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Computational Modelling to Predict the Pressure Loss Coefficient of Pipe Fitting at KKTDI

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Abstract: Water pipeline system has an important role in delivering water throughout the whole community using piping system. Any leakages or damages in any part of the water pipeline system will not only cause problem in delivering water but also could cause cost damage and affect the daily life of the community. The main objective of this research is to investigate the flow characteristics in the pipeline at Kolej Kediaman Tun Dr. Ismail (KKTDI) and to investigate the pressure drop due effect due to leakage along the pipeline system. The second objective is to assess the CFD approaches to calculate the pressure loss coefficients. Computational Fluid Modelling (CFD) simulations used to predict the flow variables such as velocity, pressure by solving the mathematical equations describing the relationship between the flow variables. This program is used in this research to determine the pressure loss coefficients using simulations. The pressure loss coefficient of the piping system is around 33.8 to 50.4 while the average pressure loss coefficient of the plotted graph is 13.1. In conclusion, the pipeline system of KKTDI residential college is studied carefully to determine the pressure loss coefficient and the objective is achieved.

Keywords: Pipeline system, pressure loss coefficient, CFD, leakage

1. Introduction

Water pipeline systems can tremble due to many sources due to the flow of internal fluids, pumps, and other auxiliary equipment in the system. The vibrational force induced in the pipe structure is partly emitted as noise and partly transmitted through the insulator that attaches the low noise pipe system to the support structure. The transmission of this vibrational force to the structure is investigated in this contribution using the method of force flow and structural mobility. The approach developed here is not limited to isolated straight pipe sections but can be applied to a series of subsections connected by components that can be expressed in terms of structural mobility. The results obtained will help in the design of quiet piping systems. The effects of various structural parameters of pipes, insulators and structures can be clearly demonstrated [1]. Controlling water loss by studying pipe dripping is a great effort to utilize the water resources of Universiti Tun Hussein Onn Malaysia (UTHM). The high cost of water charges was paid by the university authorities when there is leakage of water pipeline. The results show that the number of losses of water can exceed 20% of the input, as reported by Kolej Kediaman Tun Dr. Ismail (KKTDI). From the smallest leaks in storage tanks or pipe connections and fittings and burst leaks as a result of pipe holes and damage, various factors affecting water loss have been identified. The flow characteristics of water pipeline system at KKTDI residential college is investigated and the pressure loss coefficients of piping system is evaluated using CFD approaches. Research on predicting the pressure loss coefficient could help solve the pipe leakage problem that faced by KKTDI college. Thus, this research study gives closure to future research and helps to improve in solving pipe leakage problems. Besides, the computational fluid dynamics (CFD) also

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*Corresponding author: adrian@uthm.edu.my provide a more detail about the pressure drop in the college pipeline system which help researchers to analyze the situation better and decide what is the best action to be taken to improve the situation. By using this software, more time and cost can be saved compared to experimental research.

2. Literature Review

2.1 Pipeline, Valves, Fittings

3.

2.1.1 Pipeline

Water pipeline is any pipe or tube created to carry consuming water to humans. If the water is dealt with earlier than distribution or on the factor of use (POU) relies upon at the context. In properly deliberate and designed water supplying networks, water is typically dealt with earlier than distribution and from time to time additionally chlorinated, for you to save you recontamination at the manner to the give up user. The styles of water pipes consist of huge diameter foremost pipes, which deliver whole towns, smaller department strains that deliver a avenue or organization of buildings, or small diameter pipes positioned inside man or woman buildings. Water pipes can variety in length from massive mains of as much as 3.65 m in diameter to small 12.7 mm pipes used to feed man or woman stores inside a building. Materials normally used to assemble water pipes consist of polyvinyl chloride (PVC), solid iron, copper, metal and in older structures concrete or fired clay. Joining man or woman water pipe lengths to make up prolonged runs is viable with flange, nipple, compression, or soldered joints.

