International Journal of Sciences, Engineering & Environmental Technology (IJOSEET), 7(13): 117 – 124, 2022
ISSN 0794-9650

www.repcomseet.org

DETERMINATION OF ENERGY LOSSES IN FLUID FLOW THROUGH PIPES AND BENDS

Lukman Aremu ANIMASHAUN*[1], Taiwo Olugbenga RABIU[2], Olukayode SOGUNRO[3], Sheriff Babatunde LAMIDI[4].
[1,2,3,4] College of Engineering and Technology, Department of Mechanical Engineering,
Lagos State Polytechnic, Km 5, Sagamu Road, Ikorodu, Lagos, Nigeria.

* Corresponding Author: animashaun.l@lasustech.edu.ng.

Abstract

Pipe technology is used in the transportation of various fluids like water, steam, different types of gases, oil, and other chemicals at low and high pressures and temperatures. When a fluid flows through pipes and fittings, part of its energy the fluid possessed is used to maintain flow due to internal friction between fluid molecules and with the pipe walls. This will lead to energy loss or friction head loss. This study carried out a laboratory experiment with a hydraulic bench connected to an arrangement of local pipes of differing diameters, internal roughness, and fittings to investigate the effect of changing flow velocities and pressure drops along the pipelines and fittings. The result obtained from the experimentation was used to determine the Reynolds number, head loss, and friction factor which were plotted on a Moody diagram to obtain the relative roughness and equivalent roughness of the smooth and rough pipes. In addition, the loss coefficients for both 45 and 90° pipe bends were also determined. One major finding of this study is that major energy loss occurred with increasing mean flow velocity and that rough pipe has much more major head loss than the smooth pipe, especially as flow velocity increases. Another finding of this study is that the loss coefficient for turbulent flow in sudden pipe bends is not only significantly higher than 45° pipe bends but also varies more with the increasing mean flow velocity. The result from this study will enable laboratory determination of energy losses from pipes and fittings used to transport fluids. This will not only enable appropriate pipe roughness, diameter, and lengths to be estimated but also ensure that energy losses and costs are considered in estimating local hydraulic power sources.

Keywords: Friction head loss, Friction factor, Reynolds number, Roughnesses Turbulent flow.

Introduction

In hydraulic engineering practice, pipe technology is used in the transportation of various fluids like water, steam, different types of gases, oil, and other chemicals at low and high pressures and temperatures. When a fluid flows through pipes and fittings, part of the energy the fluid possessed is used to maintain flow due to internal friction between fluid molecules and with the pipe walls and turbulence. This energy possessed by the fluid is converted into heat energy that is obtained from the expression of energy loss in terms of head loss; usually classified into two categories. In engineering practice, it is important to increase pipe productivity by maximizing the flow rate capacity and minimizing head loss per unit length [1, 2]. This means that significant energy consumption reduction at a relatively small capital cost to overcome the frictional resistance in a pipe conveying a certain flow rate is desired.

There are two types of energy loss in pipes; a major head loss which is present throughout the length of the pipe and minor head loss due to the minor flow around pipe fittings used in the pipe network. These losses appear as changes in pressure and flow rates of fluid in the pipeline. A great number of studies were carried out by Darcy in 1857and Weisbach in 1845 [3] with a relation for the head loss in terms of friction coefficient and the relative roughness.

$$h_L = f \frac{L}{D} \frac{\overline{U}^2}{2g}$$ Equation 1

$$f = \frac{2. h_L D . g}{L \overline{U}^2}$$ Equation 2

Where h_L friction head loss in meters, L is the pipe length between tapings in meters, $\overline{U}$ is the mean velocity in m/s, f is the friction factor and D is pipe diameter in meters.

The application of Equation 2 in the determination of the pipe friction coefficient is a function of a dimensionless flow quantity known as Reynolds number (Re), this number for flows in pipes by Osborne Reynolds in1883 who showed that;

$$Re = \frac{\rho . v . D}{\mu} \qquad \text{Equation 3}$$

Where ρ and μ are respectively the density of the fluid in kg/m^{3}and dynamic viscosity in N.s/m^2. For laminar flow regime, $Re \leq 2000$ and turbulent flow regime has $Re > 4000$.

