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Research Article

THEORETICAL AND EXPERIMENTAL COMPARISON OF LOSSES IN PIPING SYSTEMS USING A SIMILAR BUT MORE COMPLEX APPARATUS THAN THAT USED BY OSBORNE REYNOLDS

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A B S T R A C T

The objective of this research work was to experimentally determine the losses in a piping system categorized into major and minor losses and compare the results obtained to their theoretical value using a similar but more complex apparatus than that used by Osborne Reynolds. Different experiments were performed and results obtained using a more complex apparatus than that used by Osborne Reynolds. In the experiment, pressure loss measurements were made as a function of flow rate on differential pipe components namely straight pipes, globe valve, gate valve, an expander (sudden expansion), a reducer (sudden contraction) standard elbow and 900 elbow. The result of this experiment was compared to that obtained from theoretical equations for pressure loss across a pipe using dimensionless groups such as Reynolds number, Moody friction factor, modified Bernoulli's theorem, Darcy - Weisbach equation and the concept of flow regime. The result shows that the flow was turbulent since the Reynolds number was greater than 2×10^3 and that the theoretical frictional head loss was 0.14m while that of the experimental head loss was 0.17m. The results when compared show that the values obtained experimentally and theoretically are within range and closely linked. The difference was mainly contributed by experimental errors.

INTRODUCTION

Flow system in pipe is basically described as either laminar or turbulent and flows through pipes, nozzles, ducts etc. are usually known as internal flows. Therefore a closed conduit of circular cross-section through which fluid flows is called a pipe.In hydraulic engineering practice, it is frequently necessary to estimate the head loss incurred by a fluid as it flows along a pipeline. For example, it may be desired to predict the rate of flow along a proposed pipe connecting two reservoirs at different levels, or it may be necessary to calculate what additional head would be required to double the rate of flow along an existing pipeline. Loss of head along a pipeline is incurred both by frictional resistance at the wall along the run of the pipe and by mixing which occurs at fittings such as bends or valves, sudden contraction, sudden expansions etc. for a long pipe with few fittings, the overall loss is dominated by wall or wall skin friction (major losses), if however, the pipe is short and there are numerous fittings, then the principal losses are those which are produced by disturbances caused by the fittings(valves) , bends etc.

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In the experiments to be later discussed, we will investigate losses along a straight pipe with smooth walls and losses at various fittings, typical of those which are used frequently in pipe systems.

In the study of engineering as a profession, scholars likewise practicing engineers are faced with challenges and problems. One of the problems and challenges connected with engineers and students is determining and finding solutions to flow problems such as losses along a pipe, intensive studies and proper understanding of principles, theories and governing equations of fluid mechanics and hydraulic, is an essential background or foundation. The flow in a pipe is termed pipe flow only when the flow completely fills the cross section. Therefore a pipe running partially full behaves like an "**open channel**". A flow in a pipe system can be characterized as laminar (viscous) and turbulent in the case of Newtonian fluid depending on characteristics of Reynolds number, VL/μ. The distinction between the laminar and turbulent flow is dependent on an appropriate dimensionless quantity (Re) which was first demonstrated by Osborne Reynolds through his study and experiment in the year 1883 [1]. Pipe flow under pressure is used for a lot of purposes. A fundamental understanding of fluid flow is essential to almost every industry related with mechanical and chemical engineering. In the manufacturing industry, large flow networks are necessary to achieve continuous transport of products and raw materials from different processing units. This requires a detailed understanding of fluid flow in pipes. This energy input is needed because there is frictional energy loss (also called frictional head loss or frictional head drop) due to friction between the fluid and the pipe wall and internal friction within the fluid. In pipe flow, substantial energy is lost due to frictional resistance. One of the most common problems in fluid mechanics is the estimation of this pressure loss. Calculating pressure losses is necessary to determine the required work and therefore select appropriate size of pump. Knowledge of the magnitude of frictional losses is of great importance because it determines the power requirement of the pump forcing the fluid through the pipe. For example, in refining, petrochemical and power generation plants or industries, these losses have to be calculated accurately to determine where booster pumps have to be placed when pumping crude oils or other fluids in pipes to distances thousands of kilometers away.

