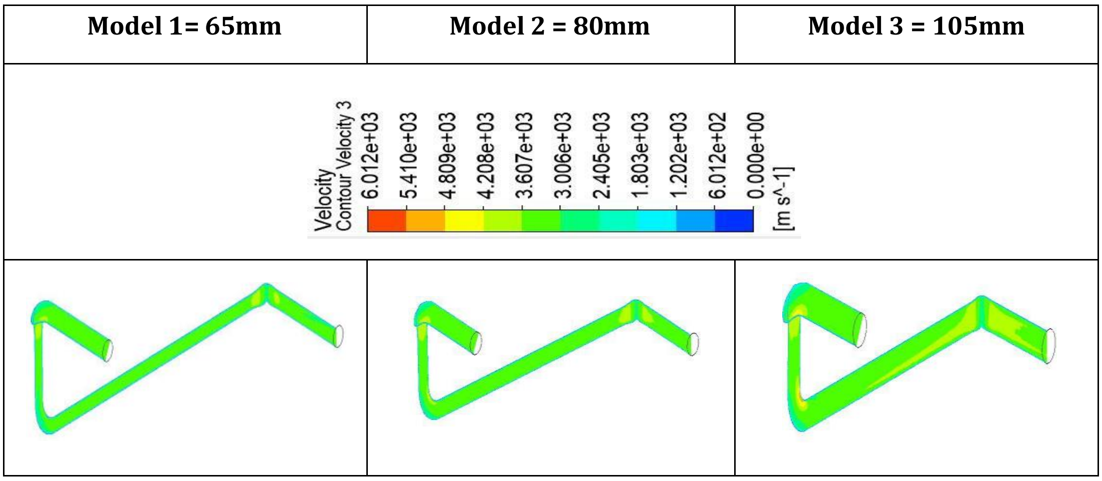


Fig. 6 *Velocity Distribution for Pressure Inlet 3 = 10 bar*

The study indicates that pipelines with larger inlet diameters, specifically represented by Model 3, tend to exhibit higher velocities. This is attributed to Bernoulli's principle, where changes in velocity are inversely proportional to changes in pressure. The higher velocity in Model 3, particularly under pressures of 8 bar and 10 bar, suggests a potential for reducing vibrations in pipelines compared to Models 1 and 2. The findings emphasise the preference for pipelines with larger inlet diameters, like those in Model 3, for minimising pipeline vibrations based on fluid dynamics principles and the Bernoulli equation.

4.2.2 Temperature Distribution

The analysis focuses on examining the temperature distribution in pipes with varying diameters under three different pressure inlets: P1 (6 bar) (Fig. 7), P2 (8 bar) (Fig. 8), and P3 (10 bar) (Fig. 9). This suggests a comprehensive investigation into how different pressure levels influence the temperature within pipes of different sizes.