In 1933, Nikuradse [4] showed by experimentation, the dependence of f on the average size of the pipe internal surface roughness, through the relation shown in Equation 4;

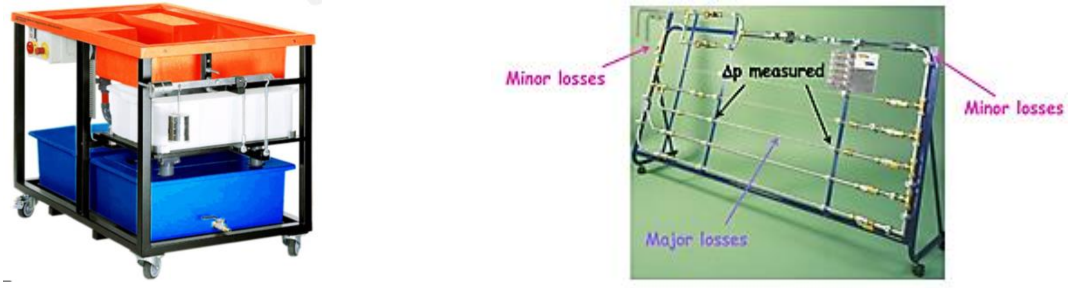
$$f = f\left(Re, \frac{\epsilon}{d}\right) \qquad \text{Equation 4}$$

The challenge in pipes and fittings is either non-delivery or insufficient delivery to the desired destination which may be due to insufficient pumping or faulty pumps or high friction losses in the delivery system. This may be caused by increased pipe roughness or pipe blockage leading to high friction losses or high positive delivery head or insufficient net positive suction head at the pump. The objectives of this study are to carry out experimentation on a hydraulic bench connected to an arrangement of pipes of differing diameters, internal roughness, and pipe bends. Another objective of this study is to analyze results of changing volumetric flow rates and pressure drops along the pipelines and fittings on the hydraulic bench to determine: Reynolds number, type of flow regime, major and minor head losses, friction factor and loss coefficients, and equivalent roughness of the pipes and fittings. These results will enable a comparison of flows between smooth pipes and rough pipes based not only on theoretical relations but also through experimentation.

Experimental Methods

Pipe friction apparatus

- This apparatus shown in has a network of pipes of different diameters and roughness connected directly to the hydraulic bench water supply through a flexible hose. The flow control valve that faces the volumetric tank has a short length of the flexible tube that should be attached to it, to prevent splashing and to regulate flow through the test pipe. The two pipes that are going to be used to investigate major head loss will be a smooth and a rough pipe with respective diameters of 17mm and 15mm. These different interiors will affect the flow and give differing results.



(a) (b)

Figure 1 Images of (a) Apparatus for (a) friction losses in pipes and fittings apparatus, (b) Hydraulic bench

In this study, the hydraulic bench from TecQuipment shown in Figure 1 (a) will be used to transport water from a reservoir using a surface centrifugal pump through pipes and fittings. In addition, flow rate measurements at different valve openings are carried out by measuring the time taken to fill volumetric tanks in the hydraulic bench [5]. The hydraulic bench gives an external flow rate for reference and comparison. By collecting data for different volumetric flow rates the mean flow velocities ($\overline{U}$) of water flow can be determined.

The main apparatus used was the fluid friction apparatus which consisted of pipes of various diameters and fittings, including a rough pipe, allowing the static pressure in the system to be measured at different points of the water flow. This pressure was measured using a digital manometer which gave the value in kPa. A stopwatch was used to record the time taken for a particular volume of water to flow through the pipe. This volume was measured using the scale on the hydraulic bench which controlled the amount of water sent through the fluid friction apparatus or using a measuring cylinder for small volumes.

The first part of the experiment involved investigating major head losses in both smooth and rough bore pipes. The procedure for achieving this is to open the valves to allow water through the smooth pipes. A manometer was then connected between the tapings in the pipe to measure pressure difference. This pressure difference can be used to calculate the major head loss where the length between tapings is 1.0 m. The calculation to do this is shown in **Equation** 5;

$$h_L = \frac{\Delta P}{\rho g} \qquad \text{Equation 5}$$

Where $\Delta P = change\ in\ pressure\ (Pa), \rho = density\ (taken\ to\ be \frac{999kg}{m^3})$, $g = acceleration\ due\ to\ gravity\ (taken\ as \frac{9.81m}{s^2})$, and $h_L = Major\ head\ loss$. To find the flow rate (Q)shown in Equation 6, a conversion from liters per second (ls^{-1}) into cubic meters per second (m^3s^{-1}) needs to be performed; $1000litres/s = 1m^3s^{-1}$.

To find the mean flow velocity $(\overline{U})$, the equation for flow rate (Q) can be rearranged and used as shown in **Equation** 6.

$$\dot{Q} = A\,.\overline{U} \quad or \quad \overline{U} = \frac{\dot{Q}}{A} \qquad \text{Equation 6}$$

A table of volumetric flow rates Q, major pipe loss (h_L), mean flow velocities $\overline{U}$ and differential pressures, ΔP are formed where the variation of major head loss can be obtained by plotting a graph of major head loss against mean flow velocity.