Therefore in this experiment, a similar related but more complex apparatus than that used by Osborne Reynolds was constructed and run to perform a different experiment. In the experiment, pressure loss measurements are made as a function of flow rate on differential pipe components namely

- ✓ Straight pipes
- ✓ Globe valve
- ✓ Gate valve
- ✓ An expander (sudden expansion)
- ✓ A reducer (sudden contraction)
- ✓ Standard elbow
- ✓ 90^0 elbow.

The main and vital purpose of this project is to study, research, and prove the losses along the pipe which is categorized into two types i.e. major and minor losses. This project is directed towards the design and construction of an apparatus used in determination of losses along piping systems, test and run related experiments and compare results with the theoretical values. The transportation of fluid such as oil, water etc. over great distances needs a thorough understanding of the kind of losses in pipes or pipelines and proper quantification of the pressure to get the measurement of flow parameter for the calculation of the Reynolds Number.

Literature Review

The basic principles that are used in calculating the pressure that are lost across a pipeline are modified Bernoulli's equation and Darcy's friction factor concept. These equations are subsequently used in developing the equations for calculating the pressure distribution in a pipeline. A thorough understanding of some basic principles and equations is required for the calculation of pressure loss across a pipeline. These fundamental principles are used to derive equations for pressure loss across a pipeline. They include the use of dimensionless groups such as the Reynolds number and the Moody friction factor, modified Bernoulli's theorem, Darcy's equation and the concept of flow regimes.

Reynolds Number

The Reynolds number Re is a dimensionless number that gives a measure of the ratio of inertial forces to viscous forces and thus shows the contribution of these forces to fluid flow [1]. The Reynolds number is an indicator of the flow regime of the flowing fluid. In general, Re less than 2100 implies laminar flow, greater than 4000 implies turbulent flow and a number in between is considered as transitional flow [2]. Laminar flow occurs when there is little mixing of the flowing fluid, and this means that the fluid flows in parallel with the pipe wall.

$$\text{RE} = \frac{inirtia\ forces}{viscous\ forces} = \frac{\frac{\rho V^2}{D}}{\frac{\mu V}{D^2}} = \frac{\rho VD}{\mu} = \frac{VD}{v} = \frac{QD}{vA} \quad \text{.... 1}$$

Re = Reynolds number
D = internal diameter of the pipes
v = kinematic viscosity of the pipe = $\frac{\mu}{\rho}$
Q = volumetric flow rate
μ = viscosity
ρ = density
V = velocity
A = Cross sectional Area

The Reynolds number is very essential to describing the flow regimes of the flowing fluids and then used to determine the necessary equations to be used in the calculation of pressure loss. It is important to know what flow regime the fluid is in before selecting the equation to use to calculate pressure loss. To solve for problems in transitional flow, the values for transitional flow are obtained via interpolation between the laminar and turbulent flow values. Figures 1a and 1b represent the velocity profiles for laminar and turbulent flow respectively. In laminar flow the velocity profile is parabolic with the maximum velocity at the center of the pipe as shown in Figure 1a. For turbulent flow however, the layers of fluid completely mix and this results in a more uniform, slightly varying, velocity profile as shown in Figure 1b.

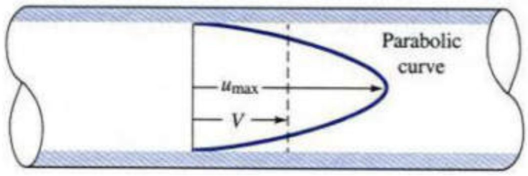


Figure 1a Velocity profiles for Laminar flow

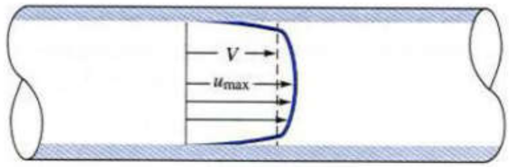


Figure 1b Velocity profiles for turbulent flow

Energy Equation

The simplest form of the energy equation for incompressible fluid is expressed as

$$h_p + \frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_L \quad \text{... 2}$$

The Bernoulli's equation is another essential equation to fluid flow calculations. Bernoulli's principle states that for an inviscid (non-viscous) flow, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy. The simplest form of the Bernoulli equation can be used for incompressible flow [3].

