Journal of Energy Technologies and Policy
ISSN 2224-3232 (Paper) ISSN 2225-0573 (Online)
Vol.6, No.5, 2016

Development of a Test Rig for the Determination of Headloss and Friction Factor of Polyvinyl Chloride (PVC) Pipes

*Musa, N.A. Jiya, J. Y Aderoju T.K.
Department of Mechanical Engineering, Federal University of Technology Minna. Nigeria

Abstract
This paper reports the design, construction and performance evaluation of a test rig for determining the head loss and friction factor of PVC pipes of different diameters (13mm, 19mm and 25mm) transporting water. On performance evaluation, friction factors of 0.0121, 0.0396 , 0.0171 and head losses of 37.8mm, 25.2mm and 12.6mm for 13mm, 19mm, and 25mm diameter PVC pipes respectively were obtained.
Keywords: Head loss, friction factor, PVC pipes, test rig, water

1.0 INTRODUCTION

When a fluid flows from one point to another in a pipe, there is always a head loss, which is caused by the friction of the fluid with the inner surface of the pipe wall and by turbulences of the fluid flow. So, the greater the roughness of the pipe wall or the more viscous the fluid, the greater the head loss (Diniz and Souza.2015)

The determination of head losses is an important engineering factor in the design of pipe networks that affects total cost as well as the hydraulic balance of the network. Pipe sizing in a network is dependent on the magnitude of allowable friction losses calculated by the pipeline designer. An over or under estimation of head loss caused by water flow in pipes will result in the selection of larger or smaller pipe and pump sizes than that are actually needed, thus affecting total cost and pressure distribution in the network(13_chapter 2.pdf, 2016)

An important and integral part of the pressure drop or head loss in a pipe involves the determination of the friction factor (Ghanbari et al, 2011). Friction factor is a function of the wall roughness, that is the internal roughness of the pipe which depends on the size , spacing and the shape. It is also a function of the flow regime characterised by the Reynolds number (Lahiouel and Haddad, 2002). Pressure drop depends upon the friction factor and researchers have proposed different correlations in the past to predict the friction factor for general fluid flow conditions (Joshi and Khandwawala, 2014).

The headloss or pressure loss in pipes can be obtained by using Darcy,s Weisbach equation which depends on friction factor, velocity of flow, pipe length, pipe diameter and acceleration due to gravity. The standard methods of calculating the fluid friction factor, the Colebrook–White and Haaland equations, require iterative solution of an implicit, transcendental function which entails high computational costs for large-scale piping networks while introducing as much as15% error (Besarati et al,2015). However, Sodiki and Adigio(2014) reviewed the historical development of the common methods of estimating the frictional loss and the loss through pipe fittings in water distribution systems (respectively, the Hazen-Williams and Darcy-Weisbach equations), furthermore, outlined the methods of applying these equations to index pipe runs. Salmasi et al(2012) evaluated the performances of explicit formulations for estimating the friction factor in the Darcy-Weisbach equation, while using artificial neural networks (ANNs) and genetic programming (GP) to avoid the need for a time-consuming and iterative solution of the Colebrook-White equation. The study involves the generation of data and comparisons between the various techniques with the numerical solutions of the Colebrook-White equation. . Ghanbari et al (2011) developed a new friction factor equation based on the nonlinear multi variable surface fitting tool in MATLAB. The equation correlates the friction factor to the Reynolds number and the relative roughness by means of simple logarithmic and exponential functions. They used statistical analysis to test and validate their model, making it easy without carrying out rigorous iterative method, Asker et al(2014) performed a review of several friction factor correlations. Relative error of these correlations was re-evaluated against the Reynolds number for a different value of relative pipe roughness. Also statistical analyses were given for each correlation**.** Ahmed et al(2011) investigated and standardized the head loss and friction factors for locally available straight flexible pipes of different dimensions. They developed an experimental setup to determine friction factor and minor loss coefficient. Frictional losses & friction factor coefficient was determined by Darcy-Weisbach equation .The experimental data shows that for a given pipe size (diameter), with the increase of Reynolds number, head loss per unit length increases. For a given Reynolds number, with increase of pipe diameter the head loss per unit length decreases. Csizmadia and H″os(2013) opined that when designing pipeline systems for transportation of non newtonia fluids , predicting the pressure drop for a given flow rate is of primary importance. They therefore studied the friction factor in straight pipelines experimentally and by means of Computational Fluid Dynamics (CFD) techniques in the case of power-law and the Bingham plastic fluids. First, the accuracy of the CFD technique was demonstrated in the case of water. Then, a power-law fluid (Carbopol 971 solution) was examined experimentally and numerically and it was confirmed that by introducing the modified Reynolds number, the classic friction factor formulae can be used. In the case of the Bingham plastic fluids, CFD simulations were performed and friction factor curves for several Hedström numbers were reported which were found to be consistent with the corresponding literature. Rettore-Neto et al (2014), remarked that plastic materials such as polyethylene allow significant changes in pipe cross section due to operating pressure, but traditional equations used for determining head loss do not account for this effect. They therefore developed an equation for determining friction head loss along elastic pipes. The equation developed is based on the Darcy–Weisbach equation and focuses on pipe cross sectional variations caused by pressure effects, hence the name pressure-dependent head loss equation (PDHLE). In addition to the parameters required by the Darcy–Weisbach equation, the PDHLE also considers the modulus of elasticity of the pipe material, the pipe wall thickness, and the internal diameter variation due to operating pressure. The PDHLE resulted in high accuracy in determining the friction head loss of elastic pipes.