The second part of the experiment involved experiments to determine the minor head losses in a system that occurs when fluid flows through obstacles in the pipework for example pipe fittings or bends. The minor head losses in two cases for consideration in this study is one where the fluid flows through smooth pipes connected to a short radius bend of 45º elbow and a 90º elbow. The same experiment for major losses is also repeated for flows through bends.

Since the relationship between major head loss and mean flow velocity for laminar flow and turbulent flow are respectively linear function [6] and power-law function [7] as shown in Equation 7 and Equation 8.

$$h_L \propto \overline{U} \qquad \text{Equation 7}$$

$$h_L \propto \overline{U}^n \qquad \text{Equation 8}$$

For turbulent flows, the natural logs of Equation 8, gives:

$$\ln h_L = n \ln \overline{U}$$

Therefore if the graph of $\ln h_L$ is plotted against $\ln \overline{U}$, then n would be the gradient of the line of best fit. A more complete expression for the relationship between major head loss and mean flow velocity can be obtained.

To find the friction factor and Reynolds number for the range of flow rates and smooth and roughened pipes, Equation 1 and Equation 2 the two equations below need to be used for a pipe tapping length of 1 m, and dynamic viscosity of water is taken as $1.15 \times 10^{-3}\,Pa.s$.

Since all the variables on the right-hand side of Equation 1 and Equation 2 are known, they can be plotted on the Moody diagram to determine the relative roughness and equivalent roughness of the pipes.

The process carried out for the major losses experiment is the same for pipe bends, whereby the difference in pressure before the bend and after was measured for a steadily increasing flow rate then converted to head loss using **Equation** 9. A mean velocity across the fitting was calculated using the average velocity values. The method for calculating velocity is identical to that used for the major head loss section. Using this value of velocity K_L can be determined for every flow rate from **Equation** 9:

$$h_m = K_L\,.\,\frac{\overline{U}^2}{2g} \qquad \text{Equation 9}$$

The equation assumed that fluid acceleration or deceleration is approximately isentropic, and mechanical energy loss takes place predominantly during the deceleration or acceleration respectively.

Results

Major losses in smooth and rough pipes

The results of experimentation and analysis for h_L and $\overline{U_m}$ for the flow of major head loss against mean flow velocity for both smooth and rough pipes are shown in

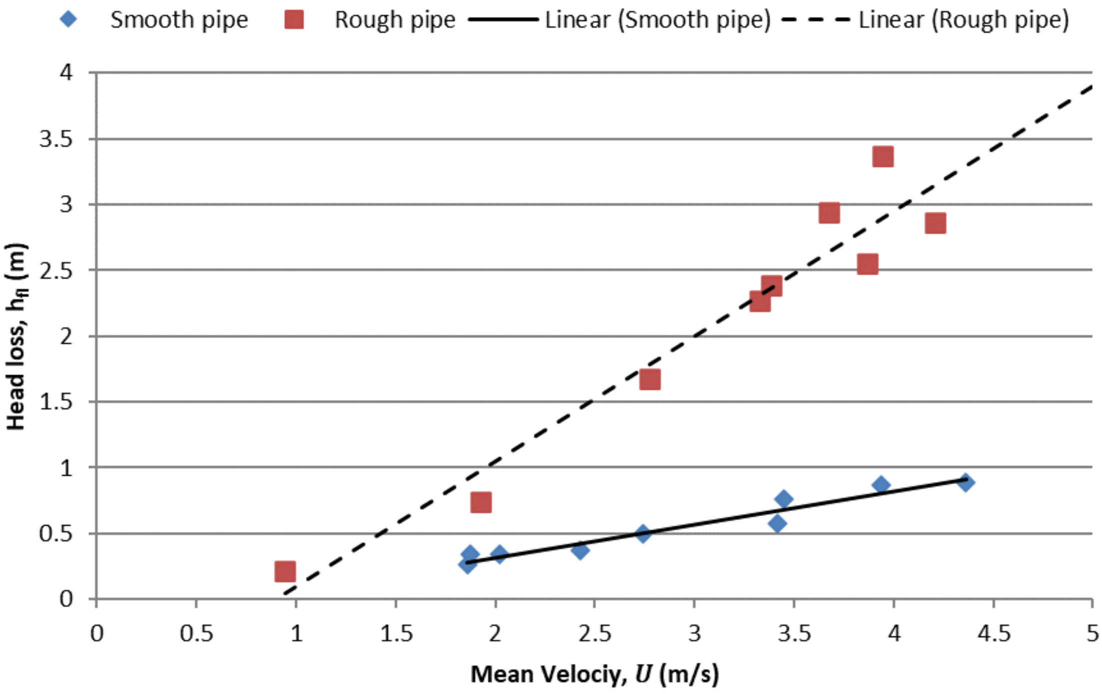


Figure 2. It indicated that the major head loss in both smooth and rough pipes increases with mean velocity. However, head losses in rough pipes are much higher in rough pipes than in smooth pipes.