Darcy's Equation

Darcy's equation in head loss form is another fundamental equation in fluid flow. It was first proposed by Darcy and modified by Weisbach in 1845. It related the head loss or pressure loss due to friction along a given pipe length to the average velocity of the fluid [3].

$$H_L = \frac{fLV^2}{2gD} \qquad .... 3$$

The above expression is called the Darcy equation in head loss form and another form of the equation called the pressure loss form. The equation in pressure loss form can be written as

$$\Delta P_f = 0.0013\frac{f\rho LV^2}{d} \qquad .....4$$

Where,

ΔP_f = pressure loss, psi
f = moody friction factor
ρ = density, lb/ft^3
L = length of pipe, ft
V = velocity, ft
d = pipe diameter, inches

Friction Factor

The Moody friction factor, credited to Moody (1944) after his study on friction factors for pipe flow is an important parameter in describing friction losses in pipe and open channel flow. It is highly dependent on the flow regime which is another reason why the Reynolds number is very important. The Moody chart relates the friction factor, f, Reynolds number, and relative roughness for fully developed flow in a circular pipe. It is used to calculate the pressure drop across the circular pipeline. The Moody chart can be divided into laminar and turbulent regions. For the laminar flow region, the friction factor is expressed as a function of the Reynolds number alone while for turbulent flow however, the friction factor is a function of Re and pipe roughness [4]; [5].

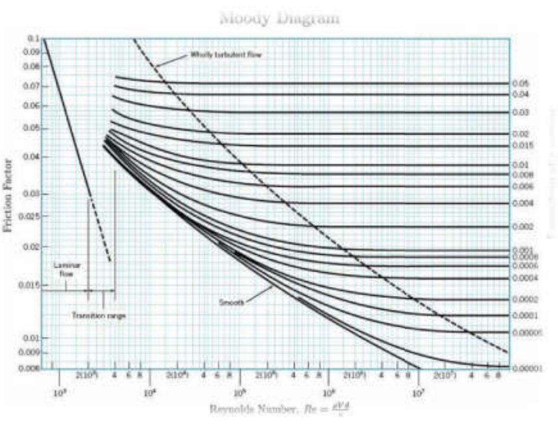


Fig 2 Moody's chart

Parameter f in the equation above is known as the Moody friction factor. It can be obtained from the Moody chart, Figure 2, which relates the friction factor, Reynolds number, and relative roughness. The Moody friction factor is also called the Darcy Friction factor and is what will be used throughout therest of this work. It will be referred to simply as the friction factor. Another less commonly used friction factor is the Fanning friction factor. It is related to the Moody friction factor by,

$$f_f = \frac{f}{4} \qquad ..... 5$$

f_f = *fanning friction factor*
f = *moody friction factor*

For laminar flow region, the moody friction factor can be expressed as

$$F = \frac{64}{Re} \qquad ..... 6$$

Several correlations are available for obtaining the friction factor for turbulent flow for both smooth pipes and rough pipes. For turbulent flow in smooth pipes, the Drew et al (1932) correlation is very common in calculating the friction factor because it is an explicit equation. It is expressed as

$f = 0.0014 + 0.125\,(Re)^{-0.32}$, for $3000 \leq Re \leq 3000000$.

The Von Karman is used for smooth pipes. These equations are implicit and the term $Re\sqrt{f}$ *is* introduced *to* eliminate velocity.

$$\frac{1}{\sqrt{f}} = 4.06\log(Re\sqrt{f}) - 0.60. \qquad ..... 7$$

Flow analysis and equations modules
Rate of flow or discharge

Rate of flow (or discharge) is defined as the quantity of liquid flowing per second through a section of pipe or a channel. It is denoted by Q. Consider a liquid flowing through pipe,

Let A = Area of cross sectional of the pipe and
V = Average velocity of the liquid
Discharge Q = area × average velocity

$$Q = A \times V \qquad ..... 8$$
$$= m^2 \times m/s = m^3/s = \text{cumecs}$$

Continuity Equation

The continuity equation is based on the principle of conservation of mass. It states that if no fluid is added or removed from the pipe in any length then the mass passing across different sections shall be the same. When a fluid is in motion, it must move in such a way that mass is conserved to see how mass conservation places restrictions on the velocity field. Consider the steady flow of fluid through a duct (that is the inlet and outlet flows do not vary with time). The inflow and outflow are one dimensional, so that the velocity and density ρ are constants over the area A. Now, we apply the principle of mass conservation, since there is no flow through the side walls of the duct. The mass of fluids that flows in A_1 goes out over A_2. (The flow is steady so that there is no mass accumulation), over a short time interval Δ