2.1.2 Fittings

Pipe fittings are constituents used to connect pipe sections to other fluid control products such as valves and pumps to create pipelines. The general meaning of the term fitting is associated with that used for metal and plastic pipes that carry liquids. There are also pipes for railings and other types of pipe fittings that can be used to connect other architectural elements that do not require tight connections. Depending on the material of the pipe, the most common mechanism is that pipe fittings can be welded or threaded, mechanically connected, or chemically bonded.

2.2.3 Valves

Valves are mechanical components that manage the circulation and pressure within the water pipeline system. They are fundamental parts of water distribution systems that transport liquids, gases, vapors, or slurries.

2.2 Pressure drop

Pressure drop can be defined as a decrease in mixing pressure from one point to another. Occurs when there are obstacles in the pipeline. Large pressure drops affect system performance and increase energy consumption. High operating pressure drops mean higher energy consumption [5]. As the liquid flows through the pipe, there is a pressure drop because of the resistance of the flow. Also, the pressure may increase or decrease due to changes in height between the start and end points of the pipe. A factor that has always affected the pressure drop across the pipeline is the friction between the liquid and the pipe wall. Second, friction occurs between the adjacent liquid layers themselves. Third, the altitude of the pipeline system can be a major factor in the pressure drop of the fluid flow through the pipeline. Fourth, friction loss is the most common factor in pressure drop in piping systems. Friction loss occurs when fluid flows through pipe fittings, bends, valves, and components. The fifth factor is the increase in pressure due to the level of liquid added by the pump.

2.2.1 Pressure drop due to pipe fitting

There are many pipe fittings together with Elbow, Tee, Reducer, Union, Coupling, Cross, Cap, Swage Nipple, Plug, Bush, Expansion Joint, Adapters, and valve. Contractions and growth are crucial component any piping machine which additionally provide impact at the stress drop. These becoming are generally used to manipulate the go with the drift price and extrude the course of go with the drift, which reasons power loss further to that due to the fluid go with the drift thru instantly pipes. Flow of fluids in a piping machine is observed via way of means of each pore and skin and shape friction, ensuing in stress or power loss. This additionally end result in shape friction that is due to pipe fittings because the fluid is subjected to surprising pace and course changes. The impact becoming losses usually referred as minor losses and generally being forget about at some stage in evaluation of piping machine. When the piping is constructed up in part open valve, the impact and head loss thru the valve ought to be covered because the valve head loss can also additionally flip to be significant. The fluid head loss through the fitting can be calculated by this equation:

$$h = Kv^2/2g \tag{1}$$

Where the h is the pressure loss in terms of fluid head. K is defined as manufacturer published K factor for the fitting. v stands for velocity of fluid and g is gravity acceleration. There were various K factors in fitting such as gradual enlargement, gradual contractions, sudden enlargement, sudden contractions, rounded entrances, and long pipe bends [4].

2.2.2 Pressure loss due to elevation

Different engineers come up with different designs for the piping system, which means that there is bound to be some sort of design error that causes issues for, example, pressure loss because of elevation. When the pipe's beginning elevation is less than its ending elevation, the flow is said to be ascending. As the pipe begins to ascend, frictional and other losses may occur because of the pressure drop that results from the change in elevation. As an alternative, frictional and other losses may be greater at the end of the elevation if the flow in the failing pipe begins at a higher height than it does at the end of the elevation.

2.2.2.1 Vertical Liquid Flow in Piping Systems

In a look at the phase of 1-in. schedule 40 pipes, isothermal conditions were used to study the flow of air and liquid up and down at the same time with the drift. Pressure drops had to be measured by connecting a mercury manometer to two pressure faucets 20 feet apart on the stage. Liquid became trapped among brief shutoff valves activated through solenoid valves. The liquid became tired from the phase to offer the holdup records. Six drinks had been used to decide the impact of density, viscosity, and floor tension. The experimental holdup, and -segment strain drop records had been now no longer in settlement with Lockhart-Martinelli sort of correlation for vertical go with the drift. A statistical correlation for holdup evolved to encompass fluid bodily properties, overall mass velocity, and the air-liquid ratio coming into the pipe. Similarly, a strain drop correlation evolved which expressed the -segment strain drop as a feature of the slip velocity, liquid bodily properties, and overall mass velocity [6].