To determine the relationship between h_L and $\overline{U_m}$, Equation 7 was utilized by taking the natural log of h_L and $\overline{U_m}$ whose results are presented for smooth pipes and rough pipes are presented in **Figure 3**. These are based on the determination of friction factor (f) and Reynolds number (Re) from Equation 2 and Equation 3 in order to obtain graphs of the natural log of h_L and $\overline{U_m}$ for both smooth and rough pipes.

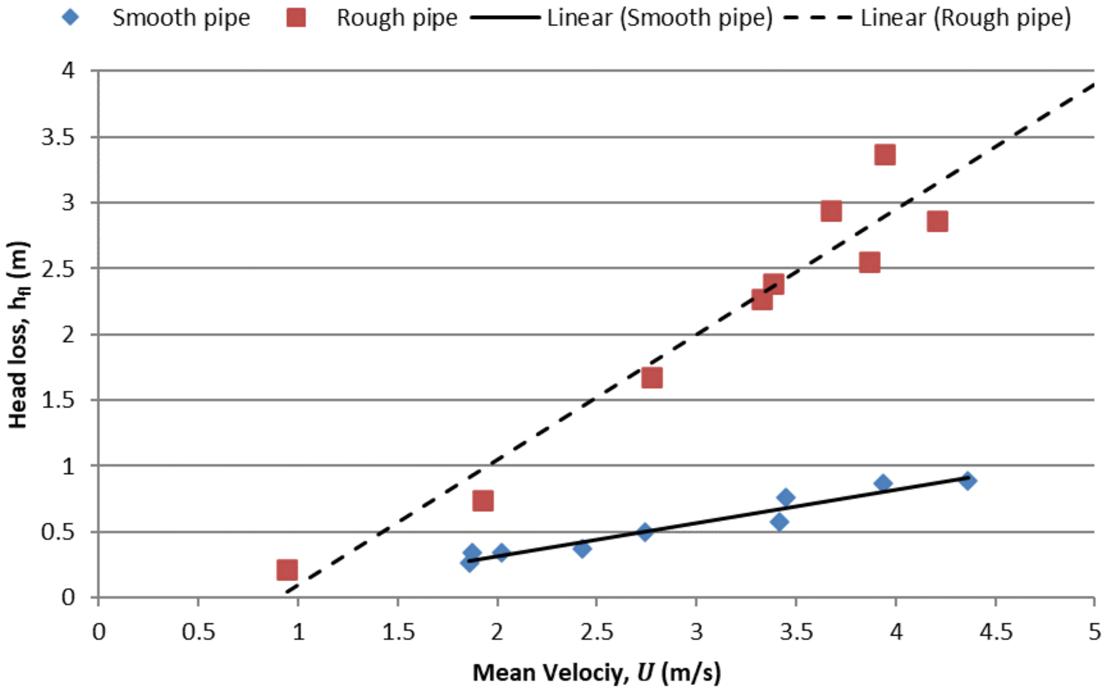
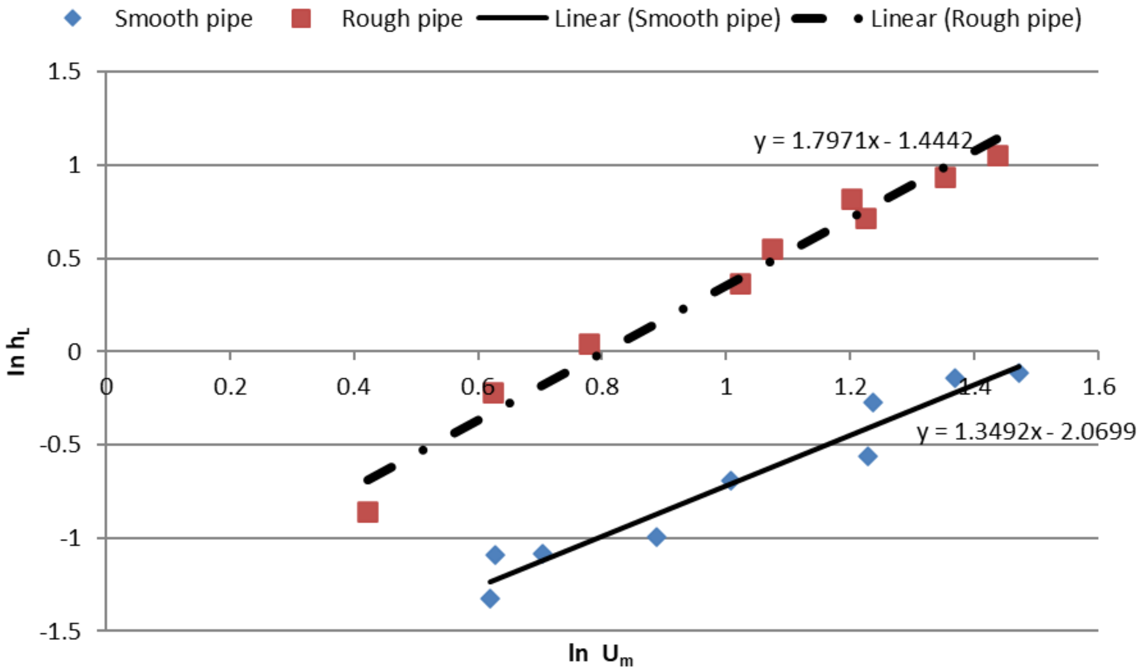