If the flow parameters of fluid(water) in pipes and pipe characteristics are known, the friction factor can be obtained or found from a Moody diagram or by solving Colebrook equation. If the flow parameters of the fluid in pipes are not known, trial and error methods and cumbersome iterations are carried out to obtained friction factor as well as the head loss.

Polyvinyl chloride (PVC) pipes are widely used both domestically and industrially to transport fluid especially water from one point to another for use. It is very scanty in known literature, where charts are used to determine the friction factor as well as the head loss of PVC pipes, which aid in determining the pump size and power requirement of the pump to transport or convey water or fluid through the pipes. So in order to obtain the friction factor, head loss and other flow parameters of PVC pipes experimentally, a test rig was developed and its performance evaluation was carried out, which form the main aim of this research work.

2.0 MATERIALS AND METHODS

2.1 Design Theory and calculations

The following materials were considered for the design of the test rig.

1. Reservoir and colleting tanks
2. Pipes (inlet and outlet) from the pump
3. Centrifugal pump
4. Pipe fittings.

2.2 Design of the Tanks (reservoir and Collecting tanks)

There are two cylindrical tanks made of aluminum, one serves as the reservoir where water which is pumped through the rig is stored. And the other serves as the collecting tank which collects the water that is used to run the experiment. Both tanks are the same.

Since the tanks are the same, the design parameters are as follows;

1. The diameter of the tank, d = 0.4m
2. The height of the tank, h = 0.49m

2.3 Determination of the Capacity of the Tanks

The capacity or volume of the tank is given as;

$$V = \pi r^2 h \quad (1)$$

$$V = \pi 0.2^2 \times 0.49 = 0.061\text{m}^3$$

2.4 Determination of the Thickness of the Tanks

These tanks (reservoir and collecting tanks) are made of aluminum sheet and are likened to be thin cylindrical pressure vessels. So, the thickness of the tanks is given by Khurmi and Gupta (2005) as;

$$t = \frac{pd}{2\,\sigma_t} \quad (2)$$

Where P = internal pressure in the tank which is due to hydrostatic pressure and atmospheric Pressure.

d = internal diameter of the cylinder

S_u = 110Mpa (MFVWS, 2014)

S_F = factor of safety of tank material = 5(assumed)

σ_t= allowable tensile stress of the material (aluminium) of the cylinder which is taken to be 22Mpa (since allowable tensile stress = $\frac{ultimate\ tensile\ stress}{factor\ of\ safety} = \frac{110}{5} = 22Mpa$)

