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Detection of Partial and Extended Blockages: A Case Study of Edible Oil Pipeline System

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Abstract

This work focuses on the development and implementation of a simulation-based approach for the detection of partial and extended blockages within an edible oil pipeline system. Blockages, whether partial or extended, pose a significant operational and safety risks. This study employs computational fluid dynamics (CFD) simulations to model the flow behaviour of edible oil through pipeline under varying conditions. It leverages advanced computational fluid dynamics (CFD) simulations to analyze pressure, velocity, and temperature variations along the pipeline. By simulating scenarios with different blockage characteristics, there is establishment of distinctive patterns indicative of partial and extended obstructions. Through extensive analysis of simulation data, sensing element, and monitoring system, processing signal input and response output, the system can accurately pinpoint the location and severity of blockages, providing crucial insights for timely intervention. The detection system represents a significant advancement in pipeline monitoring technology, offering a proactive and accurate approach to identify blockages and mitigate potential risks and ensure the uninterrupted flow of edible oil, thereby enabling timely intervention and maintenance.

Keywords

Computational Fluid Dynamics (CFD), Simulations, Pipeline, Blockages

1. Introduction

Pipelines play a crucial role in the transmission of fluids such as oil, gas, and water. Pipeline obstructions, however, have had a huge negative impact on the industrial sector, leading to decreased flow rates, higher pressure, and pipeline breakdown. A pipeline blockage is an impediment that prevents the flow of fluids such as oil, gas, or water through the pipeline. Pipeline blockages are caused by the accumulation of debris, the agglomeration of transported fluid, the partial block of a valve, and the formation of materials such as asphaltene, wax, or gas hydrate.

[1] [2] [3] [4] [5] recommended categorizing pipe obstructions into two types: discrete and extended blockages, based on their relative length to the overall pipe length. Discrete blockages are localized constrictions that might be viewed as point discontinuities; prominent examples include partially closed inline valves or orifice plates. Obstructions induced by pipe aging, on the other hand, are more prevalent and can damage substantial sections of the pipe relative to the overall pipe length—these obstructions are referred to as extended blockages [5]. In large-scale process facilities, such as edible oil processed plants, liquid pipeline obstruction is a serious concern. Pipeline damage disrupts the plant's usual operation and raises maintenance costs. Furthermore, they put the operators in an unsafe and hazardous situation. As a result, detecting and localizing blockage is a critical responsibility for maintenance and condition monitoring [6].

The transportation of edible oils is very crucial in the food industry. Edible oils are typically transported in bulk, and one of the most significant challenges of transporting vegetable oil in bulk is quality degradation. Edible oils may undergo chemical changes during transportation, which can affect their quality and nutritional value. The transportation of edible oils requires careful consideration to ensure that the oils remain safe for human consumption and maintain their quality and nutritional benefits.

The transmission of edible oil from production facilities to processing plants and ultimately to consumers is a critical step in the supply chain, and the presence of blockages in the pipelines can lead to significant downtime, product loss, and damage to the pipeline infrastructure. Thus, effective blockage detection systems are crucial for ensuring the safe and efficient transportation of edible oil in the food processing industries.

Blockages, whether partial or extended, lead to serious consequences such as reduced flow rates, increased pressure differentials, product contamination, and even catastrophic failures. Detecting blockages in a timely manner is vital to prevent accidents, minimize downtime, and maintain the integrity of the pipeline infrastructure. There exist various studies and techniques conducted to detect pipeline blockages since its inception. [7] analyzes the pressure distribution along pipeline blockages, which can be partially or fully formed based on the cause and nature of the blockage. [5] proposes a technique for detecting extended blockages in pressurized water pipelines using system frequency. Pressure drop analysis has been utilized to detect blockages based on changes in pressure [8] [9]. Wavelet transform analysis has also been employed for blockage detection using pressure data, allowing for the identification of specific frequency components associated with blockages [10]. Studies on blockage detection in pipeline networks can be broadly classified into inspection-based, acoustic-based, vibration-based, and transient wave blockage-based methodologies [11] [12]. In gas pipelines, hydrate blockages occur, and researchers have developed an apparatus for detecting such blockages.

However, the detection of blockages in pipelines is crucial for maintaining the safe and efficient transportation of fluids. It is important to take urgent precautions and measures to prevent blockages, to detect and address them quickly to minimize their impact on pipeline operations, and to curb their environmental impacts.

This paper proposes a blockage detection method for edible oil pipelines using sensing elements to detect blockages. The use of sensing elements allows for real-time monitoring of the pipeline pressure, enabling early detection of any blockages or obstructions that may occur. The designed method is non-intrusive, ensuring that the integrity of the edible oil is maintained throughout the detection process. The implementation of the method will greatly improve the efficiency and safety of edible oil pipeline operations, reducing the risk of costly pipeline failures and preventing potential damage to the pipeline caused by blockages.

2. Methodology

Design of Pipeline Components Models Using Autodesk Fusion 360

Ball Valves: Ball valves control the flow of the edible oil within the pipeline. They have a spherical ball with a hole through which the oil flows. When the ball is rotated 90 degrees, the hole aligns with the pipe, allowing flow, or closed completely to stop the oil flow.

Elbows: Elbows in a pipeline are curved fittings that change the direction of the pipeline's route. They are typically used to navigate around obstacles or to create bends in the pipeline. Elbows help in altering the pipeline's direction while minimizing flow resistance.

Reservoirs: Reservoirs serve as storage vessels for the edible oil to be transported through the pipeline. They ensure a steady and consistent supply of the edible oil substance to the pipeline. They help in maintaining pressure and flow stability within the pipeline.

Pumps: Pumps are mechanical devices used to enhance the flow of edible oil through the pipeline. They provide the necessary energy to overcome friction, elevation changes, and other resistances within the pipeline. Pumps increase the pressure and velocity of the edible oil, ensuring it reaches its destination. Pumps are essential for maintaining flow rates and pressure levels, especially over long distances.

Pipe: Pipes are the primary conduits for transporting the edible oil within the pipeline system. They connect various components of the pipeline, such as reservoirs, pumps, valves, and elbows, to facilitate the flow of the edible oil from one point to another. The size, material, and layout of pipes are designed to meet the requirements of the pipeline.

Pressure Sensor:

Pipeline Network Representation: The pipeline geometry representing the physical layout of the pipeline network. This includes the lengths, diameters, and orientations of the pipes, as well as the locations of bends, junctions, and other features specific to the system. The geometry reflects the actual pipeline infrastructure to ensure accurate simulation results. This is in line with [13] [14].

Working Principle

The detection method works effectively with the aid of sensors placed on edible oil pipeline for the detection of variations in pipeline contents as shown in **Figure 1**. When Edible Oil flows through the pipeline, the sensors placed on the pipeline detect variations in pressure, temperature and flow rate in the pipeline. **Figure 2** shows a representation of partial blockage in edible oil transmission pipeline while **Figure 3** shows the extended blockage. The changes in any of the variables are easily detected through the effective sensors placed at different location on the pipeline. These variations detected triggered the alarm system to raise concern on the operating condition of the pipeline. The operating condition is transmitted to the processing unit of the computer system which receives signal of the operating scenarios displayed on the monitor. The purpose of this study has restricted the placement of only two sensors at different location for the detection of partial and extended blockages.

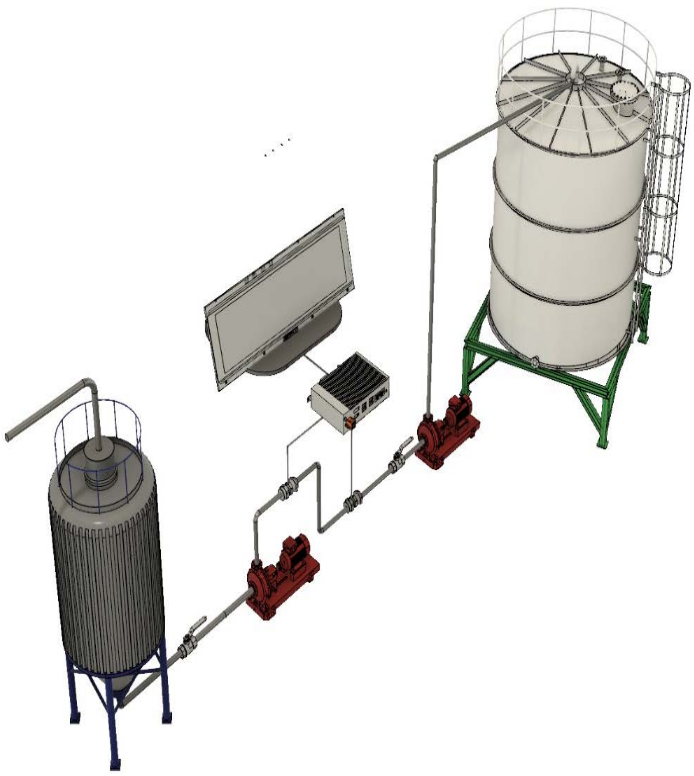

Figure 1. Final design of blockage detection model.