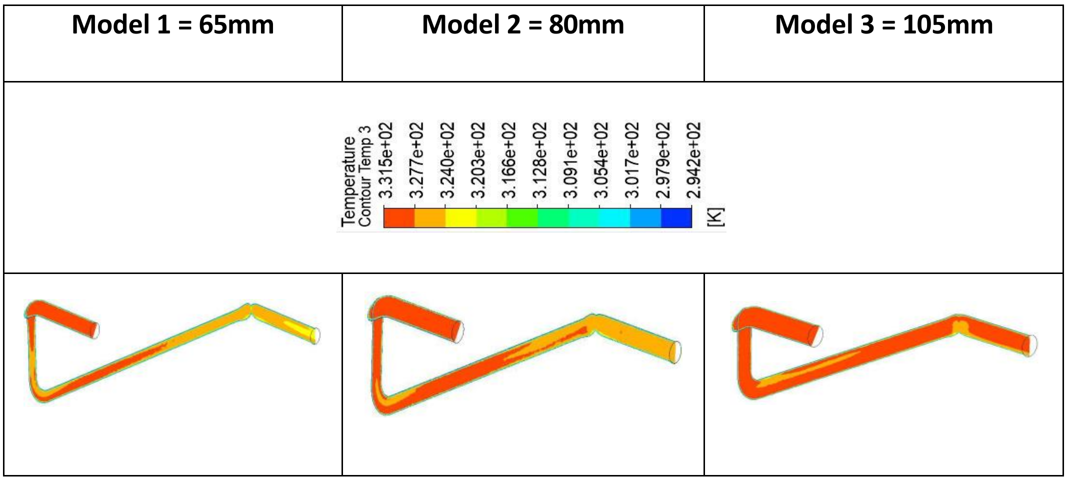


Fig. 7 *Temperature Distribution for Pressure Inlet 1 = 6 bar*

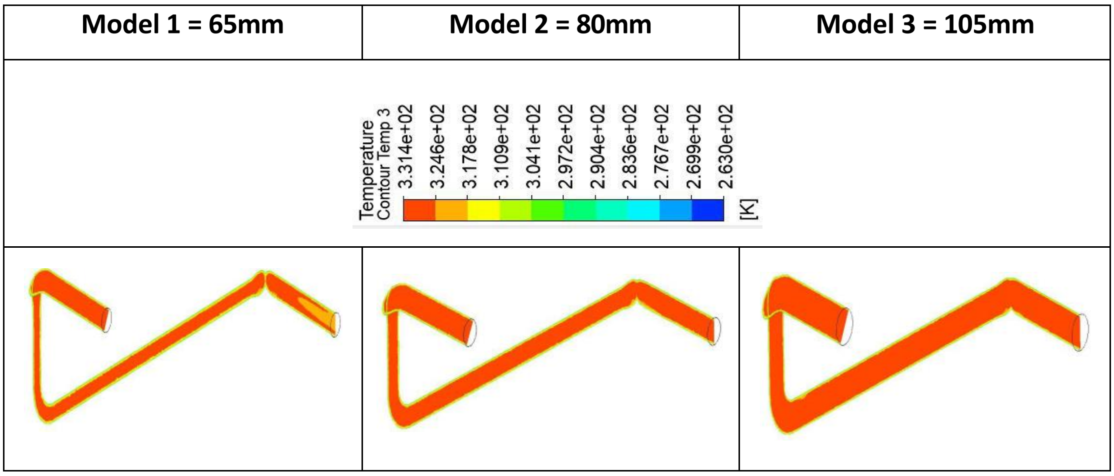


Fig. 8 *Temperature Distribution for Pressure Inlet 2 = 8 bar*

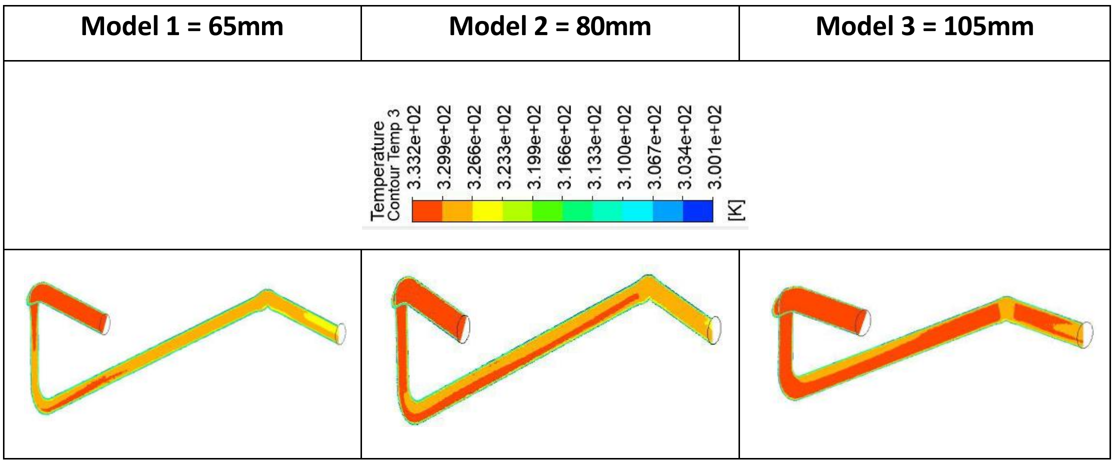


Fig. 9 *Temperature Distribution for Pressure Inlet 3 = 10 bar*

According to Bernoulli's principle and fluid dynamics, increased pressure generally raises fluid temperature by converting potential energy into kinetic energy [12]. The study confirms higher temperatures along the

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pipeline with pressure inlets at 8 bar and 10 bar, aligning with fluid dynamics principles. Notably, a 6 bar pressure inlet is linked to reduced vibrations, highlighting the importance of pressure control for pipeline stability. The larger diameter and higher pressure in the inlet pipe contribute significantly to the temperature increase, with Model 3 consistently showing higher temperatures than Models 1 and 2, supporting this observation.

4.2.3 Pressure Distribution

The analysis examines pressure distribution in pipes with different diameters under three pressure inlets: P1 (6 bar) (Fig. 10), P2 (8 bar) (Fig. 11), and P3 (10 bar) (Fig. 12). It delves into how various pressure levels influence pipes of different sizes, enhancing the study depth for a nuanced understanding of the relationship between pressure, pipe diameter, and pressure distribution.

