Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 16 Issue 4 Version 1.0 Year 2016
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 Print ISSN: 0975-5861

Study of Minor Loss Coefficient of Flexible Pipes for Different Bend Angles and Different Bend Radius by Experiment and Simulation

By M. S. Islam, Avizit Basak, M. A. R. Sarkar & M. Q. Islam
Bangladesh University of Engineering & Technology

Abstract- The aim of this work is to investigate the minor loss for locally available bended flexible pipes of different dimensions. Minor loss coefficients for different bend angles and different bend radius of these pipes are ascertained, using both experimental method and numerical analysis. Different parameters on which Minor Loss depend were observed and their relations to the Minor Loss were analyzed. Minor loss coefficient for different bend angles and two bend radiuses were determined. Minor losses were measured under different flow rates. The Minor Loss Co-efficient was also determined by solving Navier-Stokes Equation, with the help of standard computer program. For Turbulent Stresses Boussinesq assumption is used. As Turbulence model $\bar{k}$-ε is implemented. Navier-Stokes equations for viscous, incompressible flow shows mixed elliptic-parabolic behavior. So, semi-implicit method for pressure linked equation (SIMPLE) was used.

Keywords: Minor Loss Co-Efficient, Bends, $\bar{k}$-ε Turbulence Model.

GJRE-A Classification: FOR Code: 091399p

STUDYOFMINORLOSSCOEFFICIENTOFFLEXIBLEPIPESFORDIFFERENTBENDANGLESANDDIFFERENTBENDRADIUSBYEXPERIMENTANDSIMULATION

Strictly as per the compliance and regulations of:

Study of Minor Loss Coefficient of Flexible Pipes for Different Bend Angles and Different Bend Radius by Experiment and Simulation

M. S. Islam [α], Avizit Basak [σ], M. A. R. Sarkar [ρ] & M. Q. Islam [Ѡ]

Abstract- The aim of this work is to investigate the minor loss for locally available bended flexible pipes of different dimensions. Minor loss coefficients for different bend angles and different bend radius of these pipes are ascertained, using both experimental method and numerical analysis. Different parameters on which Minor Loss depend were observed and their relations to the Minor Loss were analyzed. Minor loss coefficient for different bend angles and two bend radiuses were determined. Minor losses were measured under different flow rates. The Minor Loss Co-efficient was also determined by solving Navier-Stokes Equation, with the help of standard computer program. For Turbulent Stresses Boussinesq assumption is used. As Turbulence model $\bar{k}$-ε is implemented. Navier-Stokes equations for viscous, incompressible flow shows mixed elliptic-parabolic behavior. So, semi-implicit method for pressure linked equation (SIMPLE) was used.

Keywords: minor loss co-efficient, bends, $\bar{k}$-ε turbulence model.

I. Introduction

The losses that occur in pipelines due to bends, elbows, joints, valves etc are called minor losses. Minor loss in a bend is due to flow separation on the curved walls and a swirling secondary flow arising from the centripetal acceleration. Since the flow pattern in valves, bends and fittings are quite complex, the theory is very weak. The losses are usually measured experimentally and correlated with the pipe flow parameters. In turbulent flow, the Minor Loss varies as the square of the velocity. The form of Darcy's equation used to calculate minor losses of individual fluid system components is expressed by the equation

$$h_m = k\, v^2/2g \quad \text{……………………… (1)}$$

Where, h_m = minor loss for a fitting, k = minor loss coefficient, v = velocity of the fluid for the time. Bends are provided in pipes to change the direction of flow through it. An additional loss of head, apart from that due to fluid friction, takes place in the course of flow through pipe bend. The fluid takes a curved path while flowing through a pipe bend as shown in figure 1. Whenever a fluid flows in a curved path, there must be a force acting radially inwards o n the fluid to provide the inward acceleration, known as centripetal acceleration. This results in an increase in pressure near the outer wall of the bend, starting at some point A and rising to a maximum at some point B. There is also a reduction of pressure near the inner wall giving a minimum pressure at C and a subsequent rise from C to D.

Therefore, between A and B and between C and D the fluid experiences an adverse pressure gradient (the pressure increases in the direction of flow).