Figure 2 Variation of major head loss against mean flow velocity for smooth and rough pipes

The results show that for smooth pipe $n = 1.3492$ and rough pipe, $n = 1.7971$. This result is similar to that obtained by Osborne Reynolds [6] that has the value of n varying between 1.75 and 2 for pipes and tubes of various materials in common use such as; lead, glass and cast iron. The result showing interception of the x-axis is indicative of the turbulent nature of the flow, unlike laminar flow where the straight line is expected to pass through the origin [6].



- Figure 3 Graph on the natural log of major losses against the natural log of mean velocity for both smooth and rough pipes

This result confirmed the Reynolds number calculation (Re) was higher than 4000, which is indicated that the flows are turbulent.

By plotting the values of friction factor and Reynolds number obtained on a Moody diagram, the relative roughness, and equivalent roughness was determined as shown in Figure 4;

$$\textit{For rough pipes, the relative roughness,} \quad \frac{\in}{D} = 0.03$$

$$\textit{For smooth pipes, the relative roughness,} \quad \frac{\in}{D} = 0.0001$$

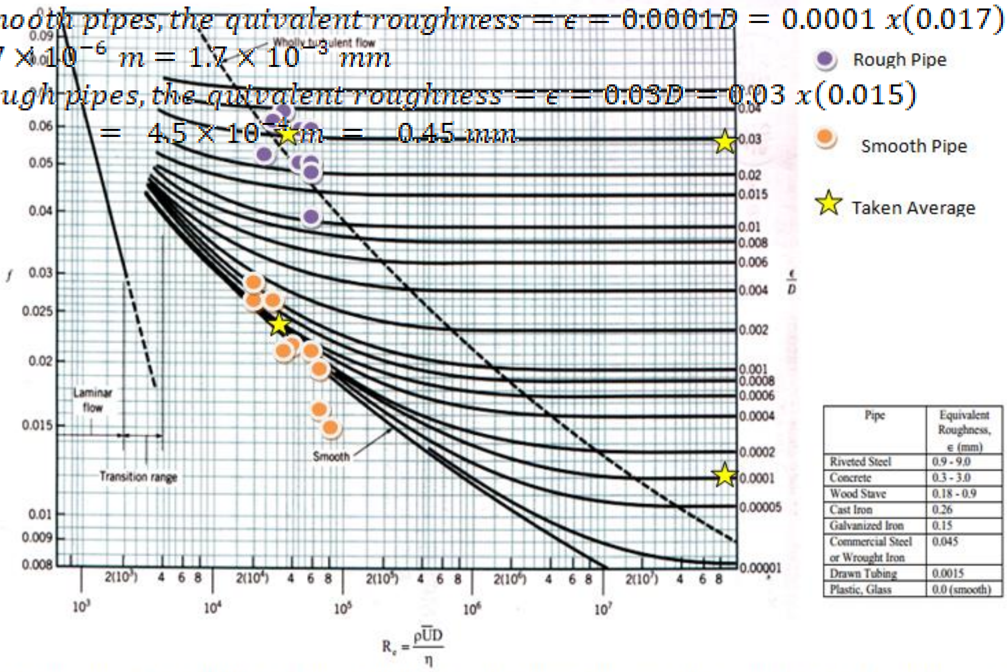
- Figure 4 Use of Moody diagram to determine pipe relative roughness

$$\textit{For smooth pipes, the quivalent roughness} = \epsilon = 0.0001D = 0.0001\ x(0.017)$$

$$\epsilon = 1.7 \times 10^{-6}\ m = 1.7 \times 10^{-3}\ mm$$

$$\textit{For rough pipes, the quivalent roughness} = \epsilon = 0.03D = 0.03\ x(0.015)$$