2.2.2.2 Horizontal Liquid Flow in Piping Systems

Horizontal is concurrent air-liquid flow was investigated under horizontal conditions in piping. The liquid was drained from the section to provide the holdup data. The horizontal flow liquid also was used to determine the effect of density, viscosity, and surface tension [6].

2.2.2.3 Flow Pattern in Vertical Flow

The regime encountered in a vertical flow is a bubble flow, the liquid is continuous, and the bubbles are dispersed in the liquid. Slug or plug flow. The bubbles grow together to form large bubbles close to the diameter of the tube. Slag flow A churn flow that bursts and gives a vibrating churn regime. An annular flow in which the liquid flows through the wall of the tube as a film, the liquid is accompanied by the core, and the gas flows through the center. In the wispy circular flow, the concentration of droplets in the gas core increases as the flow rate of the liquid increases, forming large chunks or stripes of the liquid.

2.2.2.4 Flow Patterns in Horizontal Flow

Here, gravity acts perpendicular to the direction of the flow, so the flow separates. The regime of each stream is a layered stream that completes gravity separation. Layered undulating flow; bubble flow in which bubbles are dispersed in a continuum of liquid (although there is some separation due to gravity as shown). Although the film thickness is asymmetric due to gravity, it is a circular dispersed flow similar to the vertical flow. Various intermittent flows. This latter category includes plug flows where large bubbles flow near the top of the tube. Semi-slug flow with very large waves in the layered layer. In slag flow, these waves contact the top of the tube to form a liquid slag that quickly flows through the channel. Pipe tilt is an important parameter in determining the flow regime and flow of sloping pipes and other shapes.

2.2.3 Pressure Drop Due to Leakage

Based on [2], leakage was an important issue that currently concern about water utilities which was leak detection. Leakage can be represented as undesirable treated water loss and pumping energy. However, referring to [3], inspect the available technologies for leak detection has its own advantages and disadvantages. All technologies appear capable of detecting leaks under some conditions, but none of them is a cure that can be used in all situations and users may want to consider a combination of technologies. Thus, procedures for leak detection and location that are not only faster and cheaper, but also do not require hold of pipeline operations for long periods of time as most of the existing methods do are strongly required by technicians. Leakage can be control by minimize the pressure excess, while accessible for reducing unnecessary waste, only forward the symptoms of the problem. Discussion on how leakage increases the energy expenditure of transmitting water through a pipe segment provides a useful passage point for analysis of leaky networks. The assumption made throughout this paper is that, whether the system leaks or not, the following demands and pressure condition must be met.

2.3 Pressure Loss Coefficient

Pressure loss coefficient is defined as pressure loss of certain hydraulic system or part of a hydraulic system. It can be easily measured in hydraulic loops. The loss coefficient can be calculated for both straight pipes and especially for minor losses.

2.4 Computational Fluid Modelling (CFD)

CFD fluent is a handy program and much more cost saving method compared to experiment research. However, many researchers had used this program to analyze the process of erosion only and do not consider the role of water pressure inside the object. Some of the stimulation even only take note of the initial pressure and do not consider the nozzle effect, erosion effect and the energy lost along the nozzle. Therefore, some of the research may have errors which make them different from the real-life result. The CFD Fluent program can guarantee a high accuracy of the result value as it minimizes the error between real life experiment value and the stimulation.

2.5 Governing equations

Estimating the dispensary of pressure in the case of steady flow is the main purpose of this study. In addition, calculation of the pressure frequency range response to input disturbances is also performed. It examines the reaction to flow and leaks in the pipe. The water pressure dispensary is also studied based on the effect of leak shape and size. The current calculation uses the CFD package ANSYS FLUENT R1 (2022) student version. The formula below explains the time-averaged 3D model of the Navier-Stokes equation, (2) Mass conservation equation (3) Momentum conservation equation where p is pressure, u is velocity, ρ is density and τ is viscous stress tensor

$$\frac{\partial p}{\partial t} + \nabla.(\rho\vec{u}) = 0 \tag{2}$$

$$\frac{\partial}{\partial t}(\rho\vec{u}) + \nabla.(\rho\overrightarrow{uu}) = -\nabla p + \nabla.\tau \tag{3}$$