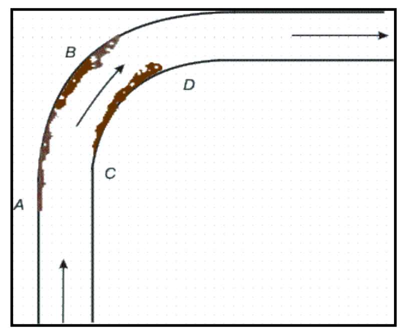

Figure 1: Flow through bend pipe

Fluid particles in this region, because of their close proximity to the wall, have low velocities and cannot overcome the adverse pressure gradient and this leads to a separation of flow from the boundary and consequent losses of energy in generating local eddies.

Losses also take place due to a secondary flow in the radial plane of the pipe because of a change in pressure in the radial depth of the pipe. This flow, in conjunction with the main flow, produces a typical spiral motion of the fluid which persists even for a downstream distance of fifty times the pipe diameter from the central plane of the bend. This spiral motion of the fluid increases the local flow velocity and the velocity gradient at the pipe wall, and therefore results in a greater frictional loss of head than that which occurs for the same rate of flow in a straight pipe of the same length and diameter.

In the context of our study, there are some contributions of particular importance. Khan and Islam [1] made an experimental investigation of flow through flexible pipes and bends. In their work they used metal made pipes. Two manometers were used: one for trough to trough and one for crest to crest readings. Khan, Ahmed, Jonayat [2] determined friction factor of

Author α σ ρ Ѡ: Department of Mechanical Engineering, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh.
e mails: Jony06_buet@yahoo.com,rashid@me.buet.ac.bd

flow through flexible pipes and minor loss coefficient of flexible bends. Ahmed, Chakraborty and Fattah [3] did their work on locally manufactured PRR pipes bends to measure friction factor and minor loss coefficient respectively. In 1895 Reynolds [4] rewrote Navier-Stokes equation in time averaging form. Jones and Launder [5] and Harlow and Nakayama [6] developed k ¯-ε turbulence around 1970 model. In 1972 Caretto, Patanker and Spalding [7] introduced SIMPLE algorithm for solving Navier-Stokes Equations for viscous, incompressible flow. Jaiman, Oakley and Adkins [8] did CFD modeling of corrugated flexible pipes. In their work they constructed a numerical model of the corrugated flexible pipes and did simulation to show variation of velocity distribution throughout the pipe, 2011).

II. Setup & Data Collection

a) Experimental Setup

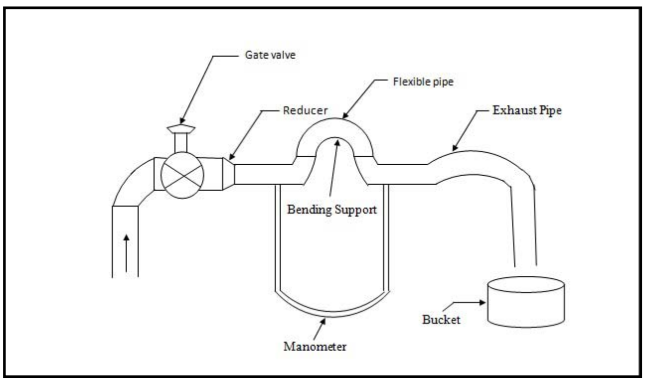

Figure 2: Schematic Diagram of Experimental Setup

b) Specimen Preparation

- At first flexible pipes are trimmed into required length using a hack-saw.
- One PVC pipe (1 inch) is selected corresponding to the diameter of reducer and threads were cut at the end of the PVC pipe to be fitted with reducer.
- The end of the PVC pipe which was to be matched with the flexible pipes was smoothened and chamfered.
- Now using drill machine, two drills transverse to the flexible pipe's length were made at two modes where manometer are required to be connected with pipe nipples With help of two pipe tubes (1.5mm diameter).
- Steps 1 to 4 were repeated for pipe bends. To hold the bended flexible pipes in the desired position stand were used.
- Now that required machining operations are done; specimen were properly washed and cleaned to eliminate dirt, oil and other undesirable internal surface matter.