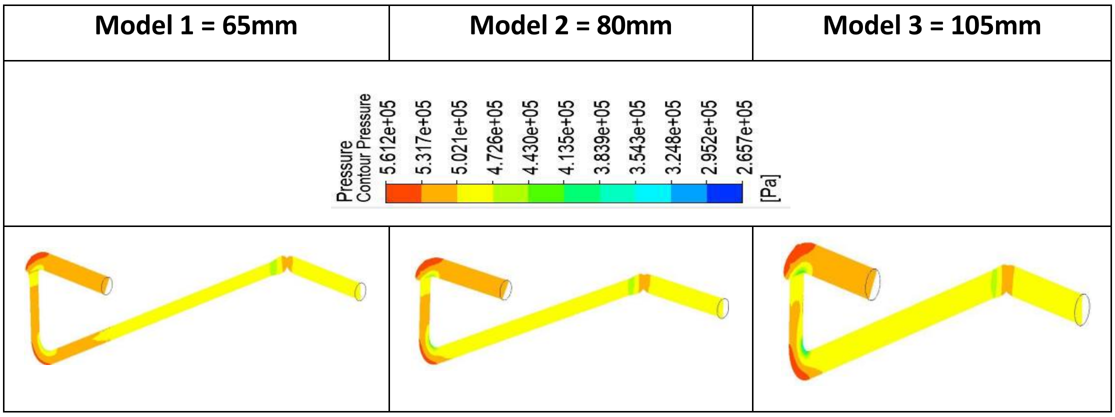

Fig.10 *Pressure Distribution for Pressure Inlet 1 = 6 bar*

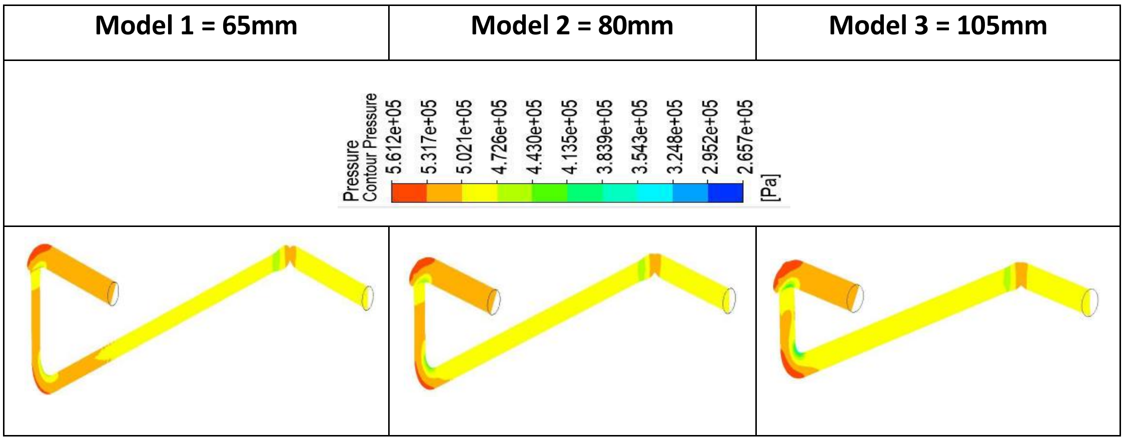

Fig.11 *Pressure Distribution for Pressure Inlet 2 = 8 bar*

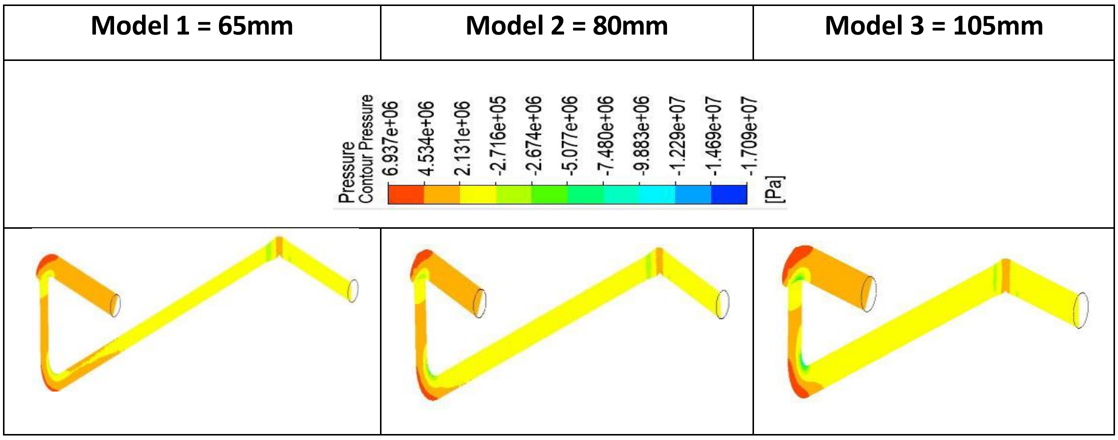

Fig. 12 *Pressure Distribution for Pressure Inlet 3 = 10 bar*

The pressure inlets with 6 bar, 8 bar, and 10 bar show consistent pressure distributions throughout the pipeline. This stability in pressure aligns with Bernoulli's equation, indicating that fluid velocity remains relatively stable. Although all models have similar pressure distributions, Model 1 shows pressure variations due to flow separation in curved pipes. This can potentially cause fluid-induced vibrations in Model 1. On the other hand, Model 2 and Model 3 are more likely to minimise vibrations in the pipeline across all pressure inlets.

4.3 Effect from Different Pressure Inlet of Pipe

This section examines the impact of different pressure inlets (P1: 6 bar, P2: 8 bar, P3: 10 bar) on velocity, temperature, and pressure distribution in pipes of varying diameters (Model 1: 65 mm, Model 2: 80 mm, Model 3: 105 mm). The analysis follows a completed simulation overview.

4.3.1 Velocity Distribution

Simulations were conducted to analyse the impact of velocity distribution from different models under the various pressure inlets in the pipeline, including 6 bar (Fig. 13), 8 bar (Fig. 14), and 10 bar (Fig. 15). The pipeline process revealed outcomes from input to output.