2.6 Parameter Assumptions and Boundary Conditions

In this study, flows are considered incompressible flows, Newtonian fluids, and no slip walls. The simulation is performed by specifying the velocity at the entrance of the horizontal pipeline. Use water with an ambient temperature (300K) as the working medium. Turbulence intensity, I and hydraulic diameter, Dh were given for initial estimation of turbulence flow rates (k and ϵ). The setting for outlet boundaries is performed using outflow boundary.

2.7 Analysis on pressure losses

The equation below is the equilibrium of mechanical energy when incompressible water distributes through the horizontal part of a uniform pipe without the input of effort where ρ is the density of water, P is flow of static pressure, F is losses of friction include losses in straight pipe (i.e., skin friction) and pipe fittings (i.e., form friction). Equation (5) describes the losses of friction where f is fanning friction factor, L is length of pipe, D is diameter of pipe, V is fluid velocity and Kf is dimensionless pressure loss coefficient. Equation (6) and (7) describes about fanning friction factor where ΔP_s is pressure loss caused by straight pipe region of length L and the pressure loss coefficient where ΔP_f pressure loss caused by pipe fitting. A plot between $\Delta P_f \ and \ \frac{\rho V^2}{2}$ results in a straight line passing through origin with Kf as the slope, which is the average value of the pressure loss coefficient for the given flow condition.

$$\sum_{g}^{F} = \frac{P_{1-}P_2}{\rho g} \tag{4}$$

$$\sum F = \sum \frac{2fV^2L}{D} + \sum \frac{K_f V^2}{2} \tag{5}$$

$$f = \frac{\Delta P_s D}{2\rho V^2 L} \tag{6}$$

$$Kf = \frac{2\Delta P_f}{\rho V^2} \tag{7}$$

3. Methodology

3.1 Details for Computational Fluid Dynamics (CFD)

The CFD program always involving five steps which are the geometry building, meshing, defining of boundary condition, computerize and visualizing. These five steps also can be categorized into three main stages which is the pre-processing, solver and post-processing stage.