c) Construction Setup

- One end of the flexible pipe was connected with the corresponding PVC pipe with the help of reducer (reducer is fitted with the gate valve).
- Thread tapes were used to ensure proper sealing in different connections.
- The other end of the flexible pipe was directed to the bucket.
- After preparing the manometer, manometric fluid (CCl4) was injected to it.
- The limbs of manometer were connected to the nipples attached to the specimen through flexible tubes (1.5mm diameter) and fine wires were used to ensure proper sealing.
- Priming of the manometer was performed.
- Two stands were used to maintain the specimen horizontal and wood piece was used to keep the discharge end at elevated height to ensure full flow of water.

d) Data Collection Procedure

In order to collecting data working fluid (water) was allowed to flow through the experimental setup for three different dimensions of the flexible pipe. Differential Manometer was used to measure pressure drop through the bend. As manometric fluid, Carbon Tetra-Chloride (CCL4) was used.

- At first, the inner diameter of the specimen was measured.
- The room temperature was observed.
- Mass of empty bucket was measured.
- The zero level of the manometer was checked.
- By opening the gate valve water was allowed to flow through the testing section and all the sealing was checked.
- Now stop-watch was turned on and water flowing through the pipe was collected to the bucket.
- Steady state manometer readings were collected.
- After a time, stop-watch was turned off and mass of water filled bucket was measured by platform scale.
- Stop-watch reading was taken.
- By changing the gate valve opening flow rate was varied and reading were taken at these flow rates by repeating step six to nine. These way four readings were taken for each bend angle.
- The above procedure was performed for three different diameters and two different bend radius.

III. Theory

The simulation of water flow in a flexible bend pipe of different diameter, bend radius and angle was done by solving the Navier-Stokes Equation, with the help of commercial simulation software ANSYS 13 (WORLBENCH and FLUNET).

The fluid flow phenomenon is governed by the Navier-Stokes Equations. As the temperature change was slight during the experiment. So the simulation was done assuming constant temperature. This simplified the process by decoupling Continuity and Momentum equation from Energy equation. Now, Reynolds Time-averaged Navier-Stokes equation,

Continuity equation:

$$\frac{\partial \bar{u}}{\partial x}+\frac{\partial \bar{v}}{\partial y}+\frac{\partial \bar{w}}{\partial z}=0 \qquad (2)$$

Momentum Equation:

x-component:

$$\rho\left(\frac{\bar{u}(\partial \bar{u})}{\partial x}+\frac{\bar{v}(\partial \bar{u})}{\partial y}+\frac{\bar{w}(\partial \bar{u})}{\partial z}\right)=-\frac{\partial \bar{p}}{\partial x}+\frac{\partial}{\partial x}\left(\mu\frac{\partial \bar{u}}{\partial x}-\rho\overline{u'^2}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial \bar{u}}{\partial y}-\rho\overline{u'v'}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial \bar{u}}{\partial z}-\rho\overline{u'w'}\right) \qquad (3)$$

y-component:

$$\rho\left(\bar{u}\frac{\partial \bar{v}}{\partial x}+\bar{v}\frac{\partial \bar{v}}{\partial y}+\bar{w}\frac{\partial \bar{v}}{\partial z}\right)=-\frac{\partial \bar{p}}{\partial y}+\frac{\partial}{\partial x}\left(\mu\frac{\partial \bar{v}}{\partial x}-\rho\overline{u'v'}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial \bar{v}}{\partial y}-\rho\overline{v'^2}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial \bar{w}}{\partial z}-\rho\overline{v'w'}\right) \qquad (4)$$

z-component:

$$\rho\left(\bar{u}\frac{\partial \bar{w}}{\partial x}+\bar{v}\frac{\partial \bar{w}}{\partial y}+\bar{w}\frac{\partial \bar{w}}{\partial z}\right)=g-\frac{\partial \bar{p}}{\partial z}+\frac{\partial}{\partial x}\left(\mu\frac{\partial \bar{w}}{\partial x}-\rho\overline{u'w'}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial \bar{w}}{\partial y}-\rho\overline{v'w'}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial \bar{w}}{\partial z}-\rho\overline{w'^2}\right) \qquad (5)$$

Here the terms $\rho\overline{u'^2}$, $\rho\overline{u'v'}$ etc are called turbulent stresses.