The internal pressure in the tank P is given as;

$$P = P_h + P_{atm} \quad (3)$$

But P_h which is the hydrostatic pressure is given as;

$$P_h = \rho g h \quad (4)$$

Where ρ = density of water = 1000kg/m^3

g = 9.81m/s^2 and

h = depth of water in the tank = 0.49m

Substituting these values into equation (4) we have,

$$P_h = 1000 \times 9.81 \times 0.49 = 4806.90 N/m^2$$

P_{atm} = atmospheric pressure = 101325N/m^2
Substituting the values of P_h and P_{atm} into the equation (3) we have that,
$P = 4806.90 + 101325$ = 106131.90N/m^2
Substituting the values of P and σ_t into equation (2) we have,

$$t = \frac{106131.90 \times 0.4}{2 \times 22 \times 10^6} = 9.64 \times 10^{-4} m \approx 0.96 mm \approx 1 mm$$

So aluminum sheet of thickness 1mm was selected and used to produce the tanks.

2.5 Design of the Pipes (inlet and outlet) of the Pump

Polyvinyl chloride (PVC) pipes were used to transport water from the reservoir by the pump through test section of the rig to the collecting tanks. What is paramount in the design is the design of the inlet pipe of the pump and the outlet pipe of the pump which are of the same sizes.

2.6 Determination of the Diameter of the Pipes

According to Khurmi and Gupta,(2005) the pipe diameter is given as,

$$D = 1.13\sqrt{\frac{Q}{V}} \qquad (5)$$

Where Q is the flow rate or discharge of water through the pipe, in this case, it is taken to be 0.0012m^3/s. and
V = velocity of water flowing through the pipe.
According to MFVWS(2014), velocity of water flowing through the pipe is between 1.0 and 2.5m/s. But in this case it is taken to be 2.0m/s.
Substituting the values of Q and V into equation (5), we have

$$D = 1.13\sqrt{\frac{0.0012}{2.0}} = 2.77 \times 10^{-2} m \approx 27.7 mm$$

So, standard PVC pipe size of 25.4mm was selected for the inlet and the outlet pipes.

2.7 Pump Selection

Centrifugal pump was used to pump water through the test rig. The selection of the pump was based on the power required to drive the pump or the power input to the pump and the power output of the pump

2.8 Determination of the Power required to drive the Pump

The power output P_O of the pump is given as,

$$P_O = \rho g Q H_{mano} \qquad (6)$$

Where manometric head, H_{mano} according to Rajput (1998) is given as

$$H_{mano} = h_S + h_d + (h_{fs} \text{ or } h_{fd}) + \frac{V^2 d}{2g} \qquad (7)$$

And the suction head h_S is taken as 0.8m, the discharge head h_d is taken to be 1.56m
The frictional head loss in the suction pipe h_{fs} = frictional loss in the delivery pipe h_{fd}

$$\therefore h_{fs} \text{ or } h_{fd} = \frac{4fLV^2}{D \times 2g} \qquad (8)$$

Where the entire length of the pipe L = 4.9m
The coefficient of friction is taken f is taken to be 0.01 for the pipe line.
V = 2.0m/s
D = 25.4mm $\approx 0.0254m$
g = 9.81m/s^2
Substituting the values of L, V, f, D, and g into equation (8), we have,

$$h_{fs} \text{ or } h_{fd} = \frac{4 \times 0.01 \times 4.9 \times 2^2}{0.0254 \times 2 \times 9.81} = 1.57m$$

Also substituting the values of h_{fs} or h_{fd}, h_S, h_d, V and g into equation (7) we have,

$$H_{mano} = 0.8 + 1.56 + 1.57 + \frac{2^2}{2 \times 9.81} = 4.13m$$

Substituting the values of H_{mano}, density ρ, of water, of 1000kg/m^3, acceleration due to gravity, g of 9.81m/s^2 and the flow rate of water, Q of 0.0012m^3/s into equation (6)

$$P_O = 1000 \times 9.81 \times 0.0012 \times 4.13 = 48.62W$$

The overall efficiency η_O of the pump is taken as 80% ≈ 0.8

∴The power input to the pump, $P_i = \frac{P_O}{\eta} = \frac{48.62}{0.8} = 60.78W$

So a centrifugal pump with power rating of $\frac{1}{2}hp$ was selected.