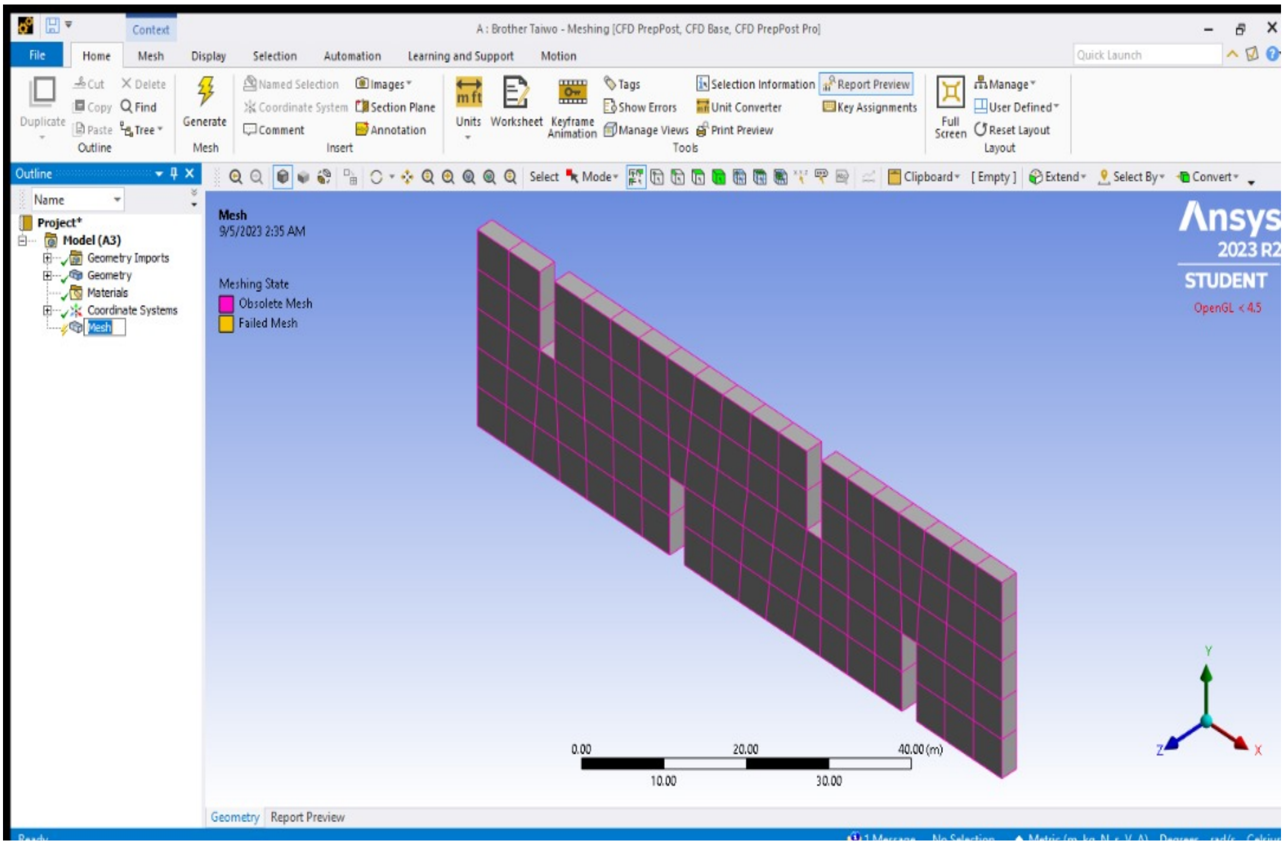

Figure 2. Partial blockage representation in Edible oil transmission pipeline.

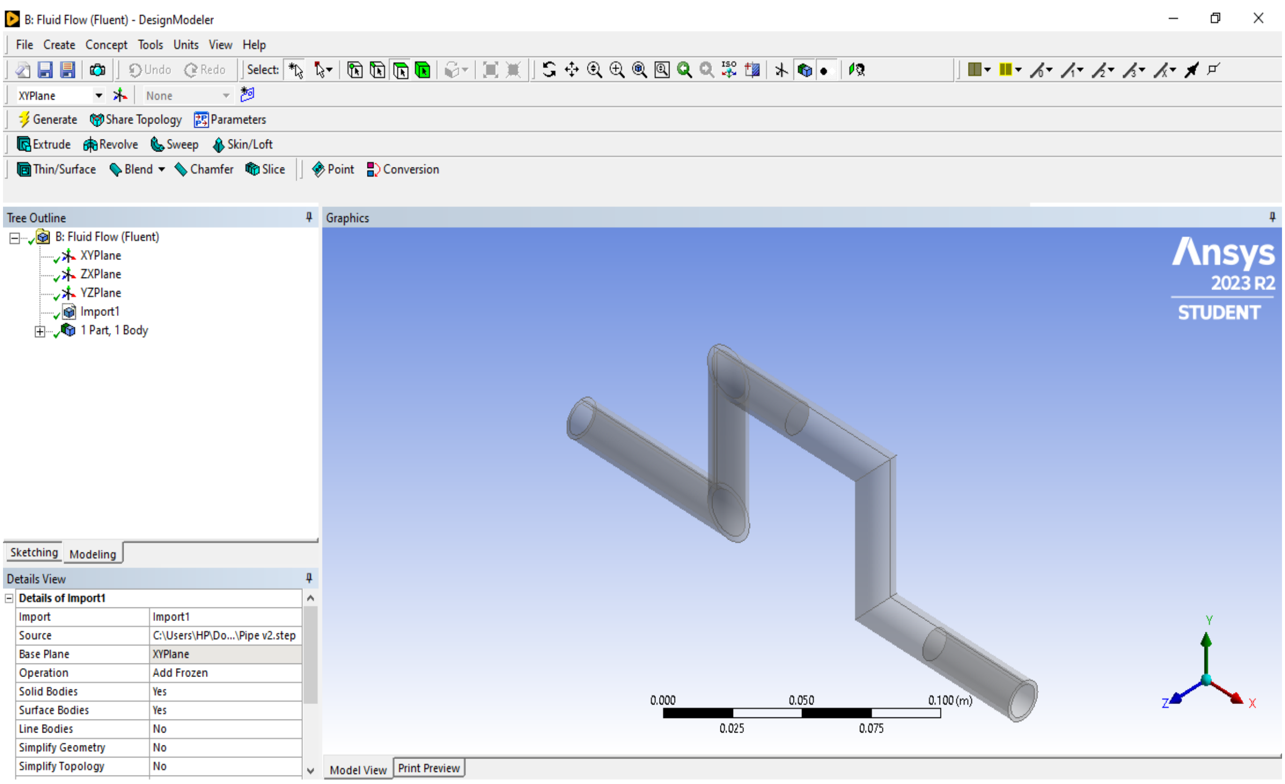

Figure 3. Extended blockage representation in Edible oil transmission pipeline.

The variation of pressure, fluid flow and temperature changes on the edible oil pipeline is monitored effectively and efficiently through the use of sensors placed at different position on the pipeline system. This detection method is achievable with the use of proper and effective sensors with distinctive features to enhance signal-response processing and fastest communication mode of the detection method.

Fluid Flow Modeling

Fluid flow modeling justify accurate modeling of the fluid flow behavior within the pipeline network for understanding the flow dynamics, pressure distributions, and identifying potential blockages. Fluid flow modeling defines the properties of the edible oil flowing through the pipeline system. These properties include density, viscosity, and specific heat capacity. Edible oils typically exhibit non-Newtonian behavior.

Flow Equation: The simulation set-up includes flow equations to describe the fluid flow behavior. In the case of Edible oil, characterize with incompressible flow, Navier-Stokes, Bernoulli's and Fluid Energy equations are applied to simulate the momentum conservation.

Continuity Equation: The continuity equation states that in the case of steady flow, the amount of fluid flowing past one point must be the same as the amount of fluid flowing past another point, or the mass flow rate is constant. Continuity equation is given by:

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2 \tag{1}$$

where: ρ = density

A = cross-sectional area,

v = the flow velocity of the fluid.

The subscripts 1 and 2 indicate two different regions in the same pipe.

Bernoulli's Equation: Bernoulli's equation relates the pressure, speed, and height of any two points (1 and 2) in a steady streamline flowing fluid of density. Bernoulli's equation can be written as follows:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \tag{2}$$

The variables P_1, v_1^2, h_1 refer to the pressure, speed, and height of the fluid at point 1, P_2, v_2^2, h_2 refer to the pressure, speed, and height of the fluid at point 2.

The governing equations for simulating fluid flow among others are the Navier-Stokes equations. This equation provides the fundamental framework for modeling the behavior of the edible oil within the pipeline system.

The Navier-Stokes equation describes the conservation of momentum for fluid flow and account for the effects of viscosity and pressure gradients. In vector form, the Navier-Stokes equations can be expressed as:

$$\rho\left[\frac{\partial \vec{V}}{\partial t} + (\nabla \cdot V)V\right] = -\vec{\nabla}P + \rho\vec{g} + \mu\nabla^2\vec{V} \tag{3}$$

where:

ρ = density of the edible oil,

V = velocity vector,

P = pressure,

μ = dynamic viscosity of the edible oil,

∇^2 = Laplacian operator,

g = acceleration due to gravity.