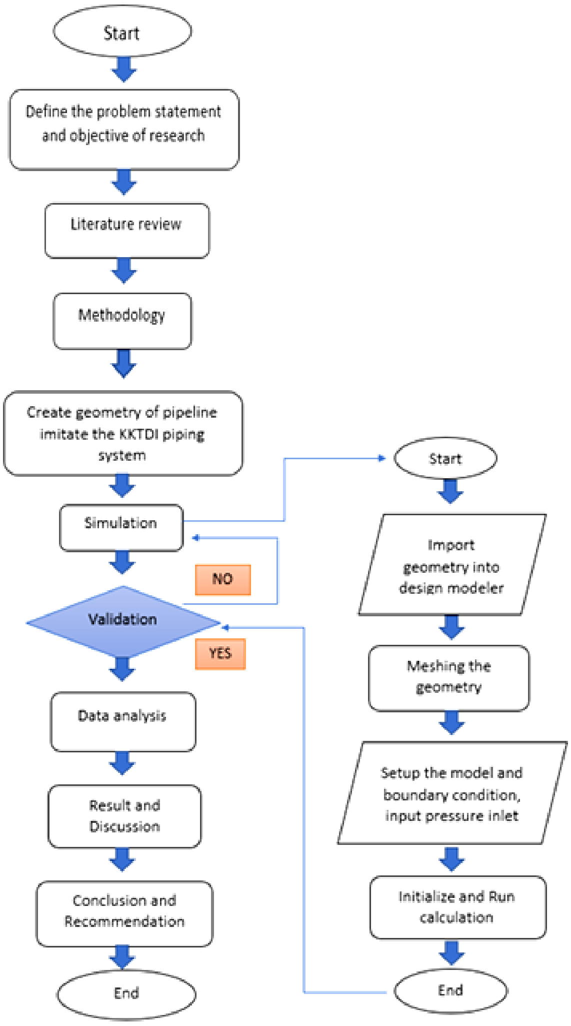

Fig. 1 - Flowchart of CFD approach

3.2 Details of KKTDI pipeline system

The pipeline system at KKTDI, UTHM The pipeline system is develop based on the actual schematic plan of piping system at residential college KKTDI, UTHM as illustrated in Fig. 2. The inner diameter of pipe is 100 mm based on the schematic diagram from the PPH, which is the thickness of pipe wall is assumed 10 mm. To determine the solidity and precision of flow prediction, a numerical generation of grid is an important issue in flow simulation. Quantization of disordered tetrahedral hybrid cell in whole flow region is the current case of flow through a 90-degree bend, as shown in Fig. 3. A detailed description of the network structure is given in Table 1. Showing an enlargement in the number of cell elements by grid independence study to determine enough nodes to use in the simulation.

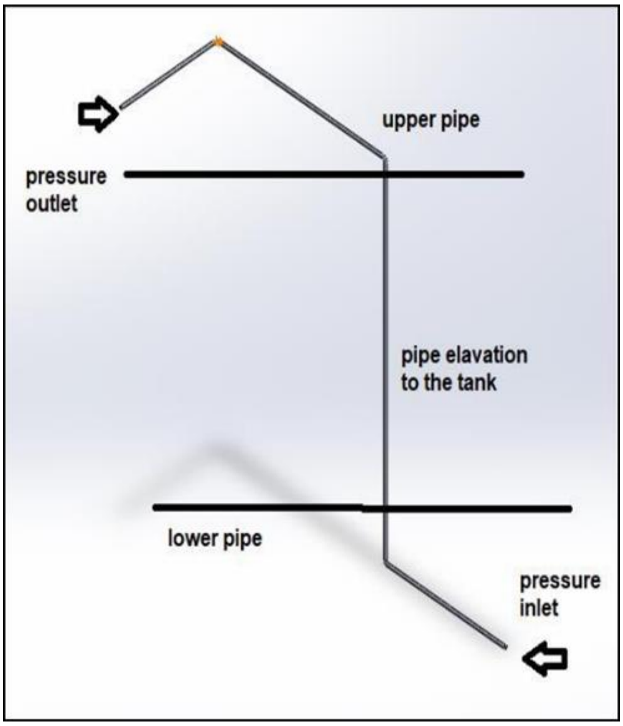

Fig. 2 - The design of piping system at KKTDI residential colleges

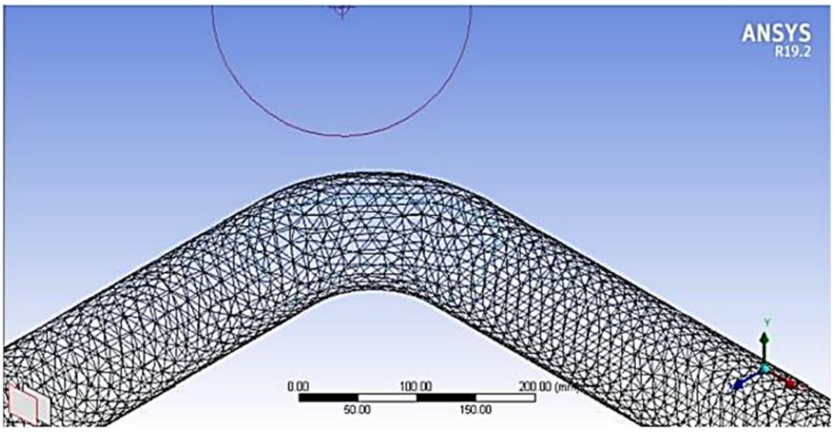

Fig. 3 - The meshing of the pipe bend

Table 1 - Parameter of meshing of pipeline

Details of Mesh	Parameter
Default	
Physic preference	CFD
Solver preference	Fluent
Export format	Standard
Sizing	
Growth size	Default (1.2)
Max size	0.219.38 m
Capture Curvature	Yes
Capture Proximity	Yes
Proximity Size Function	Faces and Edges
Quality	