2.9 Selection of Pipe Fittings

The pipe fittings which include gate valves, elbows, and various tees were selected based on the determined or designed diameter of the inlet and outlet pipes of 25.4mm. So all the pipe fittings were 25.4mm in diameter except those that were fitted to the test section of the rig which were of 1/2inch(13mm), 1inch(25mm), and 3/4inch(19mm) respectively.

The test rig was developed based on the design theory and calculations. The components drawings, assembly drawings and pictorial view of the developed test rig are shown in Figures 1, 2 and plate I respectively.

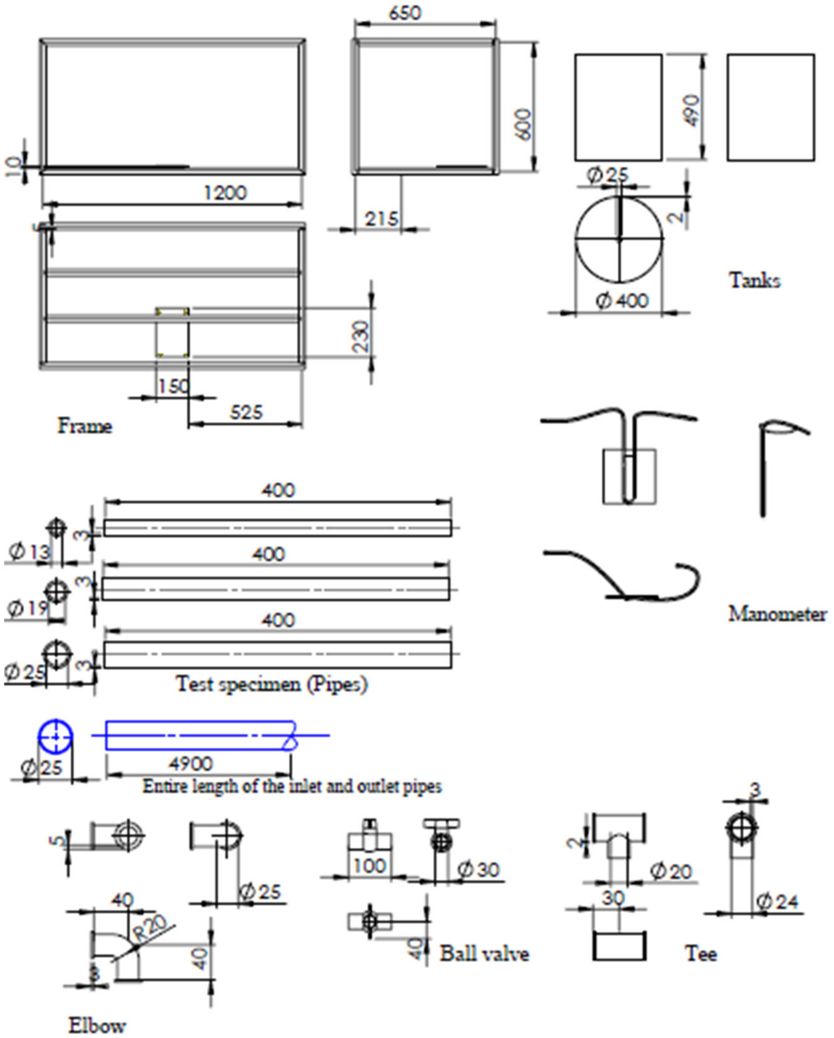
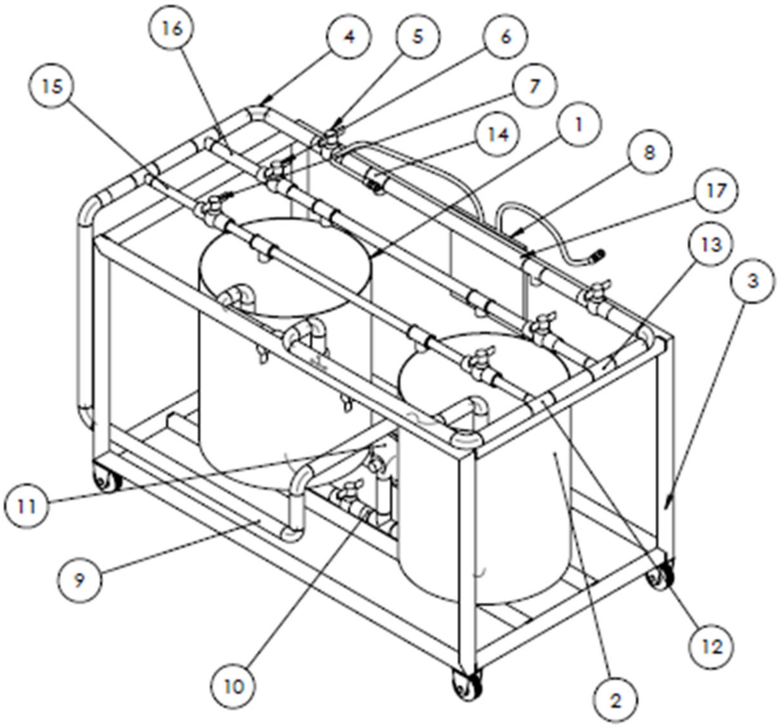