The Navier Stokes equations are a complex set of equations that can be difficult to solve analytically. However, it is solved numerically using computational fluid dynamics (CFD) software. The process of applying the Navier Stokes equations to the simulation of flow in a pipeline system with blockages is as follows:

The pipeline system is divided into a finite number of control volumes.

The Navier Stokes equations are written for each control volume.

The equations are solved numerically using a CFD software program.

The simulation results are used to identify the blockages and assess their impact on the flow in the pipeline system.

Mass and Energy Conservation: Boundary conditions encompass the preservation of mass and energy within the simulation. The conservation of mass ensures that the total inflow and outflow rates at the boundary match the actual physical conditions. Energy conservation factors such as heat transfer and any energy losses within the system. The energy loss in an edible oil pipeline system is attributed to conduction, convection and radiation of the three modes of heat transfer.

Energy Equation:

$$\rho \frac{\partial T}{\partial t} + \rho\left(u \cdot \nabla\right)T = k\nabla^2 T + \frac{Q}{V} \tag{4}$$

where:

ρ = fluid density,

u = fluid velocity,

T = fluid temperature,

μ = fluid viscosity,

k = thermal conductivity of the fluid,

Q = heat source,

V = volume of the fluid.

3. Results and Discussion

Pressure Variation for Partial Blockage

The behavior of edible oil pressure in a pipeline with a partial obstruction or blockage is influence by several key factors. When an obstruction is present, such as a partial blockage in the pipeline, the following factors are deduced which is also in concordance to [15] [16] [17]:

1) Flow Rate Reduction: The presence of partial blockages reduces the available cross-sectional area for the oil to flow through. This restriction leads to a reduction in the flow rate of the edible oil.

2) Pressure Buildup: Pressure tends to build up upstream of the blockage due to the reduced flow rate and increased resistance caused by the obstructions. This is because the oil is being pushed through the resistance leading to a rise in pressure as it can be observed from the simulation result. Pressure magnitude is at its peak at the upstream indicated in red region as shown in Figure 4 and Figure 5.

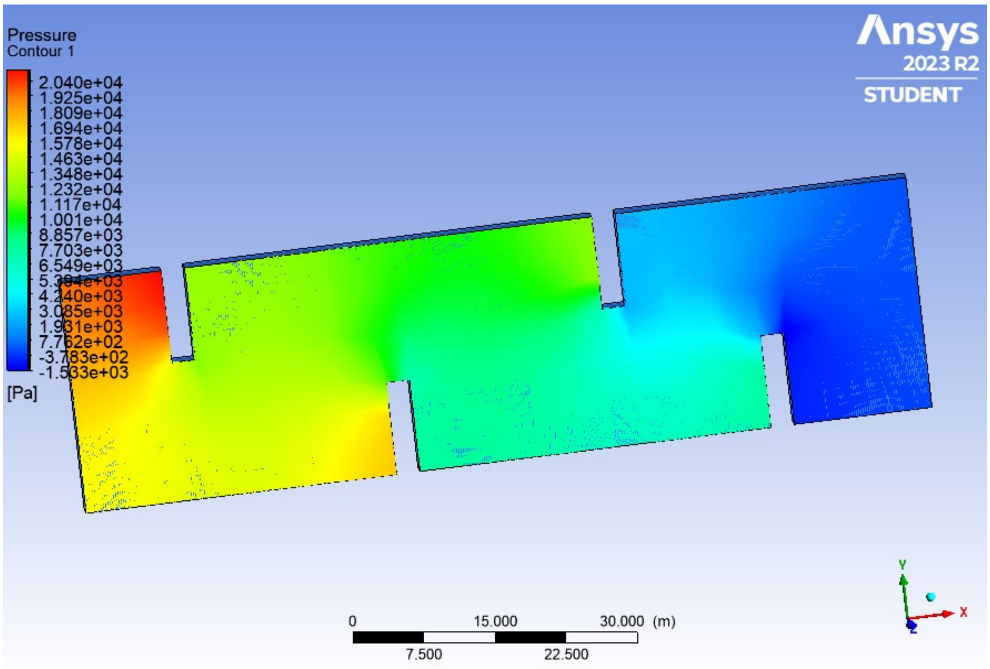

Figure 4. Pressure variation of edible oil with partial blockage.

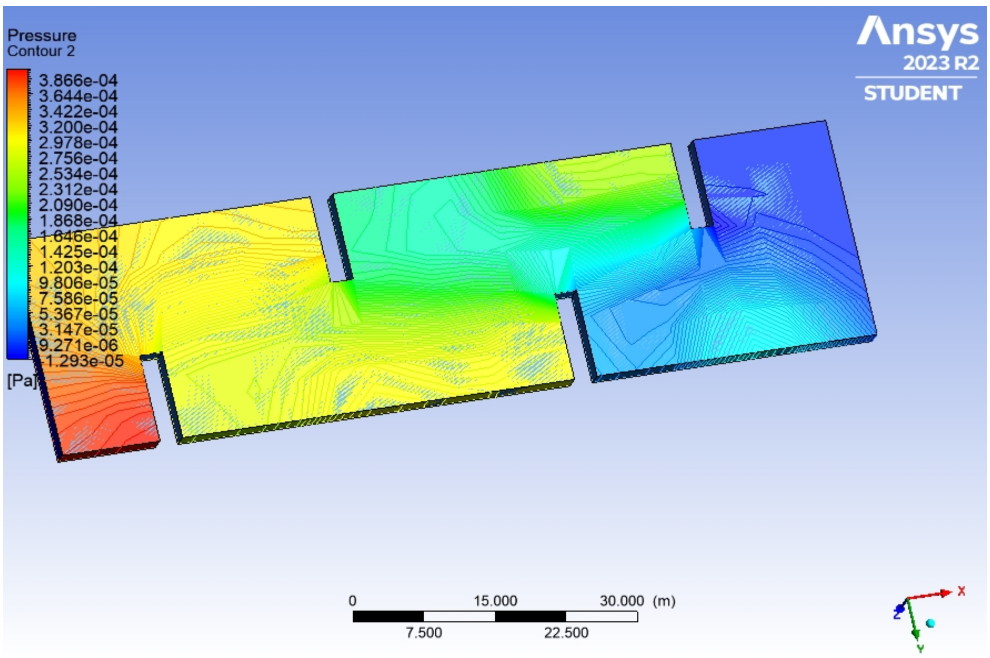

Figure 5. Pressure variation of edible oil with partial blockage.

3) Pressure Drop after the Obstruction: Downstream of the obstruction, where the flow is less restricted, pressure tends to drop. This is because the oil encounters less resistance, allowing it to flow more freely.

4) Pressure Gradient Alteration: Fluids flow from regions of higher pressure to lower pressure. When partial obstructions occur, the pressure gradient within the pipeline is affected. Upstream of the obstruction, where the flow is restricted, pressure tends to increase as the oil encounters resistance. Downstream of the obstruction, where the oil has more space to flow, pressure tends to decrease as illustrated in the simulation result shown in Figure 4 and Figure 5.

Pressure Variation for Extended Blockage

When edible oil encounters an extended blockage in a pipeline, the followings influenced the behavior of pressure and were duly observed:

1) Flow Stagnation: The extended blockage significantly restricts or stops the flow of edible oil in the pipeline. This leads to a stagnation of the fluid upstream of the blockage. As the oil is unable to pass through the blockage, it accumulates and exerts pressure on the obstruction as shown in Figure 6.

2) Pressure Buildup Upstream of the Blockage: As the oil continues to be pushed into the pipeline, but was unable to flow through due to the blockage, pressure increased significantly upstream of the blockage. This was because the oil was still being supplied, but it had nowhere to go as indicated by simulation result in Figure 7.