$$= 4.5 \times 10^{-4}\ m = 0.45\ mm$$

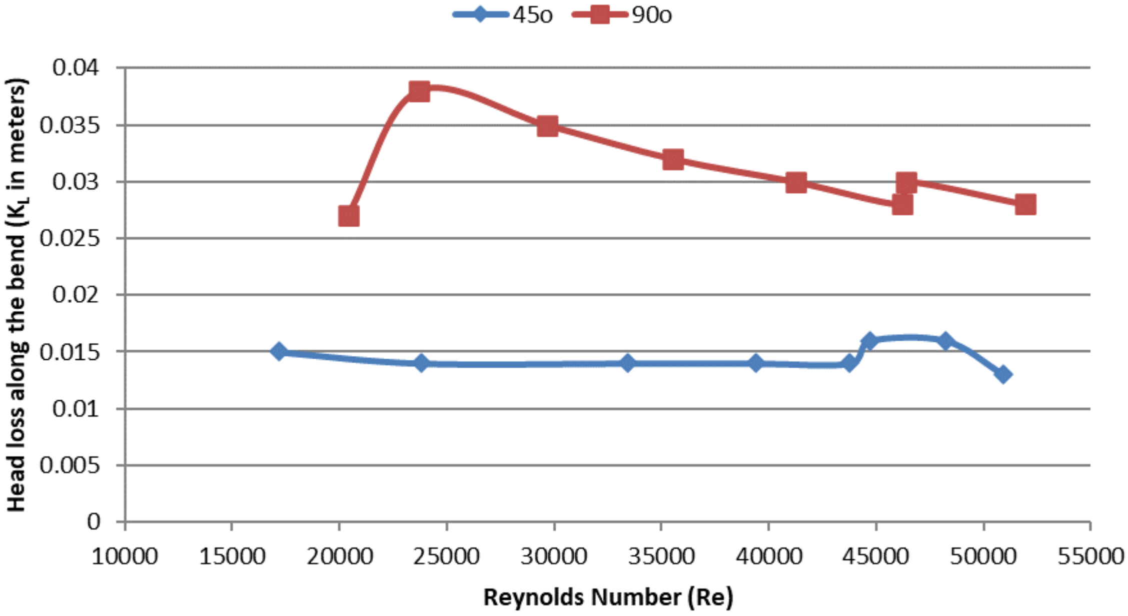


Friction factor (f) as a function of Reynolds number (R_e) and relative roughness (ϵ/D) for round pipes - the Moody Diagram (Moody, L.F., "Friction factors for Pipe Flow", Trans. ASME, Vol. 66, 1944)

The result indicated that wall roughness can affect head loss in pipes. This was similar to the results of similar studies in the literature [5, 8, 9].

Results of minor losses through pipe bends

The result of minor head losses through 45° and 90° bends where a plot of loss coefficient K_L plotted against the Reynolds number (Re) is shown in **Figure 5** for both types of bends used in the experiment. The result indicated that flows in both bends are turbulent $Re > 4000)$ and that loss coefficient for 90° bend is higher than 45°. In addition, the variation of loss coefficient with Reynolds number in 90° was significant throughout the test, unlike that of 45° bend which did not change greatly until when Re is about 43,767. These results are similar to previous studies in the literature [10, 11].