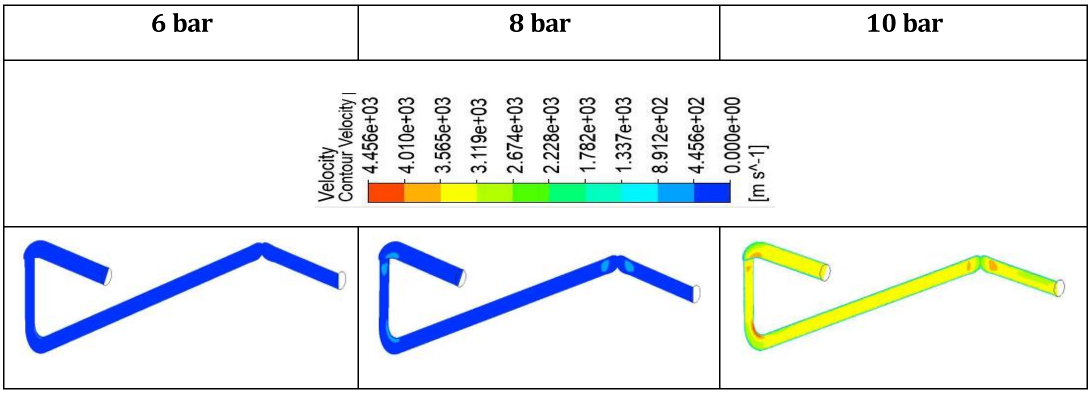

Fig. 13 Velocity Distribution for Model 1 = 65 mm

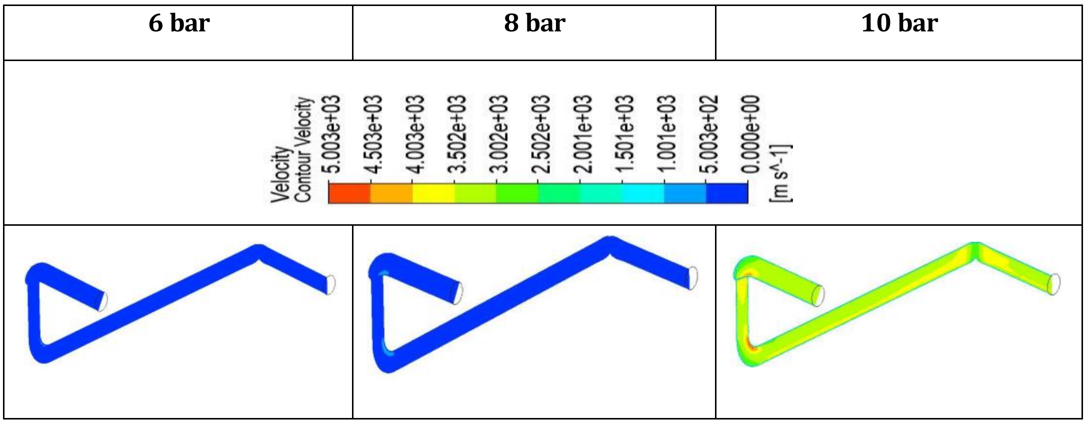

Fig. 14 *Velocity Distribution for Model 2 = 80 mm*

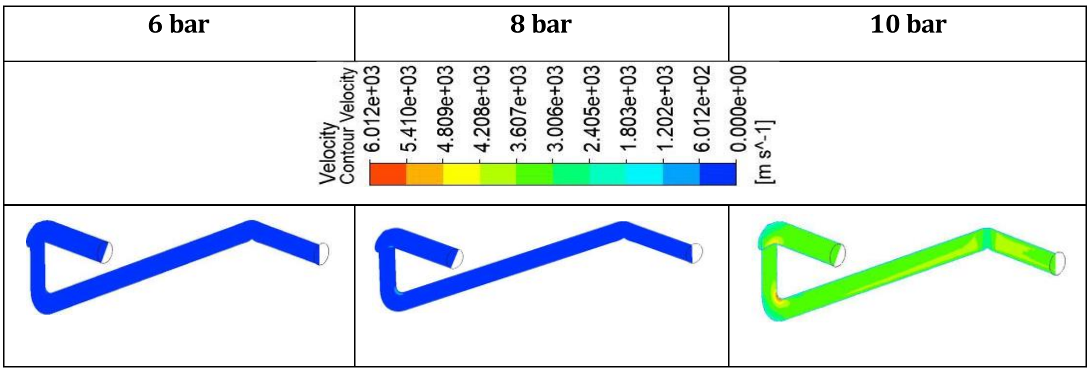

Fig. 15 *Velocity Distribution for Model 3 = 105 mm*

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The all models show increasing pressure results in higher velocities in the pipeline. This observation aligns with Bernoulli's principle, which states that higher fluid velocity is associated with lower pressure. All three models exhibit similar trends in velocity distribution, indicating that the pressure-inlet-induced velocity changes are consistent across different pipe diameters. From a vibration reduction perspective, the provided information suggests that all models, irrespective of diameter (65 mm, 80 mm, and 105 mm), experience increased velocity and potential fluid-induced vibrations with higher pressure.

4.3.2 Temperature Distribution

The analysis focuses on examining the temperature distribution in pipes with varying diameters under three different pressure inlets: P1 (6 bar) (Fig. 16), P2 (8 bar) (Fig. 17), and P3 (10 bar) (Fig. 18). This suggests a comprehensive investigation into how different pressure levels influence the temperature within pipes of different sizes.