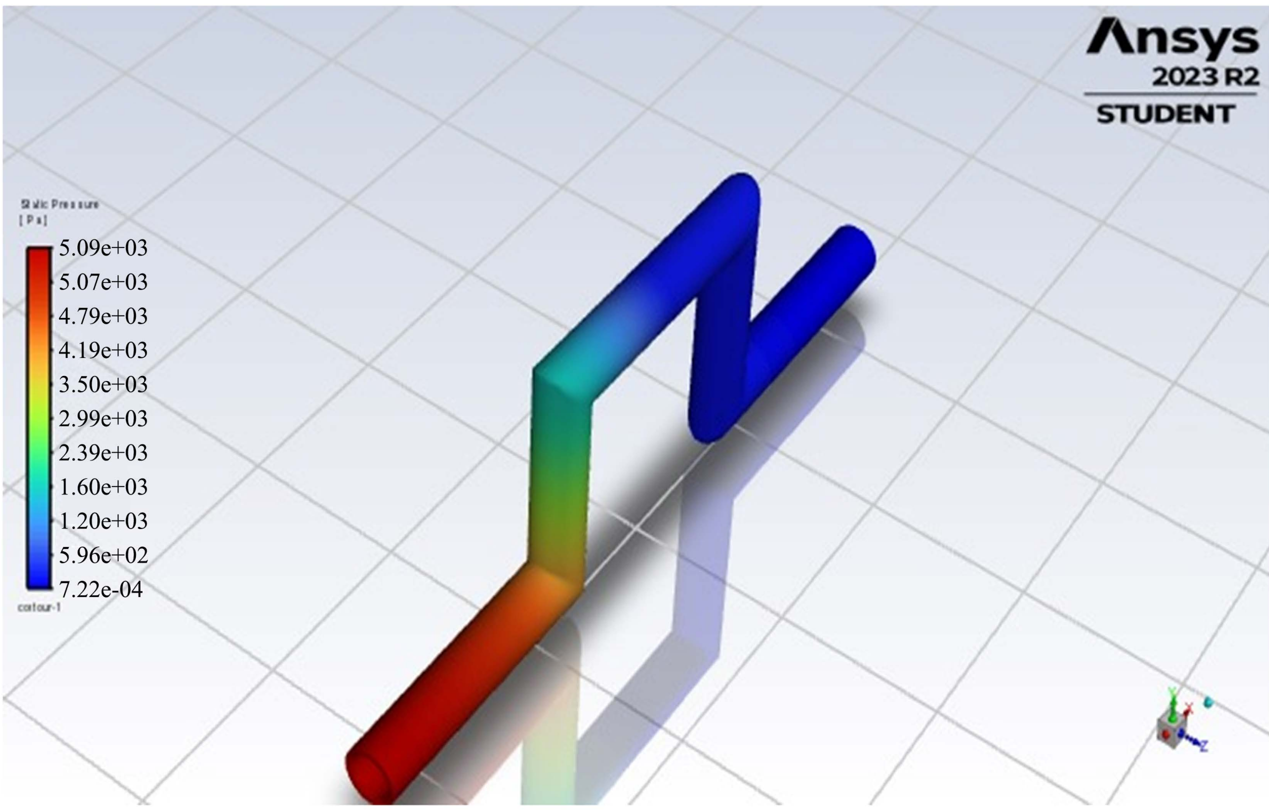

Figure 6. Static pressure magnitude in pipeline of edible oil with extended blockage.

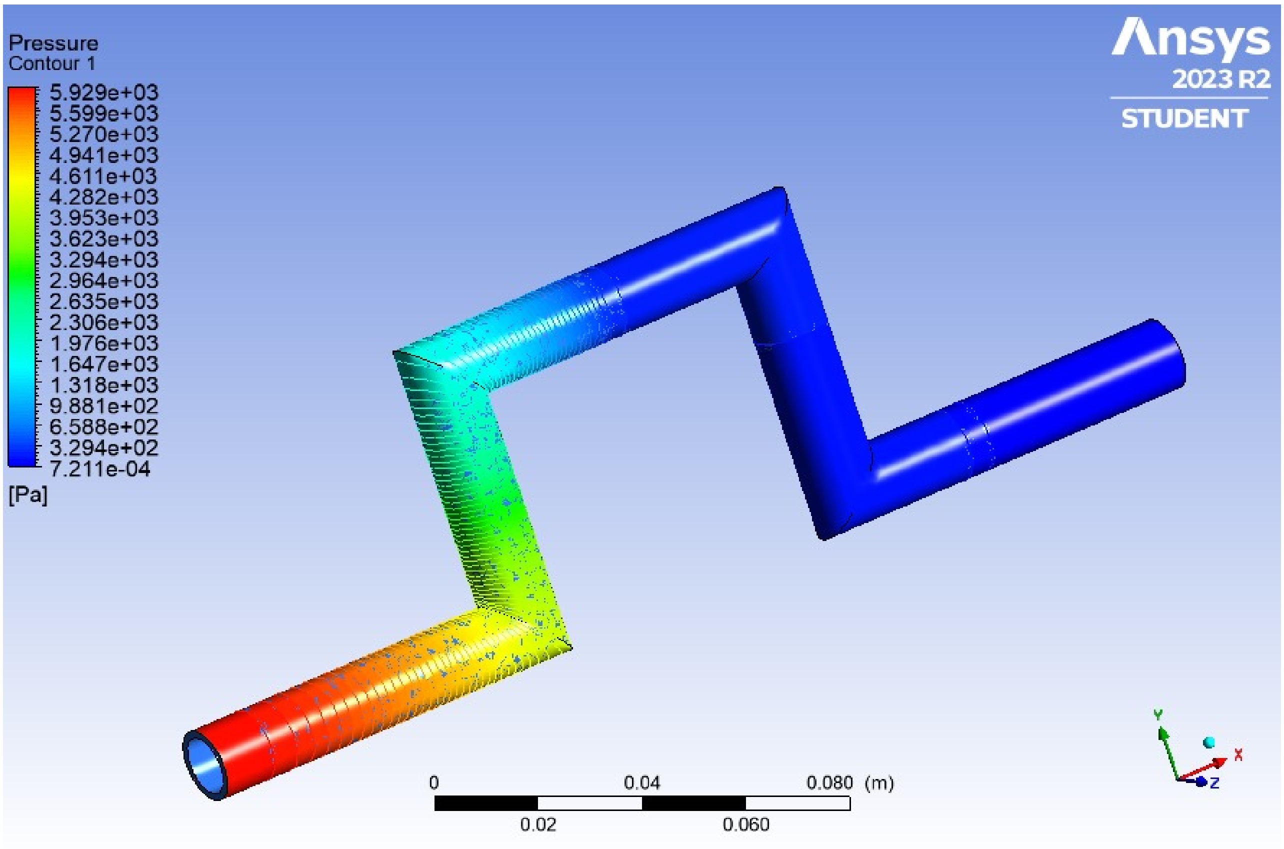

Figure 7. Pressure variation (Contour) in pipeline of edible oil with extended blockage.

3) Pressure Drop Downstream of the Blockage: Downstream of the blockage, where the flow was completely obstructed, pressure tended to drop significantly. This was because there was little to no movement of the fluid, and it remained relatively stagnant.

4) Temperature Changes: Extended blockages lead to temperature variations. If the oil remains stagnant for an extended period, it undergoes temperature changes due to external factors like ambient temperature, heat transfer through the pipeline material, and other environmental conditions such as sun intensity.

Figure 8 is a representation of static pressure distribution in pipeline of edible oil with extended blockage.

Consequences

Risk of Pipeline Failure: The prolonged buildup of pressure upstream of the blockage posed a risk to the integrity of the pipeline. If the pressure exceeds the structural limits of the pipeline, it may result in a rupture or leak.

Potential Backflow or Reverse Flow: If the pressure buildup upstream of the blockage is extremely high, it may lead to backflow or reverse flow when pressure differential is strong enough to force the oil to flow back in the opposite direction.

The pressure coefficient of edible oil pressure along an extended blockage pipeline quantifies pressure variations caused by extended blockage. It is a measure of the pressure drop across the blockage to the pressure in the pipeline upstream of the blockage. The pressure coefficient provides insights into the pressure variations along the pipeline. It increases as the length of the blockage, viscosity and roughness of pipeline wall increases and as the flow rate of the oil decreases as illustrated in **Figure 9**. **Figure 10** shows histogram of static pressure of edible oil with extended blockage.

Velocity Variation of Partial Blockage

When edible oil encounters a partial obstruction or blockage in a pipeline, several factors influence its velocity:

Flow Constriction: As the edible oil approached the partial obstruction, the available cross-sectional area for flow was reduced. This constriction caused an increase in the velocity of the oil as it tries to maintain a constant volumetric flow rate (**Figure 11**).

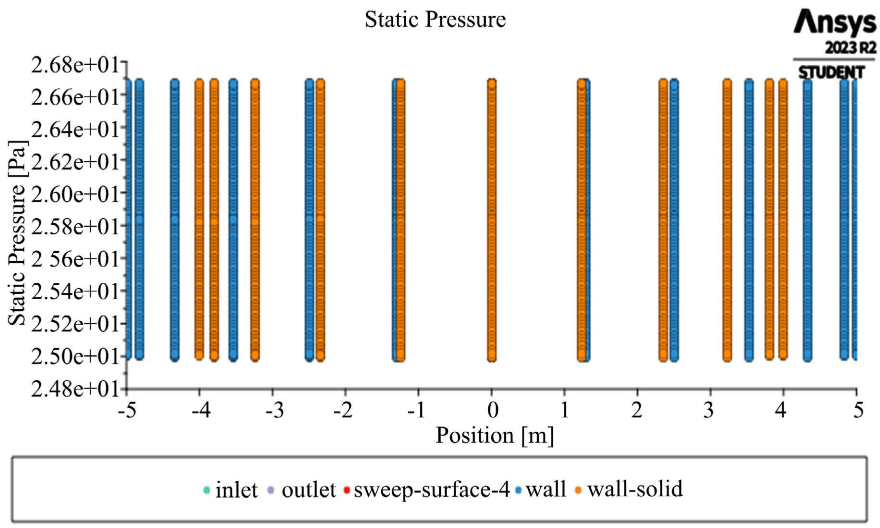

Figure 8. Static pressure illustration in pipeline of edible oil with extended blockage.