According to Boussinesq assumption[9]

$$\rho\overline{u'_i u'_j}=2\mu_T S_{ij}-\frac{2}{3}\delta_{ij}\left(\mu_T\frac{\partial u_k}{\partial x_k}+\rho\bar{k}\right) \qquad (6)$$

Where, $S_{ij}=\text{mean strain tensor}=\frac{1}{2}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)$, $\mu_T=$ Turbulent viscosity, $\bar{k}=$ Kinetic energy of turbulence, $u=(u,v,w)$ Fluctuating velocity vector, $x=(x,y,z)=$ Position Vector.

According to $\bar{k}$-ε model [5][6]

$$\mu_T=\frac{C_\mu\rho(\bar{k})^2}{\varepsilon} \qquad (7)$$

Here, ε= Dissipation rate.

The transport equation for kinetic energy of turbulence $\bar{k}$,

$$\rho\left(\bar{u}\frac{\partial \bar{k}}{\partial x}+\bar{v}\frac{\partial \bar{k}}{\partial y}+\bar{w}\frac{\partial \bar{k}}{\partial z}\right)=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_T}{Pr_k}\right)\frac{\partial \bar{k}}{\partial x_j}\right]-\rho\varepsilon+\left(2\mu_T S_{ij}-\frac{2}{3}\rho\bar{k}\delta_{ij}\right)\frac{\partial u_i}{\partial x_j} \qquad (8)$$

The transport equation for Dissipation rate ε,

$$\rho\left(\bar{u}\frac{\partial \bar{\varepsilon}}{\partial x}+\bar{v}\frac{\partial \bar{\varepsilon}}{\partial y}+\bar{w}\frac{\partial \bar{\varepsilon}}{\partial z}\right)=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_T}{Pr_\varepsilon}\right)\frac{\partial \bar{\varepsilon}}{\partial x_j}\right]+C_{\varepsilon 1}\frac{\varepsilon}{\bar{k}}\left(2\mu_T S_{ij}-\frac{2}{3}\rho\bar{k}\delta_{ij}\right)\frac{\partial u_i}{\partial x_j}-C_{\varepsilon 2}\rho\frac{\varepsilon^2}{\bar{k}} \qquad (9)$$

Where, $C_\mu, C_{\varepsilon 1}, C_{\varepsilon 2}, Pr_k$ are constant. The values used in simulation are 0.09, 1.44, 1.92 and 1.0 respectively. And water density and viscosity used are $995.325\ kg/s$ and $7.9\times10^{-4}\ Ns/m^2$ respectively. Boundary condition for simulating water flow in bends are listed below,

1. At velocity inlet u=w=0;v=0.625 m/s
2. At pressure outlet p(gage)=0;
3. At wall no-slip condition.

Navier-Stokes equations for viscous, incompressible flow shows mixed elliptic-parabolic behavior. So, semi-implicit method for pressure linked equation (SIMPLE) [7], [12], [13] was used.

The under-relaxation Constant and Spatial Discretization Method are as follows,

Parameter	Under-relaxation	Spatial Discretization Method
Pressure	0.3	Second Order
Momentum	0.7	Second Order Upwind
Turbulent Kinetic Energy	0.8	Second Order Upwind
Turbulent Dissipation Rate	0.8	Second Order Upwind

And the Stopping Criterion for different equation are given below,

Equation	Residual
continuity	0.0001
x & y - momentum	0.00001
z-momentum, kinetic energy, dissipation rate	0.001

IV. Results

The values of Minor Loss Co-efficient are tabulated for different Pipe Diameter, Bend Radii and Bend Angles. Both data from experiment and simulation are mentioned below.

a) *Experimental Results*

Table 1: Minor Loss Co-efficient (simulation data) at an inlet velocity of 0.625 m/s