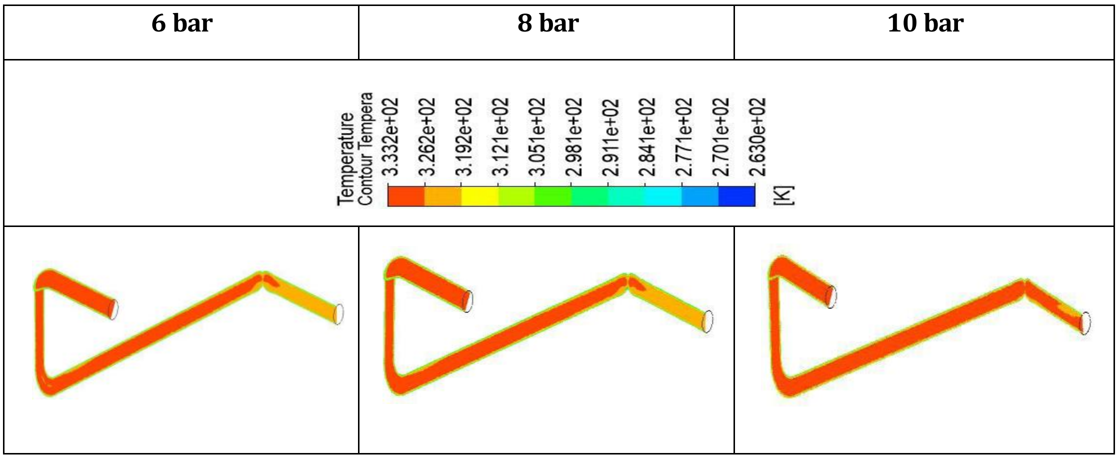

Fig. 16 *Temperature Distribution for Model 1 = 65 mm*

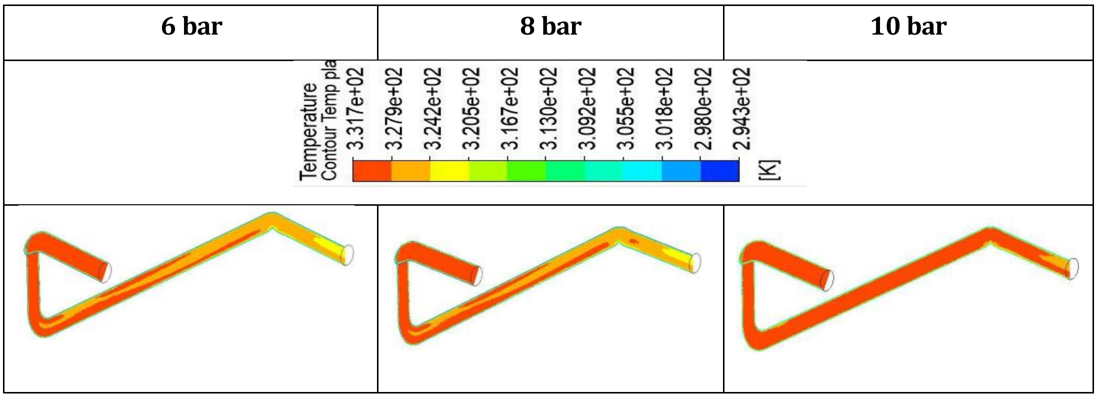

Fig. 17 *Temperature Distribution for Model 2 = 80 mm*

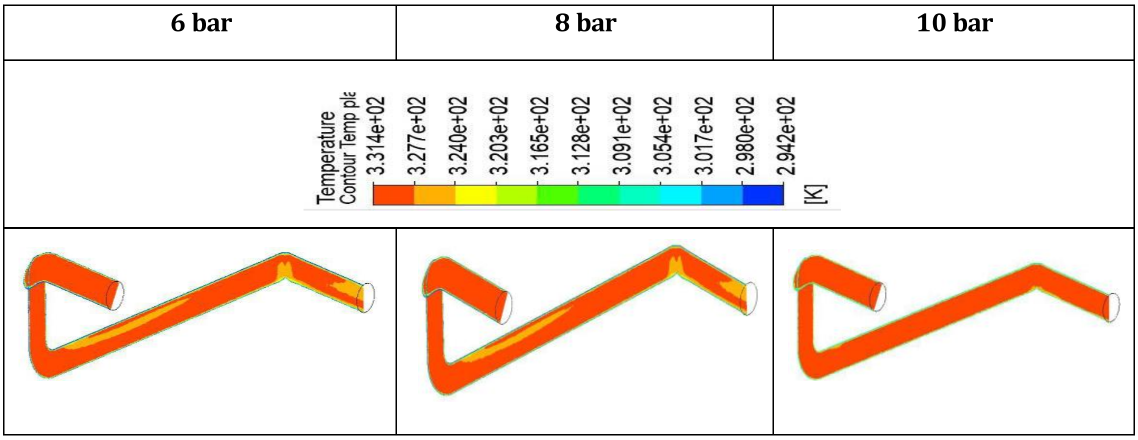

Fig. 18 *Temperature Distribution for Model 3 = 105 mm*

The analysis of temperature distribution under varying pressure inlets for Model 1 (65 mm), Model 2 (80 mm), and Model 3 (105 mm) demonstrates that higher pressure correlates with elevated temperatures along the pipeline, in accordance with fluid dynamics principles. Although temperature increases at 10 bar, leading to warmer colour ranges, there is no significant variance in trends among the models. The data implies that all models exhibit similar temperature responses to varying pressure conditions, regardless of pipe diameter. Consequently, selecting a specific model or pressure inlet for effective vibration reduction proves challenging, as none provides a distinct advantage in mitigating vibrations.

4.3.3 Pressure Distribution

The analysis examines pressure distribution in pipes with different diameters under three pressure inlets: P1 (6 bar) (Fig. 19), P2 (8 bar) (Fig. 20), and P3 (10 bar) (Fig. 21). It delves into how various pressure levels influence pipes of different sizes.