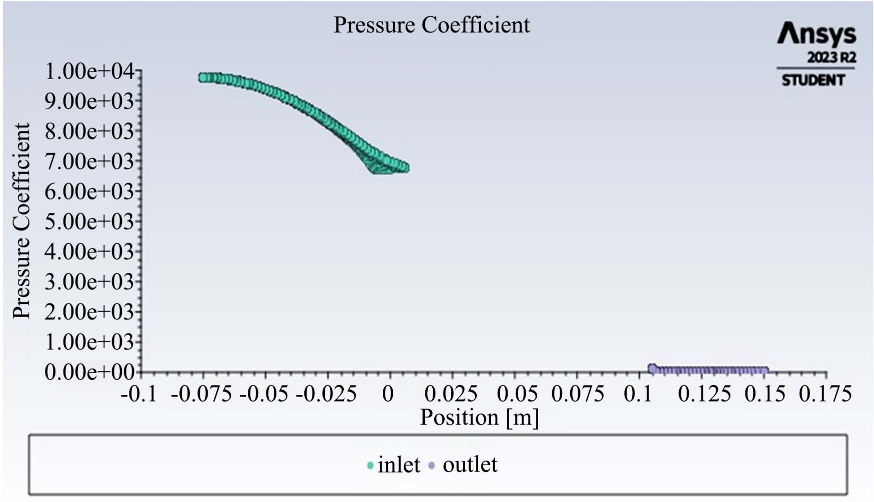

Figure 9. Pressure coefficient in pipeline of edible oil with extended blockage.

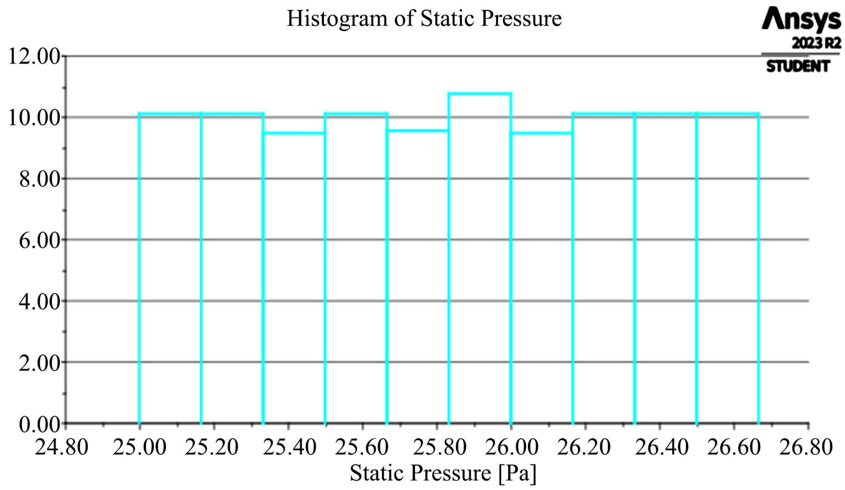

Figure 10. Histogram of static pressure of edible oil with extended blockage.

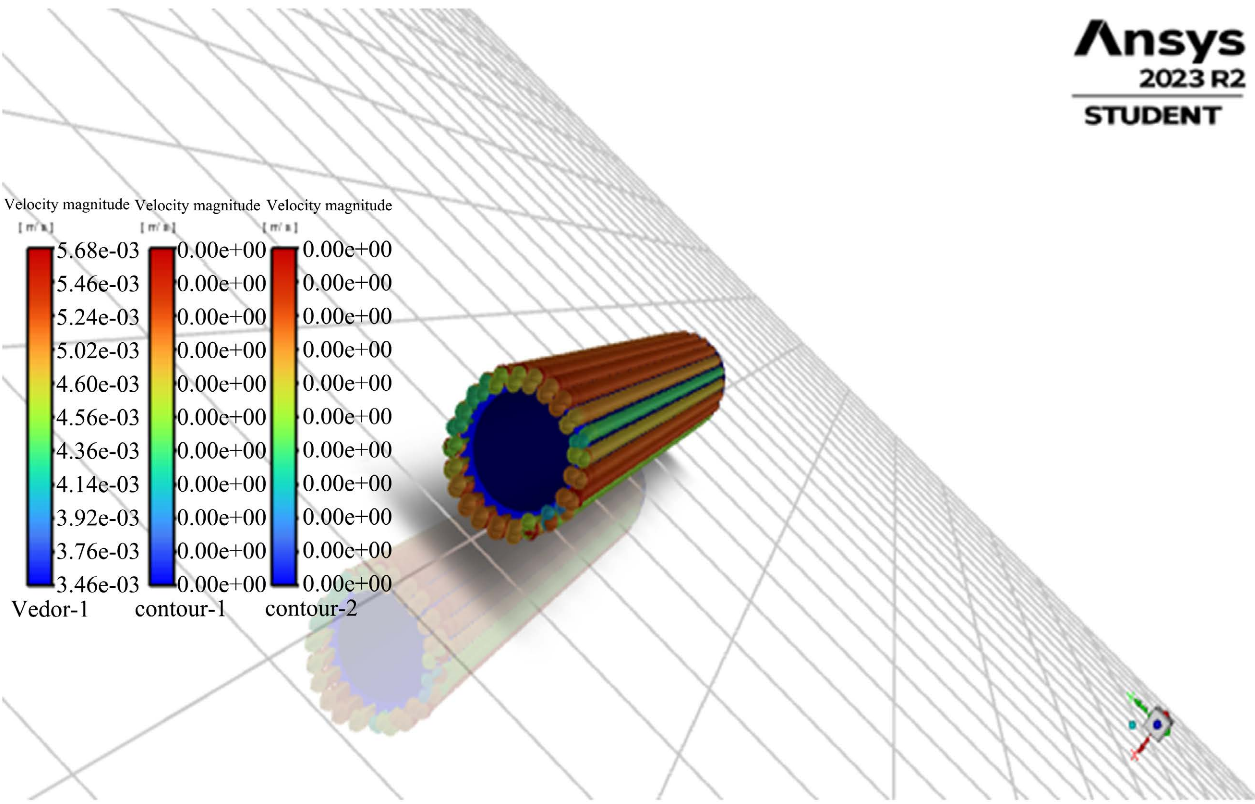

Figure 11. Velocity flow of edible oil in partial blockage.

Bernoulli's Principle: The fluid velocity increases as the cross-sectional area decreases according to Bernoulli's principle, assuming no energy losses. The oil speeds up as it passes through the constricted area.

Pressure Gradient: The pressure gradient within the pipeline was altered due to the presence of the obstruction. Pressure tends to increase upstream of the obstruction where the flow was restricted (**Figure 12**). The increased pressure, along with the constriction, contributed to the higher velocity.

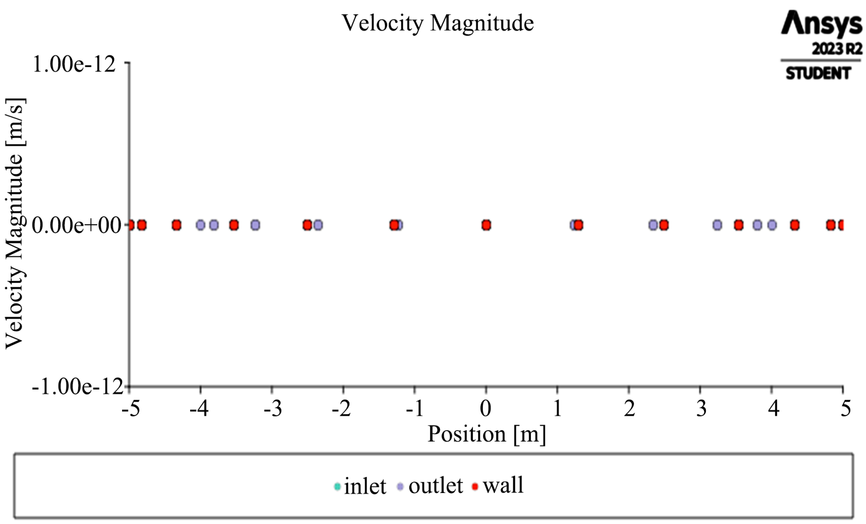

Figure 12. Velocity magnitude of edible oil in partial blockage.

Velocity Profile Changes: The velocity profile of the oil changed as it encounters the blockage. The velocity near the obstruction where the flow was most restricted was the highest. As the oil moves further downstream, away from the obstruction, the velocity decrease gradually (**Figure 13**).

Velocity Variation of Extended Blockage

When edible oil encounters an extended blockage in a pipeline, the behavior of its velocity undergoes several notable changes:

Velocity Reduction: The most significant and immediate effect of an extended obstruction in a pipeline is a substantial reduction in fluid velocity. As the oil flows towards the obstruction, its ability to move forward was impeded, leading to a decrease in its velocity.

Velocity Gradients: The velocity was effectively zero near the obstruction's surface, where it comes into direct contact with the blockage as shown in **Figure 14**.