Volume flow in over $A_1 = A_1V_1\Delta t$
Volume flow out over $A_2 = A_2V_2\Delta t$
Therefore,
Mass in over $A = \rho A_1V_1\Delta t$
Mass out over $A = \rho A_2V_2\Delta t$
So, $\rho A_1V_1 = \rho A_2V_2$ 9

In the case of incompressible fluid, $\rho_1 = \rho_2$, the continuity equation reduces to

$$A_1V_1 = A_2V_2 \qquad ... 10$$

This is the statement of the principle of mass conservation for a steady one dimensional flow, with one inlet and outlet. This equation is called the continuity equation for steady one dimensional flow. For a steady flow through a control volume with many inlets and outlets, the net mass flow must be zero, were inflows are negative and outflows are positive.

Head Losses

When a fluid with uniform velocity enters a pipe, the layers of fluid adjacent to the wall slow down, with the formation of the boundary at the entrance. The boundary layer thickness increases as the fluid as the fluid moves into the pipe. At some distance away from the entrance the entrance, the boundary layer thickness is equal to the radius of the pipe and joined at the axis. Subsequently, the flow conditions remain constant; mean free velocity is thus attained and fully developed flow exists in the pipe. If regime transition has already taken place, turbulent flow persists in the region of fully developed flow.

Head loss is the measure of the reduction in the total head of the liquid as it moves through a system. The total head is the sum of the elevation head, velocity head, and pressure head. Head loss is unavoidable and is present because of the friction between the fluid and the walls of the pipe and is also present between adjacent fluid particles as they flow along the pipe. The head loss for fluid flow is directly proportional to the length of the pipe as flow rate increases, the pressure will drop. The head is the vertical distance, height or energy of water above a point. A head of water can be measured in either height (ft) or pressure (psi). Head loss is the combination of different types of losses:

a. Head lost due to friction or major losses
b. Other minor losses.

Total head loss can be represented as follows

$H_{loss} = \Sigma H_{major\_loss} + \Sigma H_{minor\_loss}$

Where

H_{loss} = total head loss in the pipe or duct system

H_{major_loss} = major loss due to friction in the pipe or duct system

H_{minor_loss} = minor loss due to the components in the system.

Finally the total head loss is given as

$$H_{loss} = h_f + h_{exp} + h_{con} + h_b + h_{ft} \quad \text{..... 11}$$

$$H_{loss} = \frac{4fLv^2}{D\times 2g} + \frac{(v_1-v_2)^2}{2g} + 2k\frac{v^2}{2g} + \frac{v_2^2}{2g}\left[\frac{1}{c_c} - 1\right]^2 \quad \text{.... 12}$$

Head Lost Due To Friction or Major Losses

Head lost due to friction is incurred both by frictional resistance from the fluid acting on the wall of the pipe and frictional resistance between the fluids (viscosity). It is denoted by h_f, and can be calculated using Darcy - Weisbach equation and chezy's equation.

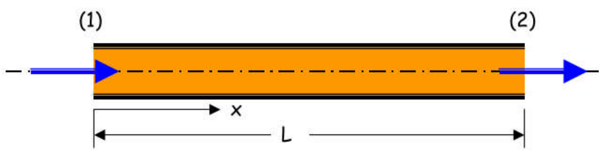


Fig 1 Loss along a straight pipe

$$h_f = \frac{4fLv^2}{D\times 2g} \quad \text{..... 13}$$

Where h_f = loss of head due to friction

F = coefficient of friction (a function of Reynolds number)

$f = \frac{0.0791}{(Re)^{\frac{1}{4}}}$ For Re varying from 4000 to 10^6 (turbulent flow)

$f = \frac{16}{Re}$ For Re < 2000 (laminar / viscous flow)

L = length of the pipe
V = mean velocity of the fluid
D = diameter of the pipe
g = acceleration due to gravity.

$$V = C\sqrt{mi} \quad \text{..... 14}$$

Were C = chezy's constant

m = hydraulic radius or hydraulic mean depth = D/4
D = diameter of the pipe
V = mean velocity
I = slope = h_f/L
L = length of the pipe
h_f = head loss due to friction.

Equations (13) and (14) are Darcy's and Chezy's equations for calculating head losses due to friction.