No.	Bend RadiD (mm)	Pipe Dia. d (mm)	Ratio $\frac{d}{D}$	Minor Loss Co-efficient k			
				30^0	60^0	120^0	180^0
1	80	5.2	0.065	7.063	5.935	7.028	8.796
2	80	7.2	0.090	6.859	7.928	7.511	7.640
3	80	8.3	0.104	3.545	3.621	3.719	3.556
4	120	5.2	0.043	6.033	6.061	7.856	7.815
5	120	7.2	0.060	7.918	9.345	8.183	7.065
6	120	8.3	0.069	76.31	0.919	4.034	8.500

b) *Simulation Results*

Table 2: Minor Loss Co-efficient curve fitted at an inlet velocity of 0.625 m/s

No.	Bend RadiD (mm)	Pipe Dia. d (mm)	Ratio $\frac{d}{D}$	Minor Loss Co-efficient k			
				30^0	60^0	120^0	180^0
1	80	5.2	0.065	7.494	4.568	12.38	20.01
2	80	7.2	0.090	5.221	2.830	6.066	10.68
3	80	8.3	0.104	4.465	2.128	5.240	11.69
4	120	5.2	0.043	1.156	1.696	2.718	3.734
5	120	7.2	0.060	0.773	1.127	1.827	2.532
6	120	8.3	0.069	0.654	0.963	1.531	2.123

V. Discussion

a) *Error Analysis*

The experimental data has some inevitable errors which affects the result in a little degree. These errors can be classified into two types

- Error in experimental procedure
- Error due to inaccuracy of measuring Devices

The susceptible reasons for the error in experimental data are described briefly below

(a) The pipes used for the experiment may have variable roughness and cross-sectional area. This may have caused error.

(b) Basically, the channels to fit the pipes were made by curving the wooden structure and these channels were not smooth enough to ensure precise data readings.

(c) Traditional Multiple-lever weighting system (bucket_platform) was used for measuring water mass. This method has very poor accuracy.

(d) Priming of manometer was one of the major concerns. As inaccurate priming leads to erroneous pressure drop reading. It is a difficult task. Every time the pipe was changed, manometer had to be primed. It was very time consuming. Even after all the efforts, may be priming was not accurate to its desired level.

(e) Despite all the effort, experimental setup wasn't leak proof. This introduced additional pressure in the system. And in this type of experimental thesis work a small pressure variation can induce a large discrepancy from standard value.

(f) The water flow was controlled by a Gate valve, incorporated with the main water supply line of the laboratory. It is not quite accurate method for flow control. Moreover, while the data was taken from Bend Radius = 120mm, the flow was fluctuating. This induced large error which can be clearly seen from the large difference between experimental and simulation data.

(g) Pipes were flexible. When bend was formed with them, there cross-sectional area got distorted slightly, from uniform circular section to elliptical section. This also caused variable cross-sectional area in the bend.

(h) As CCl4 has low density, it showed large deflection due to small pressure variation. In the setup Manometer scale has limited range. This forced to limit the flow rate to narrow range, as manometric deflection increased with flow rate.

(i) Experiment was done with limited number of pipe, bend radius and bend angle. All the graphs, both experimental and simulation, presented in this paper are best fitted curve, based on quadratic regression.

(j) For simulation temperature variation is not considered, as it complicated matter immensely with only a little change in result. Besides, during our experimentation temperature remained nearly constant.

b) Graph Analysis

i. *Minor Loss Co-efficient Vs. Reynolds Number*

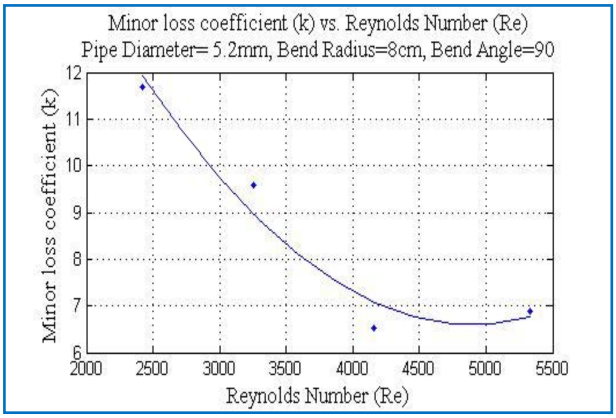

Figure 3: Minor Loss Co-efficient Vs. Reynolds Number

Following observation can be made from the above graph between Minor Loss Co-efficient Vs. Reynolds Number for Pipe of 5.2 mm diameter and Bend Radius and angle of 8 cm and 900.