Flow Separation and Recirculation: There were regions of flow separation and recirculation behind and around the obstruction where the velocity became negative, signifying the reversal of flow direction.

Pressure Distribution: The obstruction caused changes in pressure distribution within the pipeline. Upstream of the blockage, there were pressure buildup as the oil accumulates and pushed against the extended obstruction. Downstream of the blockage, pressure was a total decrease of flow rate due to the reduced flow.

Potential for Turbulence: When the oil encounters an extended obstruction, it leads to turbulence in the flow. This turbulence disrupted the velocity profile and potentially resulted in increased energy losses and wear on the pipeline.

Energy Dissipation: The energy of the flowing oil was dissipated as it navigates around and through the extended obstruction. This energy loss resulted in reduced velocity and potential for additional pressure changes within the pipeline.

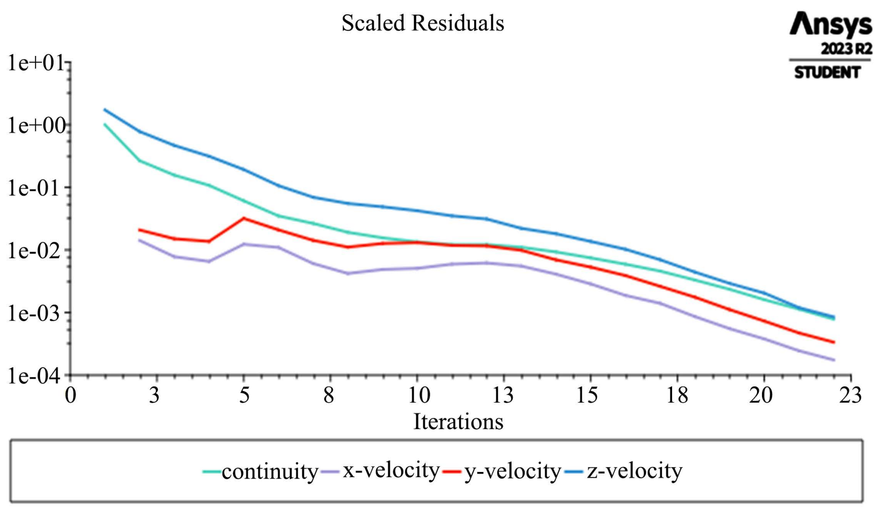

Figure 13. Flow rate continuity results through a pipeline with partial blockage.

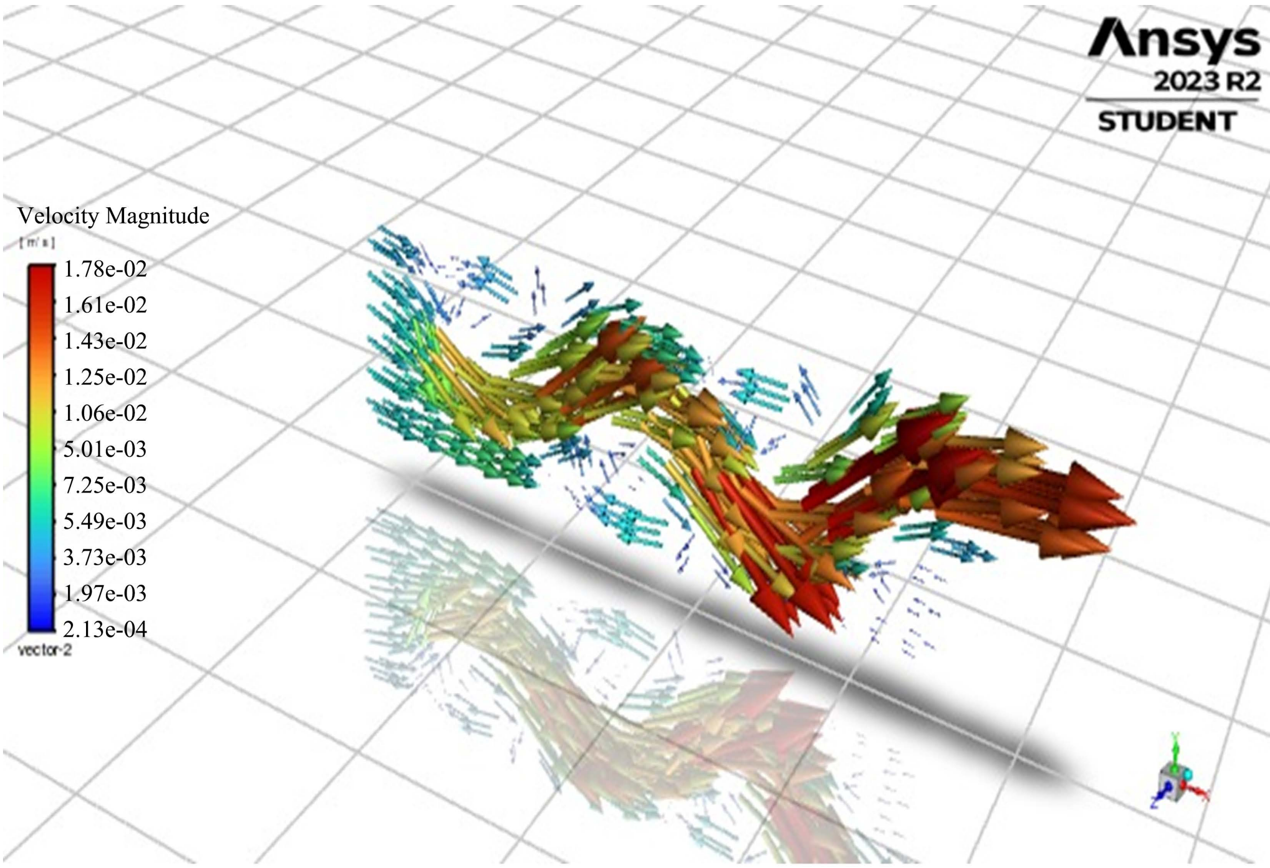

Figure 14. Velocity profile with magnitude of edible oil with extended blockage.

The velocity magnitudes of edible oil along an extended blockage pipeline signify the speed or rate at which the oil is flowing through the pipeline. It provides how fast the oil was moving at different points along the pipeline in the presence of the extended blockage as shown in Figure 14. Velocity profile with magnitude of edible oil with extended blockage is depicted in Figure 15.

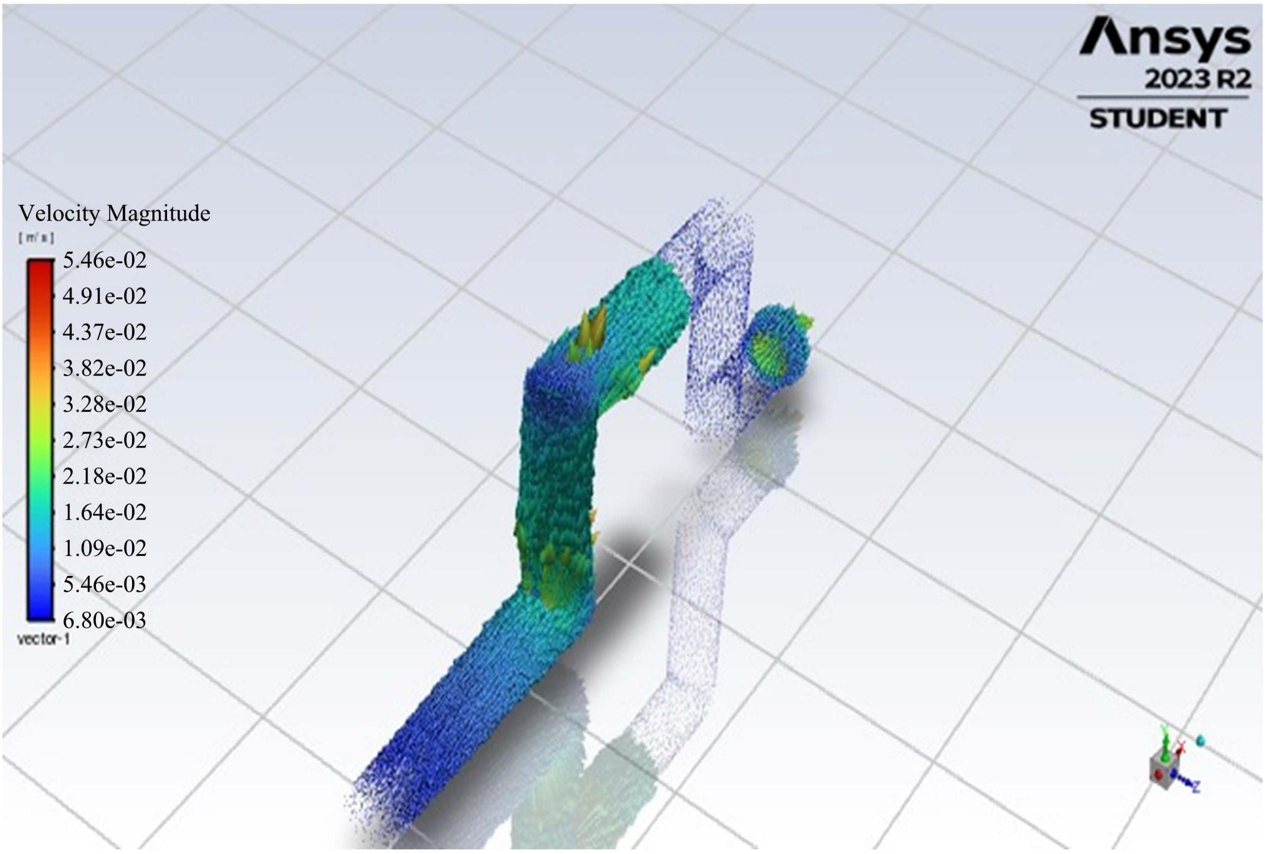

Figure 15. Velocity profile with magnitude of edible oil with extended blockage.