- Figure 5 Graph of head loss along pipe bends against Reynolds number

Discussions

The results from this study shown in

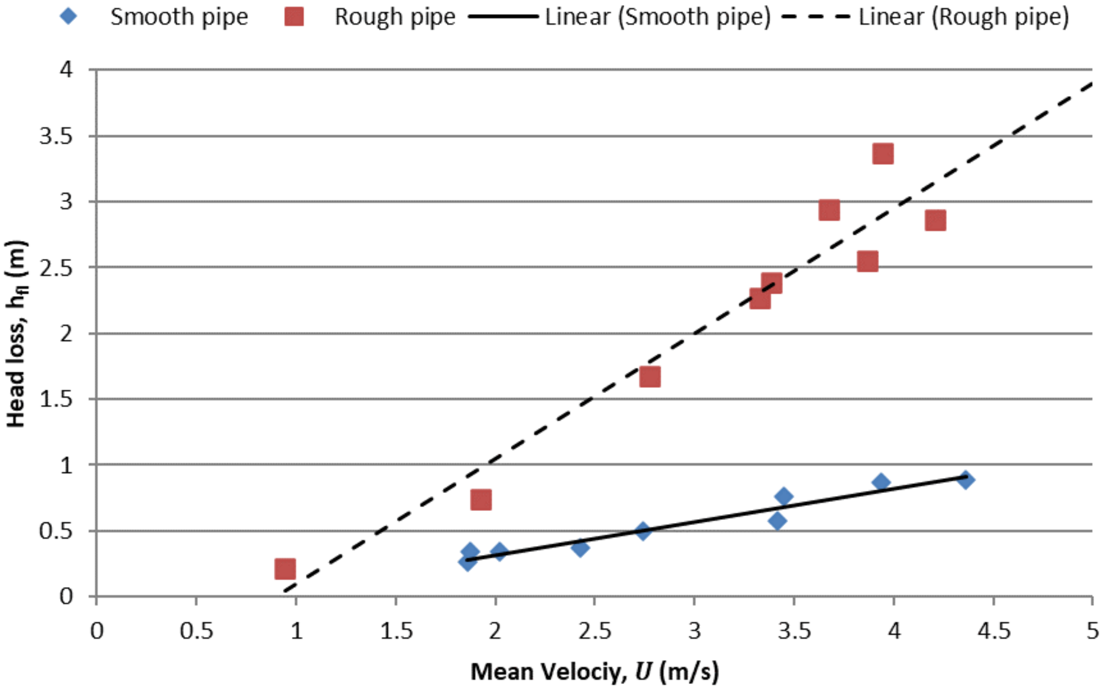


Figure 2 indicated that major head loss increases with the increasing mean flow velocity. This is because the flow is more turbulent and more friction within the water molecules. This means that more energy or head loss as velocity increases. It is also clear from the graph that the rough pipe has much more major head loss than the smooth pipe, especially as flow velocity increases. This is in agreement with the results of similar studies that involve both numerical analysis and experiments [12]. The rough pipe provides more obstruction to the flow and therefore takes energy out of it. This is shown as the gradient of the line for the rough pipe is higher than the smooth pipe. The use of experimental results with Moody's chart shows it is a powerful technique for analyzing fluid flow in pipes. However, other techniques like explicit equations can also be used to estimate friction factors based on the range of Reynolds numbers. These can range from the Colebrook-White equation [13] and its modified form with three logarithmic factors in the works of Dejan Brki´c and Žarko Cojbaši´c. [14] for friction factor estimation to a newly developed accurate estimation with two logarithmic factors by Offor, U.H., and Alabi, S.B. [15].

It is not possible to distinguish from where the flow changes from laminar to transitional and back to turbulent flow in the study. The graph shows just a linear line of data points which seem to suggest the water stays in the same type of flow for the entire experiment. This could mean that the flow rate was not high enough to make the flow turbulent. For the pipe bends, the Reynolds number ranges from 27000 to 65000 and was far greater than pipe lows.

Looking at **Figure 4** where the average points were used to estimate $\frac{\epsilon}{D}$ from the Moody diagram to give other parameters of the pipe. The stars represent an average point that has been estimated by the eye. However, any anomalies such as the two points for the smooth pipe which are not close to any lines were ignored. The values obtained for equivalent roughness can be compared to the table next to the moody diagram in **Figure 4**. The smooth pipe value of 1.7×10^{-3} is similar to that of drawn tubing which has a value of 0.0015.

This shows that the smooth pipe is near the perfectly smooth end of the scale and therefore the losses in the smooth pipe would be lesser than the rough pipe. Numerically, the equivalent roughness of the rough pipe was found to be 0.45. This is much higher and is more similar to the woodstove. The moody diagram, therefore, confirms that the rough pipe is a lot rougher and the energy losses will therefore be significantly higher.

The results of experimentation for pipe bends under turbulent flow $(Re > 4000)$ as shown in **Figure 5** indicated that there is less variation in loss coefficient for 45^o than 90^o pipe bend, where was observed that the maximum pressure loss coefficient occurs in the 90^o pipe bend. This is mainly due to the development of secondary flow and magnified swirl intensity of secondary flow and as Re increases, pressure loss coefficient K_L becomes lower and almost the same for higher Re due to higher velocity heads. In addition, **Figure 5** shows the dependency of the average pressure loss coefficient on Reynolds number and pipe bend curvature as observed in the study of P. Dutta and N. Nandi [11]. As Reynolds number increases around the bends, rapid change of pressure increase both separation and friction effects, despite lower pressure loss coefficient due to higher velocity head. This may be down to errors in the way the mean flow velocity was measured and calculated.

Looking at **Equation** 9, the results shown in **Figure 5**, implies that the loss coefficient should decrease as the mean flow velocity increases. This could be because there is much more energy in the flow when it has a higher velocity and therefore this overcomes a lot of the losses in the fittings. The almost horizontal straight line for 45^o bend on the graph shown in **Figure 5** may represent the horizontal part of the moody diagram, and as the flow is completely turbulent there was no sign of any transition to laminar flow.