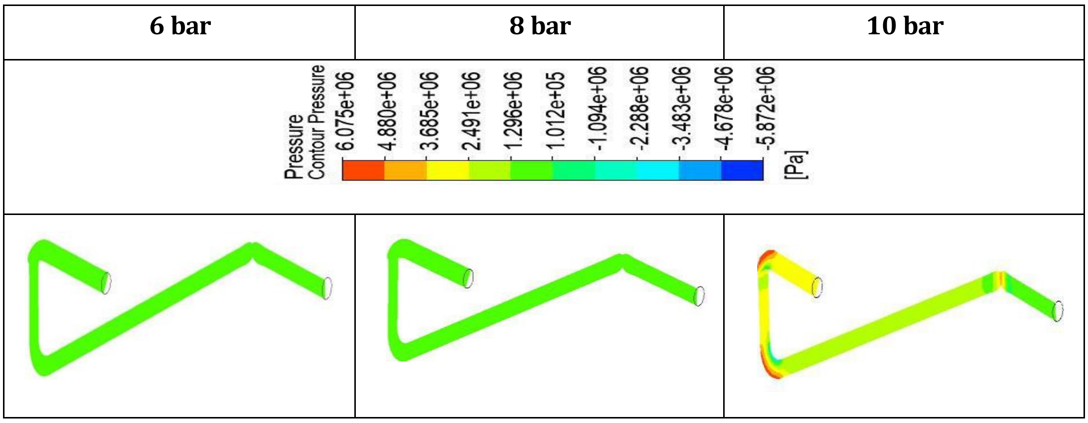

Fig.19 *Pressure Distribution for Model 1 = 65 mm*

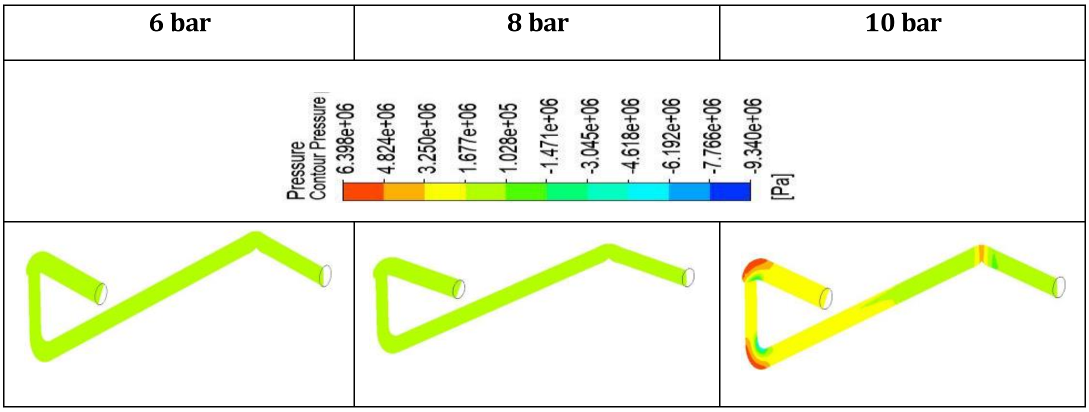

Fig. 20 *Pressure Distribution for Model 2 = 80 mm*

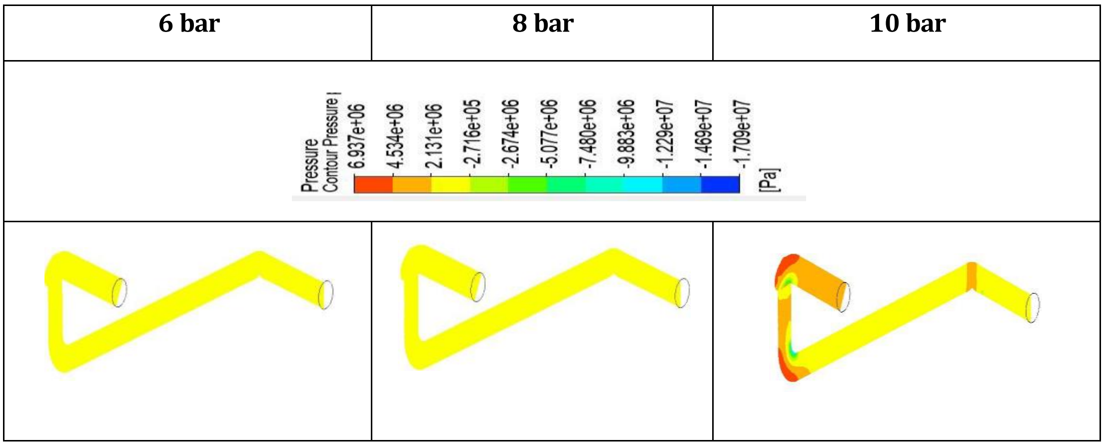

Fig. 21 *Pressure Distribution for Model 3 = 105 mm*

The analysis of pressure distribution under different pressure inlets for Model 1 (65 mm), Model 2 (80 mm), and Model 3 (105 mm) provides insights into the impact of inlet pressure variations on pipeline stability. The data aligns with Bernoulli's principle, indicating that consistent pressure distribution along the pipeline leads to reduced fluid-induced vibrations. Specifically, all three models exhibit stable pressure distributions under varying pressures (6 bar, 8 bar, and 10 bar). This stability suggests that maintaining a consistent pressure environment is crucial for minimising vibrations irrespective of pipe diameter. Consequently, each model has the potential to reduce vibrations when pressure distribution remains stable along the pipeline.