The Velocity Graph

The flow rate velocity graph of edible oil along an extended blockage pipeline provides a visual representation of how the flow rate varies along the length of the pipeline affected by the blockage.

The graph signifies the following deductions:

Flow Rate Changes: The graph illustrated how the flow rate of edible oil changes along the pipeline. It shows areas where flow was restricted due to the extended blockage resulted in a reduction in flow rate as shown in **Figure 16**.

Location of Blockage: The graph identified the location of the extended blockage within the pipeline. The point where the flow rate starts to decrease indicates the approximate position of the obstruction as shown in **Figure 16**.

Extent of Flow Reduction: The magnitude of the decrease in flow rate was directly related to the severity and length of the extended blockage. A steep drop in the graph indicated a more significant obstruction as shown in **Figure 16**.

The Velocity Histogram

The velocity histogram of the edible oil along an extended blockage pipeline provided a graphical representation of the distribution of flow velocities at different points within the pipeline affected by the blockage. Each bar in the histogram represents a range of velocities, and the height of each bar indicates the frequency or number of occurrences of those velocities within their ranges.

Among others, the velocity histogram signifies:

Velocity Distribution: The histogram shows how velocities are distributed within the pipeline. It provides information about the range of velocities and how frequently each range occurs as shown in Figure 17.

Velocity Magnitude Range: The x-axis of the histogram represents different velocity ranges, while the y-axis represents the frequency or count of occurrences as shown in Figure 17. This helps in understanding the variation in velocity magnitudes at different points along the pipeline.

Peak Velocities: The tallest bar in the histogram represents the most common or prevalent velocities as shown in Figure 17. These are the velocities that occur most frequently within the affected section of the pipeline.

Variability in Flow: The spread of bars across different velocity ranges indicated how much the flow velocities vary within the section of the pipeline affected by the blockage. A wider spread suggested a greater range of velocities.

Effect of Blockage: The histogram revealed how the presence of the extended blockage impacts the velocity distribution.

Temperature Variations in Edible oil Pipeline

Extended blockages lead to temperature variations. When the oil remains stagnant for an extended period, it undergo temperature changes due to external factors such as ambient temperature, energy dissipation or heat transfer through the pipeline material, and other environmental conditions. Near the blockage, the flow became stagnated and become more turbulent. This resulted in uneven distribution of temperature within the oil pipeline due to temperature difference in the pipeline material content. The phenomenon indicated the existence of blockage in the Edible oil pipeline as illustrated in Figure 18.

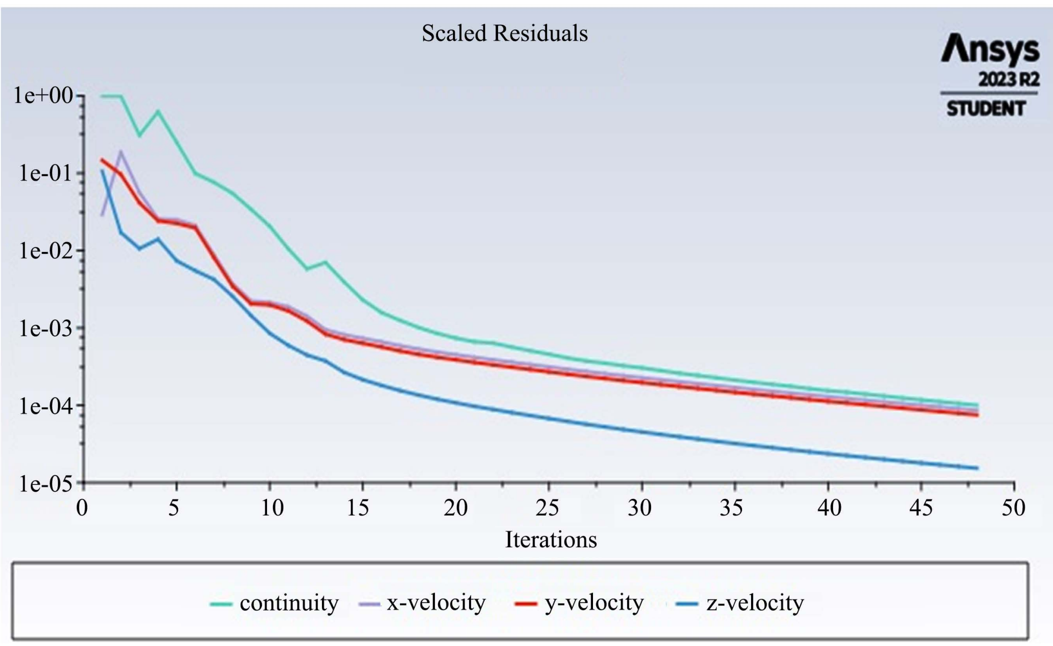

Figure 16. Flow rate continuity of edible oil through a pipeline with extended blockage.

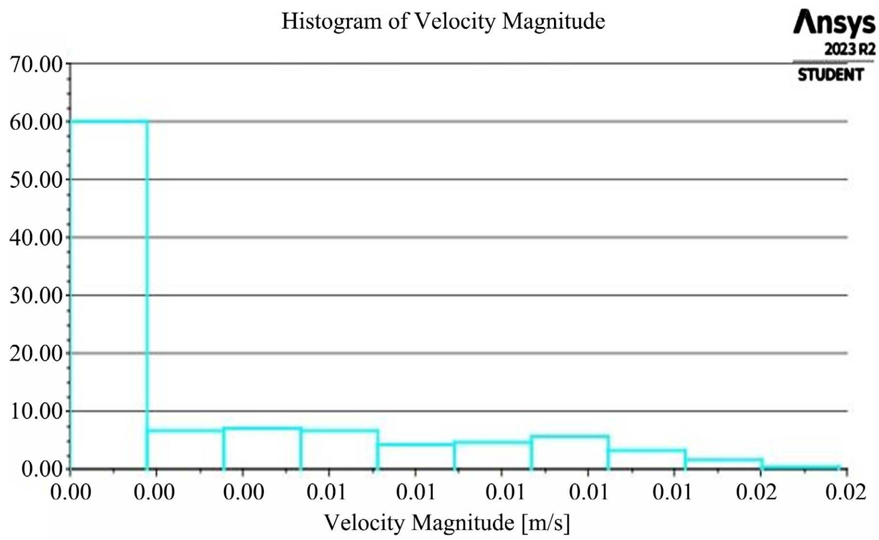

Figure 17. Histogram profile of edible oil with extended blockage.