This makes sense as the water will receive a greater loss as the flow tries to move around the 90^o pipe bend than 45^o. A component of flow velocity due to the vector action of impulse-momentum effects at the 90^o pipe bend is more than 45^o. This may cause eddy currents and cause the flow to lose some energy. However results from this study did not agree with the findings of similar studies that for 90^o bend and at low Reynolds Number within the transition zone (2000-4000), minor loss co-efficient diminished at a high rate, but at large Reynolds Number (above 4000) the curve becomes flatter [16]. In this study, the 45^o bend provided a more horizontal line of loss coefficient than the 90^o bend. In addition, higher loss coefficient results in this study for 90^o bend than 45^o bend agrees with the power relation [16]. The errors in the experiment may have come from several sources. There may be some manufacturing tolerances in the pipes which may have contributed to the error including the surface finish inside the pipes. The temperature of the water may have increased slightly within the piping due to the frictional effect on viscosity.

Conclusions

This study has investigated through experimentation and analysis major and minor losses in pipes and pipe bends. The followings are the conclusions from this study:

- Major losses in pipes are more significant in rough pipes than smooth pipes when the flow is turbulent. Hence, the interior of pipes used for the transportation of liquids at high pressure and flow rates should be as smooth as they can be produced.
- To provide efficient fluid flow, there is a need to avoid sharp bends in pipes as much as possible.
- Future work will consider friction factor estimation for turbulent flows in corrugated pipes.

Acknowledgments
The authors wish to thank the management of Lagos State Polytechnic for their supports in this work.

References

1. Ntengwe, F., M. Chikwa, and L. Witika, *Evaluation of friction losses in pipes and fittings of process engineering plants.* International Journal of Scientific and Technology Research, 2015. **4**(10): p. 330-336.
2. Kabir, H.A.a.S.M.I., *Applied Fluid Mechanics Lab Manual*, ed. G. Bowers2019: Mavs Open Press.
3. Haktanır, T. and M. Ardıçlıoğlu, *Numerical modeling of Darcy–Weisbach friction factor and branching pipes problem.* Advances in Engineering Software, 2004. **35**(12): p. 773-779.
4. Nikuradse, J., *Stromungsgesetze in rauhen Rohren.* VDI-Forschungsheft, 1933. **361**: p. 1.
5. Lahiouel, Y. and R. Lahiouel. *Evaluation of energy losses in pipes*. in *Congrès français de mécanique*. 2015. AFM, Association Française de Mécanique.
6. Zuck, D., *Osborne Reynolds, 1842-1912, and the flow of fluids through tubes.* British journal of anaesthesia, 1971. **43**(12): p. 1175-1182.
7. Gerhart, P.M., A.L. Gerhart, and J.I. Hochstein, *Munson, Young and Okiishi's Fundamentals of Fluid Mechanics*2016: John Wiley & Sons.
8. Nosrati, K., A. Tahershamsi, and S.H.S. Taheri, *Numerical analysis of energy loss coefficient in pipe contraction using ansys cfx software.* Civil Engineering Journal, 2017. **3**(4): p. 288-300.
9. Lahiouel, Y., A. Haddad, and K. Chaoui, *Evaluation of head losses in fluid transportation networks.* Sciences & Technologie. B, Sciences de l'ingénieur, 2005: p. 89-94.
10. Kalpakli, A., *Experimental study of turbulent flows through pipe bends*, 2012, KTH Royal Institute of Technology.
11. Dutta, P. and N. Nandi, *Effect of Reynolds number and curvature ratio on single phase turbulent flow in pipe bends.* Mechanics and Mechanical Engineering, 2015. **19**(1): p. 5-16.
12. Pisarenco, M., et al., *Friction Factor Estimation for Turbulent Flows in Corrugated Pipes with Rough Walls.* Journal of Offshore Mechanics and Arctic Engineering-transactions of The Asme, 2011. **133**: p. 011101.
13. Colebrook, C.F., et al., *Correspondence. turbulent flow in pipes, with particular reference to the transition region between the smooth and rough pipe laws.(includes plates).* Journal of the Institution of Civil engineers, 1939. **12**(8): p. 393-422.
14. Brkić, D. and Ž. Ćojbašić, *Evolutionary optimization of Colebrook's turbulent flow friction approximations.* Fluids, 2017. **2**(2): p. 15.
15. Offor, U.H. and S.B. Alabi, *An accurate and computationally efficient explicit friction factor model.* Advances in Chemical Engineering and Science, 2016. **6**(03): p. 237.

16. Islam, M., et al., *Study of minor loss coefficient of flexible pipes for different bend angles and different bend radius by experiment and simulation.* Global Journal of Research In Engineering, 2017.