Smoothing	High
Mesh Matric (skewness)	Make sure below than 0.9 (0.84676)
Assembly Meshing	
Method	Tetrahedrons

4. Result and Discussion

4.1 Pressure Contour

Pressure contour is the post processing result which shows the distinction of color of pressure along the pipeline as shown in Fig. 4. The pressure of inlet pipe as Fig. 5 (a) indicates the pressure of about 55.93 kPa. The pressure in the pipe starts to decrease along way the pipe as the color changes, this is due to the friction in the pipe. As can see in Fig. 5 (b), the color contour greenish yellow is appeared at the fitting of pipe. This is because the pipeline experience pressure drops at the junction as more pressure appear at the pipe fitting. The simulation later reveals that pressure loss occurs as it drops 55.93 kPa to 49.97 kPa. Fig. 5 (c) shows the pressure contour at the outlet of pipeline, and it tells that the keeps dropping before the outlet. The pressure loss is happened due to friction in pipe wall. The outlet pressure of the pipeline is 8.36 kPa to 2.30 kPa.

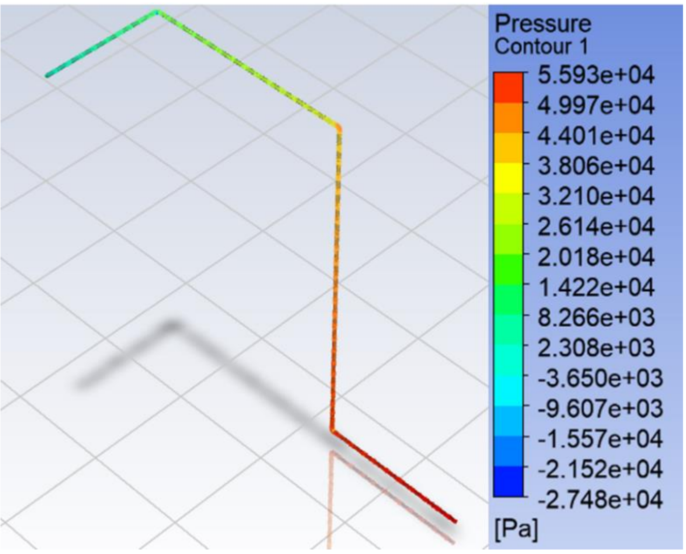

Fig. 4 - The pressure contour of pipeline system

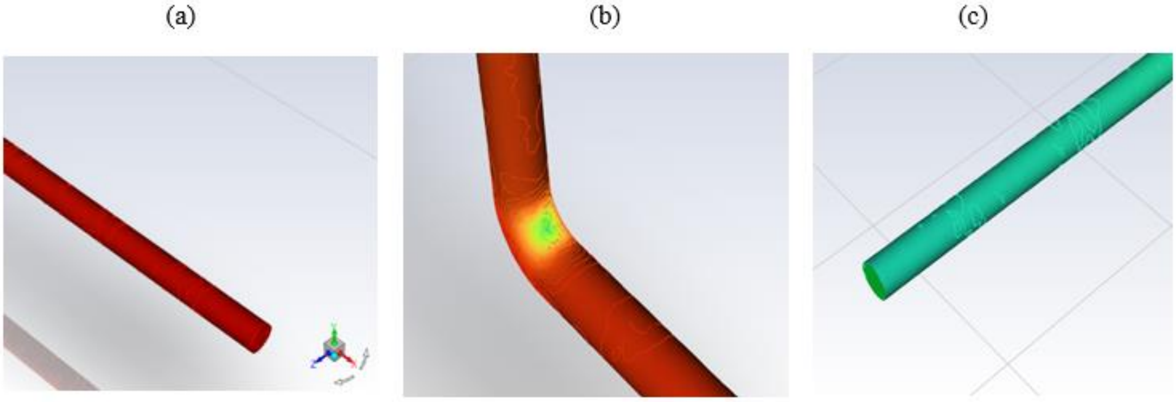