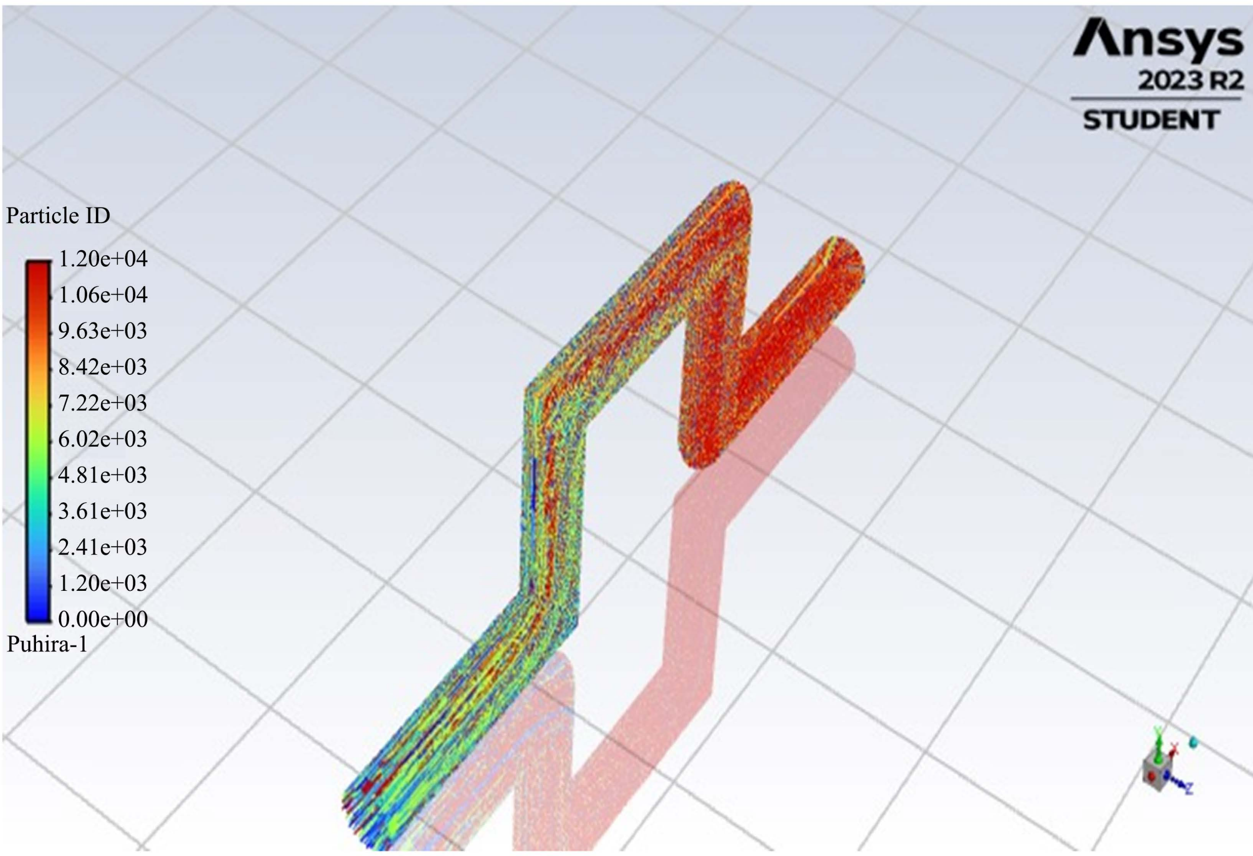

Figure 18. Temperature variation in edible oil pipeline with obstruction.

4. Conclusions

The reduced velocity, turbulence, and energy losses associated with the extended blockage negatively impact the overall efficiency of the pipeline system, resulted in decreased throughput and increased operational costs.

The presence of the partial blockage lead to flow restrictions, resulted in increased pressure upstream and reduced velocity downstream. This elevated the risk of overpressure related issues and impacted the overall efficiency of oil transport. Additionally, the pressure coefficient and velocity magnitude distributions offered valuable insights into the behavior of the oil within the pipeline.

In the extended blockage, flow stagnation occurred upstream of the blockage which led to a substantial increase in pressure. This increased pressure gradient posed a significant risk to the pipeline's structural integrity. Moreover, the velocity of the oil was severely impeded which caused flow reductions and potential turbulence effects.

Temperature variations were influenced by factors such as heat transfer, insulation and flow rate changes within the oil. These variations play a crucial role in determining the overall stability and quality of the transported oil.

The adoption of blockage monitoring system through sensing element incorporated with signal response system and strategies such as regular maintenance, insulation enhancements, and flow control measures are effective measures to mitigate potential risks associated with partial or extended blockages.

Overall, understanding the complexities that interplay between pressure, velocity, and temperature variations are paramount in ensuring the continued safe and efficient operation of edible oil pipelines. Engineers and operators can ensure that pipelines are designed to safely and efficiently transport edible oils.

Simulation based detection of partial and extended blockage in Edible oil pipeline system has shown high efficacy technique for the detection of partial and extended blockages in edible oil pipeline system through effective signal and response monitoring system. Therefore, this technique is highly recommended for edible oil industries to ultimately monitor pipeline system, safeguarding pipeline contents, the environment and the integrity of the pipeline infrastructures. Nevertheless, it's important to note that this project is strictly simulation-based detection technique adopted for the detection of partial and extended blockage in edible oil pipeline infrastructure. It does not investigate pipeline leakages.

Consequently, it is advisable to carry out substantial experimental evaluation when developing blockage detection system in Edible oil pipeline infrastructure.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Tjuatja, V., Keramat, A., Pan, B., Duan, H.F., Brunone, B. and Meniconi, S. (2023) Transient Flow Modeling in Viscoelastic Pipes: A Comprehensive Review of Literature and Analysis. *Physics of Fluids*, **35**, Article 081302.
https://doi.org/10.1063/5.0155708

[2] Faris, N., Zayed, T., Aghdam, E., Fares, A. and Alshami, A. (2024) Real-Time Sanitary Sewer Blockage Detection System Using IoT. *Measurement*, **226**, Article 114146.

https://doi.org/10.1016/j.measurement.2024.114146

[3] Aiyejina, A., Prasad, D., Pilgrim, A. and Sastry, M.K.S. (2011) International Journal of Multiphase Flow Wax Formation in Oil Pipelines : A Critical Review. *International Journal of Multiphase Flow*, **37**, 671-694. https://doi.org/10.1016/j.ijmultiphaseflow.2011.02.007

[4] Banki, R., Hoteit, H. and Firoozabadi, A. (2008) Mathematical Formulation and Numerical Modeling of Wax Deposition in Pipelines from Enthalpy. *Porosity Approach and Irreversible Thermodynamics*, **51**, 3387-3398. https://doi.org/10.1016/j.ijheatmasstransfer.2007.11.012

[5] Duan, H.F. and Asce, M. (2020) Development of a TFR-Based Method for the Simultaneous Detection of Leakage and Partial Blockage in Water Supply Pipelines. *Journal of Hydraulic Engineering*, **146**, 1-10. https://doi.org/10.1061/(ASCE)HY.1943-7900.0001764

[6] Fahimipirehgalin, M., Trunzer, E. and Odenweller, M. (2020) Automatic Visual Leakage Detection and Localization from Pipelines in Chemical Process Plants Using Machine Vision Techniques. *Engineering*, **7**, 758-776. https://doi.org/10.1016/j.eng.2020.08.026

[7] Chu, J., Liu, Y., Song, Y., Yang, L., Li, X., Yan, K. and Zhao, J. (2020) Experimental Platform for Blockage Detection and Investigation Using Propagation of Pressure Pulse Waves in a Pipeline. *Measurement*, **160**, Article 107877. https://doi.org/10.1016/j.measurement.2020.107877

[8] Huang, R., Tao, Z., Lin, Y., Wei, J., Zhou, W. and He, Y. (2024) Current Situation of Drainage Pipe Network in China and Its Detection Technology: A Brief Review. *Polish Journal of Environmental Studies*, **33**, 19-29. https://doi.org/10.15244/pjoes/166899

[9] Brunone, B., Maietta, F., Capponi, C., Duan, H.F. and Meniconi, S. (2023) Detection of Partial Blockages in Pressurized Pipes by Transient Tests: A Review of the Physical Experiments. *Fluids*, **8**, 19. https://doi.org/10.3390/fluids8010019

[10] Biasi, A., Evnin, O. and Malomed, B.A. (2023) Obstruction to Ergodicity in Nonlinear Schrödinger Equations with Resonant Potentials. *Physical Review E*, **108**, Article 034204. https://doi.org/10.1103/PhysRevE.108.034204

[11] Datta, S. and Sarkar, S. (2016) A Review on Different Pipeline Fault Detection Methods. *Journal of Loss Prevention in the Process Industries*, **41**, 97-106. https://doi.org/10.1016/j.jlp.2016.03.010

[12] Gurav, S., Kumar, P., Ramshankar, G., Mohapatra, P.K. and Srinivasan, B. (2020) Machine Learning Approach for Blockage Detection and Localization using Pressure Transients. 2020 *IEEE International Conference on Computing*, *Power and Communication Technologies* (*GUCON*), Greater Noida, 2-4 October 2020, 189-193. https://doi.org/10.1109/GUCON48875.2020.9231242

[13] Li, W., Wang, Y., Yang, H., Ye, Z., Li, P., Liu, Y.A. and Wang, L. (2023) Development of a Mixed Reality Method for Underground Pipelines in Digital Mechanics Experiments. *Tunnelling and Underground Space Technology*, **132**, Article 104833. https://doi.org/10.1016/j.tust.2022.104833

[14] Zhu, H., Xiao, F., Zhou, Y., Lai, W.W.L. and Zhang, Q. (2023) A Framework for GPR-Based Water Leakage Detection by Integrating Hydromechanical Modelling into Electromagnetic Modelling. *Near Surface Geophysics*, **22**, 175-187. https://doi.org/10.1002/nsg.12281

[15] Rasouli, S., Ghomeshi, M., Shafai Bejestan, M., Rahmanshahi, M. and Keramat, A. (2024) Experimental Analysis of Elastic Blockage in Viscoelastic Pipeline Systems.

Journal of Hydraulic Structures, **9**, 35-52.

[16] Yang, Z., Huang, B. and Zhu, D.Z. (2024) Flow in Sewers with Bottom Obstacles. *Journal of Hydraulic Engineering*, **150**, Article 04024011. https://doi.org/10.1061/JHEND8.HYENG-13746

[17] Pratap, V., Rajendran, S., Agrawal, R.K., Indimath, S.S., Reddy, B.P. and Balamurugan, S. (2021) Blockage Detection in Gas Pipelines to Prevent Failure of Transmission Line. *Journal of Pipeline Systems Engineering and Practice*, **12**, Article 04021031. https://doi.org/10.1061/(ASCE)PS.1949-1204.0000568