4.4 Analysis of Pressure Drop Distribution

Fig. 22 shows points 1 and 2 as references in this analysis of pressure drop distribution in all models. This point is strategically positioned from the inlet and outlet of the pipeline.

Fig. 22 *Location of Point 1 & 2 Line as Reference for Pressure Drop*

The pressure drop data is presented in Table 3, which was acquired by computing the variances between the readings at points 1 and 2, corresponding to each pressure inlet of varying diameter pipe sizes. This tabulated information is a comprehensive reference for evaluating pressure drop variations at different pipe sizes, providing a detailed representation of the system's performance under various conditions.

Table 3 *Pressure Drop Distribution Value*

Diameter Pipes	**Pressure Inlet**		
	6 bar	8 bar	10 bar
	Pressure Drop, Pa		
Model 1 = 65 mm	0.0382	0.0307	0.3922
Model 2 = 80 mm	0.0284	0.0272	0.3441
Model 3 = 105 mm	0.0251	0.0262	0.2393

Observations in the table indicate that models with lower pressure drops have smoother flow conditions, potentially contributing less to vibration. Consistent testing shows Model 3 (105 mm diameter) consistently exhibits the lowest pressure drop. Therefore, it is recommended as a potential solution to minimise vibrations. In contrast, Model 1 (65 mm) has the highest pressure drop, especially at 10 bar. Balancing pressure is crucial to avoid excessive pressure drops and control vibration. Overall, Model 3 is the best option for minimising vibration due to its consistently lower pressure drop across different inlet pressures.

4.5 Summary

The analysis focused on studying fluid behaviour, specifically high pressure, velocity, and temperature conditions that can lead to vibration in the piping system. Higher pressure led to increased fluid velocity along the pipeline for all models, irrespective of diameter. Larger inlet diameters Model 3 (105 mm) tended to have higher velocities, potentially reducing vibrations. Stable pressure distribution along the pipeline is crucial for reducing fluid-induced vibrations.

Fig. 23 *Graph of Analysis Pressure Drop at Different Pressure Inlets*

Fig. 23 compares pressure drops for different pipe diameters and inlet pressures. The 65 mm diameter pipe has the highest pressure drop (0.0382 Pa at 6 bar, 0.0307 Pa at 8 bar, and 0.3922 Pa at 10 bar), with the latter being the highest overall. The 80 mm diameter pipe shows a moderate pressure drop (0.0284 Pa at 6 bar, 0.0272 Pa at 8 bar, and 0.3441 Pa at 10 bar). The 105 mm diameter pipe consistently exhibits the lowest pressure drop (0.0251 Pa at 6 bar, 0.0262 Pa at 8 bar, and 0.2393 Pa at 10 bar).

In the analysis, larger diameter pipes (Model 3) align with Bernoulli's principle, showing higher velocities and lower pressure drops. Larger pipes generally offer less resistance, making them favourable for reducing vibration. It can be concluded that pressure drop is proportional to pipeline vibration, emphasising the importance of considering both diameter and pressure inlets for vibration reduction.

5. Conclusion

The study used Ansys software to simulate fluid flow, analyse pressure drop effects on pipeline vibration, and investigate different pipe diameters with three pressure inlets.[13] Achieving its objectives, the analysis indicates that larger diameter pipes, like the 105mm in Model 3, contribute to reduced vibrations due to lower pressure drops. Higher pressure leads to lower velocity flow, and different pressure inlets do not significantly affect pressure distribution along the pipeline. In summary, larger-diameter pipes tend to minimise vibrations by having lower pressure drops, higher velocities, and increased temperatures.

For future research, it is recommended to conduct experiments alongside simulations to validate findings, ensuring a more accurate understanding of real-world conditions. Despite potential higher costs and longer duration, this approach enhances the study's reliability. Combining simulations and experiments provides a comprehensive understanding of the phenomena under investigation. The study's findings can be applied to specific design requirements of piping systems, serving as a valuable guideline for researchers and engineers in developing new designs aimed at reducing pipeline vibration. Recognising the effect of clamp supports on pipe vibration emphasises the importance of adopting comprehensive system design and maintenance practices for optimal performance and longevity.

Acknowledgement

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

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