Figure 1: Components drawing of the Test rig.



s/n	PART	MATERIAL	Qty
1	TANK (RESERVOIR)	ALUMINUM	1
2	COLLECTING TANK	ALUMINUM	1
3	FRAME	MILD STEEL	1
4	ELBOW	PLASTIC	16
5	BALL VALVE 25mm	PLASTIC	6
6	BALL VALVE 19mm	PLASTIC	2
7	BALL VALVE 13mm	PLASTIC	2
8	MANOMETER	RUBBER	1
9	OUTLET PIPE	PLASTIC	1
10	INLET PIPE	PLASTIC	1
11	CENTRIFUGAL PUMP		1
12	TEE JOINT 13mm	PLASTIC	2
13	TEE JOINT 19mm	PLASTIC	2
14	TEE JOINT 25mm	PLASTIC	8
15	PVC PIPE 13mm	PLASTIC	1
16	PVC PIPE 19mm	PLASTIC	1
17	PVC PIPE 25mm	PLASTIC	1

Figure 2: Assembly Drawing of the Test rig

Plate I: Pictorial view of the developed Test rig

2.10 Performance Evaluation

Water was fed into the reservoir tank and the volume was noted.The outlet valve of the reservoir tank was opened and the pump was switched on, Prior to switching on the pump, the header valve for the test section as well as the valve for the pipe to be tested were opened, while the valves of other pipes were closed. As the water flows through the tested pipe to the collecting tank, the manometric deflection on both limbs of the mercury manometer was noted and the time it takes to fill the collecting tank was taken by stop watch. These experiment were repeated five times for pipe diameters of 13mm, 19mm and 25mm respectively in the test section. The arithmetic means of the values of obtained were used for the computations

For each pipe ,the actual discharge, velocity, headloss , friction factor and Reynolds number were determined using the following relations:

Actual discharge, $Q_{act} = \frac{Volume\ of\ water\ collected}{Time\ taken}$ (9)

The velocity of flow of water, $V = \frac{Q_{act}}{A}$ (10)

Where A is the pipe cross sectional area

The headloss, $h_f = (\frac{\rho_m}{\rho_w} - 1)(h_2\text{-}h_1)$ (11)

Where ρ_m is the density of the manometric fluid(mercury), ρ_w is the density of water and h_2-h_1 is the manometric deflection of the manometer.

Friction factor, $f = \frac{2gDh_f}{lV^2}$ (12)

Where D, l and g are the pipe diameter, pipe length and acceleration due to gravity respectively.

The Reynolds, Number, $Re = \frac{VD}{\gamma}$ (13)

Where γ is the kinematic viscosity of water.

3.0 RESULTS AND DISCUSSION

The flow parameters through the PVC pipes viz-a-viz volume, time, velocity, actual discharge and Reynolds number are shown in Table 1.