- The Minor Loss Co-efficient decreases with increase in Reynolds Number. An inverse relation between Minor Loss Co-efficient and Reynolds Number is observed which is in accordance with Ito's formula for Minor Loss Co-efficient.

$$K = constant \times Re^{-0.17}$$

- At low Reynolds Number (2000-4000) Minor Loss Co-efficient diminished at high rate. But At large Reynolds Number (above 4000) the curve becomes flatter. This is may be due to transition from laminar to turbulent flow.

ii. *Minor Loss Co-efficient Vs. Bend Angle*

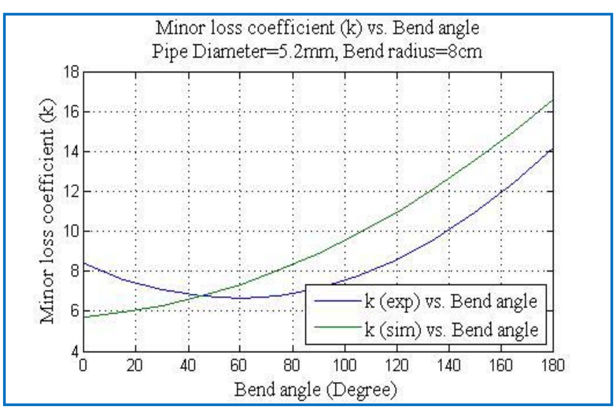

Figure 4: Minor Loss Co-efficient Vs. Bend Angle

The points that can be noticed are listed below:

- The Minor Loss Co-efficient increases with Bend angle, for both experimental and simulation data. These show a power relation between Minor Loss Co-efficient and Bend Angle.

$$(k = constant \times \theta^{n})$$

- The experimental data closely matches with the simulation data.
- The differences between simulation and experimental data are due by many errors and limitation in both experiment and simulation which are briefly discussed in Error Analysis.

iii. *Minor Loss Co-efficient Vs. Ratio between Pipe Diameter and Bend Radius*

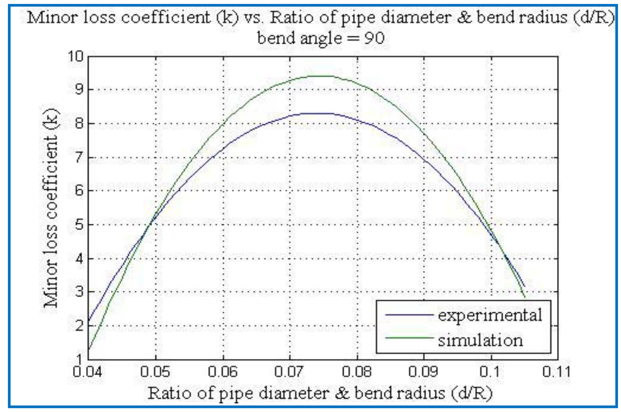

Figure 5: Minor Loss Co-efficient Vs. Ratio between Pipe Diameter and Bend Radius

Discussed below are some observable points,

- The Minor Loss Co-efficient rises until it reaches the maximum (between $\frac{d}{R}$ = 0.06 to 0.08) then it diminishes to lower value.
- The experimental data simulation data are similar.
- The Minor Loss Co-efficient has a parabolic relation with the Ratio of Pipe Diameter and Bend Radius.

VI. Conclusion

This section concludes the study of the minor losses in locally available flexible pipes of diameter 5.2mm, 7.2mm and 8.3mm for bend angle of 300, 600,900,1200,1500,1800 and bend radius 12cm and 8cm.

- Minor loss coefficient in general shows a decreasing trend with respect to Reynolds number for a given angle and pipe diameter.
- For a given Pipe Diameter and Bend Radius increase in bending angle increases Minor loss coefficient.
- For a given Bend angle Minor loss coefficient increases with the ratio of Pipe Diameter and Bend Radius until it reaches a maximum value, then it decreases.

VII. Scope for Future Works

Some guideline for future work is as follows,

1. The thesis work center on the minor losses occurred in locally available flexible pipes. Therefore it will be beneficial to determine total head loss, both minor and frictional loss, developed in a piping system

using flexible pipes and finally required power of the piping system.