Fig. 5 - (a) The inlet pressure; (b) the junction; (c) the outlet pressure

4.2 Velocity streamline

Fig. 6 shows the velocity streamline at inlet of pipe where there are many numbers of streamline form the beginning of pipe inlet. The velocity indicates at post processing stage is around 4.33 m/s to 6.49 m/s. At the fitting of pipeline, the velocity streamline indicates the velocity declines along the junction about 6.49 m/s to 2.16 m/s as shown in Fig. 7 (a). Fig. 7 (c) shows the velocity streamline at outlet pipeline and there are very few streamlines which indicate the declination of velocity. The velocity at the outlet is 4.33 m/s to 6.49 m/s.

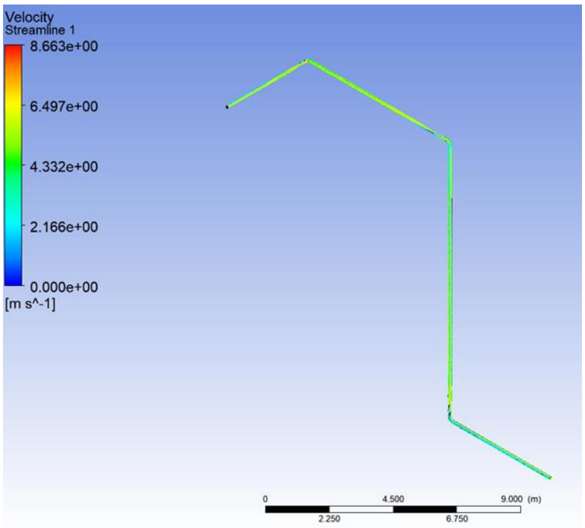

Fig. 6 - The velocity streamline of pipeline

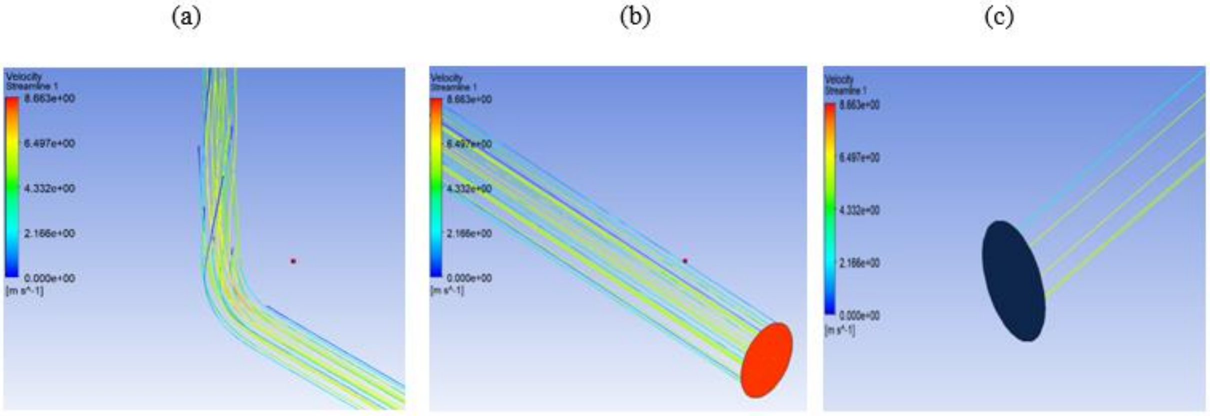

Fig. 7 - (a) The junction; (b) the inlet velocity; (c) the outlet velocity

4.3 Pressure loss coefficient

From the post processing stage, the simulation indicates the inlet and outlet pressure are figured. The pressure loss throughout the pipeline has been recorded as seen through the pressure color contour. The details of pressure loss through straight pipe and pipe fitting shown in Table3.