Table 1. Flow parameters through the PVC pipes

Pipe diameter(mm)	Volume(m^3)	Time(s)	Actual discharge(m^3)	Velocityof flow(m/s)	Reynold,s Number(Re)
13	0.0225	120	$1.875x10^{-4}$	1.41	15,275
19	0.0175	80	$2.1875x10^{-4}$	0.77	13,191.67
25	0.0140	30	$4.667x10^{-4}$	0.95	19,791.67

It can be seen from Table 1 that as the pipe diameter increased the, volume of water and time of flow decreased but the actual discharge increased. The velocity of flow and the Reynolds number fluctuated as the pipe diameter increased from 13mm to 25mm.

The Variation of head losses with PVC pipe diameters is shown in figure 3.

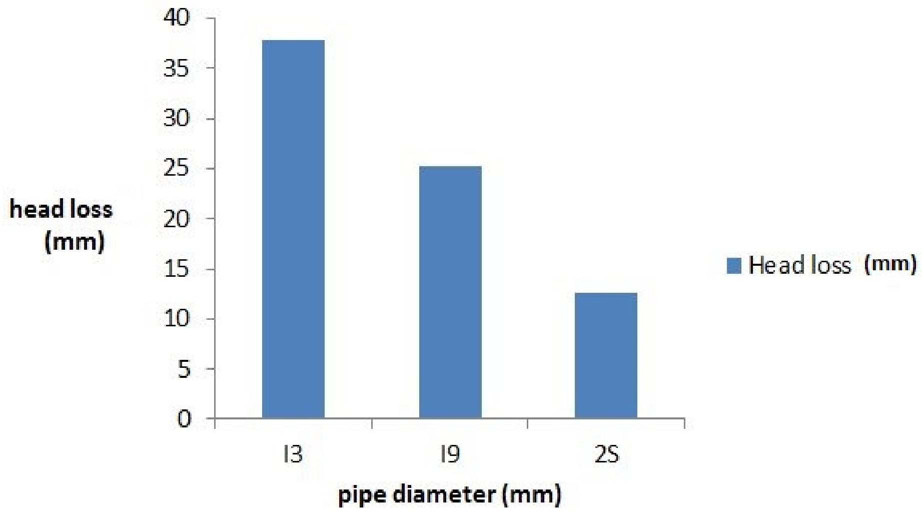


Figure3:Variation of head losses with PVC pipe diameters

It can be seen from Figure 3 that the head loss reduced from 37.8mm to 25.2mm and 12.6mm as the pipe diameter increased from 13mm to 19mm and 25mm respectively.

The variation of friction factors with PVC pipe diameters is shown in figure 4.

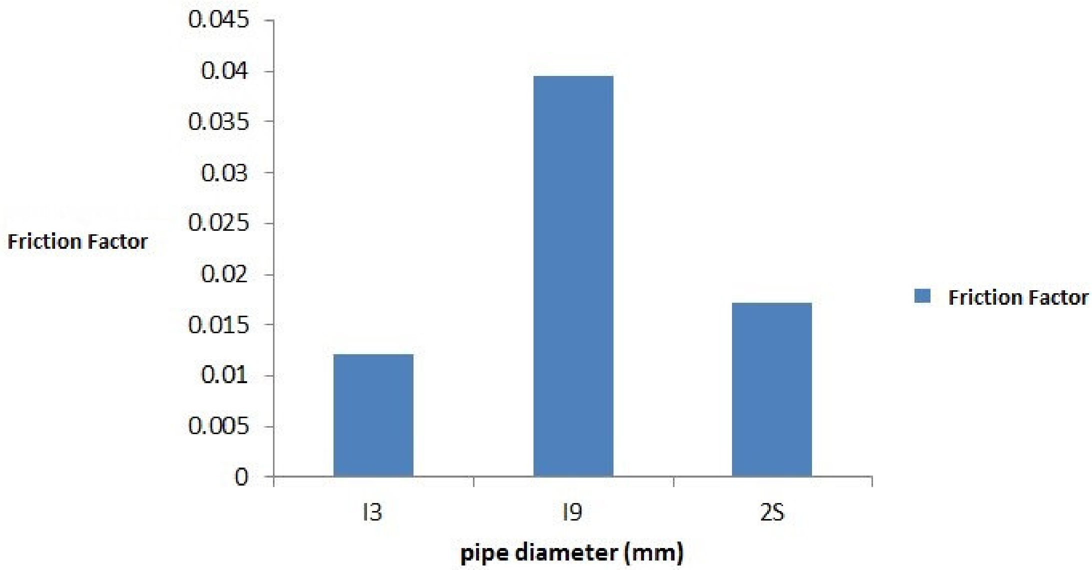


Figure 4: Variation of friction factors with PVC pipe diameters

It can be seen from figure 4 that the friction factor fluctuated as the pipe diameter increased from 13mm to 25mm. Friction factor was 0.0121 for 13mm pipe, it became 0.0396 and 0.0171 when pipe diameter changed to 19mm and 25mm respectively.