2. The simulation was done using SIMPLE solution method, other solution method can be employed to see whether more accurate results are obtained or not.
3. $\bar{k}$-ε turbulence model is utilized in simulating the flow. Different other model like k-ω, Spalart-Allmaras can be used and compared with experimental to find the best model suitable for this specific fluid flow problem.
4. Manometric fluid other than Carbon-tetrachloride (CCl_4) should be used, as CCl_4 manometer shows very large deflection due to small change in pressure.
5. The traditional Platform-Scale method is an outdated measuring technology. It has been a prime source of experimental error. It should be replaced by more modern measuring device like Turbine Flow Meter etc.
6. Further experiment must be conducted on more Pipe Diameter (d), Bend Angle (ϴ) and Bend Radius (R). So that an empirical co-relation between Minor Loss Co-efficient (K) and Reynolds Number (Re), d/R and ϴ can be developed. Present study concluded that K has an inverse relation with Re, parabolic relation with d/R and quadratic relation with ϴ.
7. Further experiment should be conducted to find out the velocity profile. Present study provides with simulated velocity profile.

References Références Referencias

1. V. L. Streeter, E. Benjamin Wylie, Fluid Mechanics. First SI Metric Edition, McGraw-Hill Book Co., Singapore.
2. P.N. Modi, S.M. Seth, Hydraulic and Fluid Mechanics Including Hydraulic Machines. Fourteenth edition 2002, Standard Book House.
3. Md. Quamrul Islam, A.K.M Sadrul Islam, Fluid Mechanics Laboratory Practice, World University Service Press, ISBN 984-518-000-0
4. M.H. Khan, Md. Quamrul Islam, "An Experimental Investigation of Flow Through Flexible Pipes and Bends", Journal of Institution of Engineers, Bangladesh, Vol7,No. 3 July,1979.
5. R. K. Jaiman, O. H. Oakley Jr., J.D. Adkins, "CFD Modeling of Corrugated Flexible Pipe", OMAE 2011-20509.
6. Z. H. Ayub, S. F. Al-Fahed, "The effect of gap width between horizontal tube and twisted tape on the pressure drop in turbulent water flow, Int. J. Heat and Fluid Flow", Vol. 14, No. 1, March 1993.
7. A. W. Date, "Prediction of Fully developed Flow in a Tube Containing a Twisted Tape", Int. J. Heat Mass Transfer, Vol. 17, pp. 845-859. Pergamon Press 1974, Great Britain.
8. Md. Hafizur rahman, A. K. Roy, Md. S. Hossain, "Determination of Minor head Loss and Friction Factor for locally Available PVC pipe Reducers". BUET, September-2009.
9. Md. Rokonuzzaman Khan, Saad Ahmed, A. S. M. Jonayat, "Determination of friction Factor of Flow through Flexible Pipes and Minor Loss Coefficient of Flexible Bends", BUET, February-2011.
10. Isfak Ahmed, Pranay Chakraborty, Md. Rizwanul Fattah, "An Experimental Study of Loss Characteristics of Polypropylene Random (PPR) Pipes Pipe Elbows". BUET, February-2011.
11. F.M. White, Fluid Mechanics, 5th ed., McGraw-Hill, New York, 2003.
12. W.P. Jones and B.E. Launder. "The prediction of laminarization with a two-equation model of turbulence", Int. J. Heat Mass Transfer, vol. 15, 1972.
13. F.H. Harlow and P.I. Nakayama, "Transport of turbulence energy decay rate", Los Alamos Scientific Laboratory Report LA-3854, Los Alamos, New Mexico, 1968.

Nomenclature

Symbol	Meaning	Unit
p	Pressure	(Pa)
V	Velocity	(m/s)
Z	Elevation	(m)
g	Acceleration due to Gravity	(m/s^2)
d_o	Outside diameter of pipe	(m)
d	Inside diameter of pipe	(m)
t	Time	(sec)
R	Bend radius	(m)
θ	Bend angle	(degree)
γ_m	Specific weight of manometric fluid	(kN/m^3)
T	Temperature	(^oC)
H_m	Deflection in manometer	(m)
γ	Specific weight of water	(kN/m^3)
ρ	Density	(kg/m^3)
μ	Absolute viscosity	(Ns/m^2)
$h_{f(total)}$	Total head loss	(m)
$h_{f(major)}$	Major head loss	(m)
$h_{f(minor)}, h_m$	Minor head loss	(m)
Q	Volumetric flow rate	(m^3/s)
Q_m	Mass flow rate	(kg/s)