Table 2 - The pressure loss caused at straight pipe region of length L

Inlet Pressure	Outlet Pressure	Pressure loss, ΔP_s (kPa)
55.93	13.20	42.7
53.93	11.70	42.2
51.93	10.20	41.4
49.93	8.70	41.2
47.93	7.20	40.7

Table 3 - The pressure loss at pipe fitting

Inlet Pressure, P1	Outlet Pressure, P2	Pressure loss, ΔP_f (kPa)
44.01	2.308	41.7
42.01	2.108	39.9
40.01	1.908	38.1
38.01	1.708	36.3
36.01	1.504	34.5

Table 4 - The fluid velocity of pipeline

Inlet Velocity, V1	Outlet Velocity, V2	Fluid velocity, V (m/s)
5.69	4.12	1.57
5.89	4.42	1.47
6.09	4.72	1.37
6.29	5.02	1.27
6.49	5.32	1.17

From the data collected from the Ansys simulation after post processing stage, the value of pressure loss coefficient is also can be predicted from the equation drawn in past study research. By substituting the value of pressure loss at fittings (ΔP_f) and velocity (v) inside the equation given, can draw out the pressure loss coefficient at pipeline system. The density of water (ρ) is 1000 kg/m^3. As the value of pressure loss coefficient has been calculated, it is certain to explain that the pressure loss coefficient increases as the velocity of the fluid in pipeline system decreases.

Table 5 - Pressure loss coefficient

Pressure loss, ΔP_f (kPa)	Fluid velocity, V (m/s)	*Kf*
41.7	1.57	33.8
39.9	1.47	36.9
38.1	1.37	40.6
36.3	1.27	45.0
34.5	1.17	50.4

Fig. 8 shows the average pressure loss coefficient (*kf*) of pipeline. In this figure, the y axis represents the pressure loss and the x axis represent the $\rho v^2/2$. The slope, m represents the average pressure loss coefficient. The straight line has been plotted as per pre-determined in previous research study, but the straight line does not pass through the origin as expected but the average pressure loss coefficient is predicted through the plotted graph. The average pressure loss coefficient from the plotted graph is 13.1. The average value of pressure loss coefficient from the plotted graph is far less than the pressure loss coefficient calculated from the equation drawn from past research study.

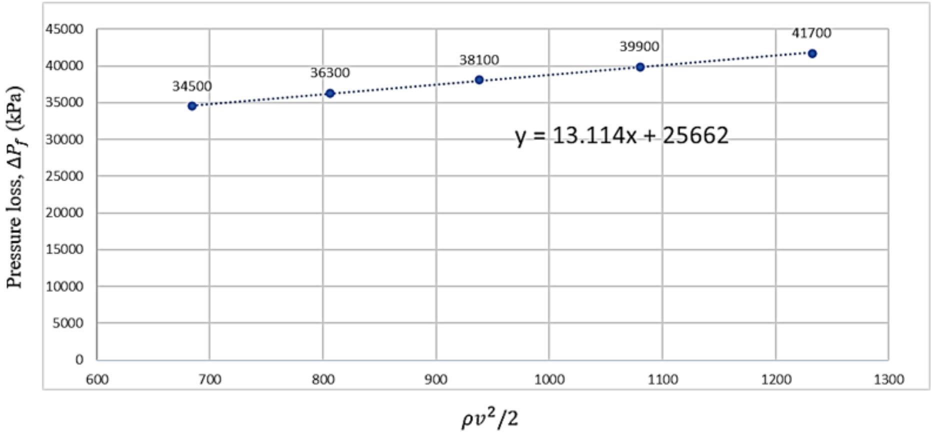

Fig. 8 -The graph of ΔPf and ρV2 /2

5. CONCLUSION

In conclusion, the KKTDI residential college pipeline system loses pressure because of friction, the height of the pipeline, and the fittings on the pipes. Hence, the longer the pipeline and more fittings and elevations, the pressure loss will happen. The KKTDI pipeline system has been carefully studied by taking measurements of the pipe's size and shape so that it can be remade in Computer Aided Design (CAD) software and then analyzed in Computational Fluid Design (CFD) software. After doing a full analysis with the CFD method, the pressure loss coefficient is found, as Kumar Perumal [7] explains. Hence the objective for the study has been achieved.

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