4.0 CONCLUSION

The development of a test rig which allows the actual determination of headloss and friction factor of PVC pipes has been achieved in this research work. It can be concluded that the cumbersome and time consuming iteration process coupled with trial and error method of determining friction factor and headloss of pipes (PVC pipes) can be overcome by the use of the developed testrig.

REFERENCES

Ahmed, S; Islam M. Q. and Jonayat A. S. M(2011) Determination of loss coefficient for flow through flexible pipes and bends. Proceedings of the International Conference on Mechanical Engineering 2011 (ICME2011) 18-20 December 2011, Dhaka, Bangladesh.

Asker, M; Turgut, O. E and Coban, M. T(2014). A review of non iterative friction factor correlations for the calculation of pressure drop in pipes. Bitlis Eren Univ J Sci & Technol 4 (1), 1-8.

Besarati; S.M, Myers; P.D, Covey; D.C and Ali Jamali; A(2015). Modeling friction factor in pipeline flow using a GMDH-type neural network. *Cogent Engineering* (2015), 2: 1-14

Csizmadia; P and H″os; C(2013).Predicting the friction factor in straight pipes in the case of bingham plastic and the power-law fluids by means of measurements and CFD simulation. Periodica Polytechnic Chemical Engineering 57/1–2 (2013) 79–83.

Diniz, V. E. M. G and Souza, P. A (2016) Four explicit formulae for friction factor calculation in pipe flow. Retrieved on the 24th of February, 2016 from http://ssrn.com/abstract=1667304

Ghanbari A., Farshad F. F and Rieke H. H(2011) Newly developed friction factor correlation for pipe flow and flow assurance. Journal of Chemical Engineering and Materials Science Vol. 2(6) : 83-86.

Joshi, R and Khandwawala, A.I(2014) Effect of relative surface roughness of condenser material on friction factor in a domestic refrigerator. International Journal of Engineering Science Invention. 3(2):13-18.

Khurmi, R.S. and Gupta, J.K. (2005). A text book of Machine Design. First multicolored revised edition and updated Edition. Eurasia publishing home P. Ltd Ram Nagar New Delhi

Lahiouel; Y and Haddad; A(2002). Evaluation of energy losses in pipes. The 6th Saudi Engineering Conference, KFUPM, Dhahran, December 2002 Vol. 5,pp577-589

MFVWS(2014). Maximum flow velocities in water systems. Retrieved from http://www.engineeringtoolbox.com/flow-velocity-water-pipes-d on November 1, 2014

Rajput, R. K. (1998). A text book of Fluid Mechanics and Hydraulics Machine in SI units S.Chand and company Ltd. Ram Nagar New Delhi.

Rettore- Neto, O; Botrel, T A; Frizzone, J A; Camargo, A P(2014). Method for determining friction head loss along elastic pipes. **Irrigation Science**, (2014)32 : 329-339.

Salmasi, F, Khatibi, R and Ghorbani, M. A(2012).A study of friction factor formulation in pipes using artificial intelligence techniques and explicit equations. Turkish J. Eng. Env. Sci.36 (2012) :121 – 138.

Sodiki, J. I and Adigio, E. M(2014). A review on the development and application of methods for estimating head loss components in water distribution pipework. American Journal of Engineering Research (AJER) 3(9): 91-96 13_Chapter 2.pdf(2015). Friction Factor Studies on domestically used PVC pipes. Retrieved on the 5th of June, 2015from Shodhganga.inflibnet.ac.in/bitstream/10603/4525/13/13_chapter %202.pdf