Minor Losses

Losses due to local disturbances or obstructions of fluid flows in pipes such as sudden expansion or contractions in the cross-section of the pipe, bends, elbows, joints, valves, flow meters, projecting gaskets and other standard pipe fittings are called minor or local losses. The term minor losses are quite misleading because in many instances they are more important than losses due to friction. In order to minimize or eliminate errors in pump and system matching or specification for a given pressure differential, this minor losses have to be included in a pipelines total resistance to flow. The minor losses are usually determined by experiment. Pressure drop across such pipe fittings are often referred to as **separation loss** since the term (separation loss) describes such phenomena which occur at such fittings, resulting in the generation of wakes and eddies in the flow. Consequently, there will be a pressure drop. Considering a very long pipe or channel, the minor losses have negligible effect with the fluid friction in the length concerned. For short pipes or channels, the so-called minor losses may become major losses. If in turbulent flow the velocity of a flowing fluid changes in magnitude or direction, wakes and eddies set in with subsequent energy loss in excess of the pipe friction in the same length. In laminar flows, minor losses are not pronounced because irregularities in the flow boundaries create a minimal disturbance to the flow and separation therefore does not exist. Minor loss includes [3]:

Sudden Enlargement

The figure below depicts two pipes of cross sectional area A_1 and A_2 flanged together with a constant density fluid from the smaller diameter pipe to the larger diameter pipe. The fluid fails to make an adjustment with the change in direction needed for complete filling of the larger diameter pipe. The flow brakes away from the edges of narrow section, eddies form and the resulting turbulence causes dissipation of energy. The initiation and on set of turbulence is due to fluid momentum and its inertia

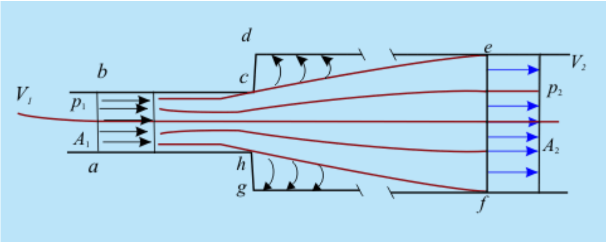


Fig 2 Sudden enlargement

$$h_{exp} = \frac{(v_1 - v_2)^2}{2g} \qquad \text{..... 15}$$

Were V_1 and V_2 = mean velocity of the small pipe and large pipe respectively

g = acceleration due to gravity

h_{exp} = head loss due sudden enlargement

Sudden Contraction

The figure below depicts a pipeline in which abrupt contraction occurs. The analysis for head loss is the same as that for sudden expansion, the effective area for flow gradually decreases as the sudden contraction is approached and then continues to decreases for a short distance to what is known as the vena contracta. Beyond the vena contracta the flow area gradually approaches that of the smaller pipe. Reduction in velocity and loss of energy in turbulence leads to pressure drop [3].

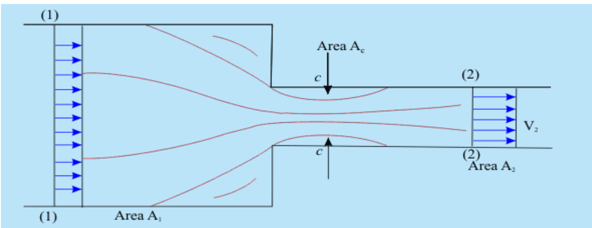


Fig 3 Sudden contraction

The head loss for sudden contraction, can be represented with the formular

$$h_{con} = \frac{v_2^2}{2g}\left[\frac{1}{c_c} - 1\right]^2 \qquad \text{... 16}$$

Where V_2 = mean velocity of the large pipe

g = acceleration due to gravity

c_c = coefficient of contraction

In some cases, the value of c_c is given but in situation, when it is not given, the formula becomes, $h_c = 0.5\frac{V_2^2}{2g}$

Table 1 Loss coefficient for sudden contractions

A_2/A_1	0	0.1	0.2	0.3	0.4	0.6	0.8	1.10
K	0.50	0.46	0.41	0.36	0.30	0.18	0.06	0.00

Losses due to Bends

The equation is given as $h_b = k\frac{v^2}{2g}$ 17

Where v = mean velocity of flow of fluid and

k = coefficient of bend, it depends upon angle of bend, radius of curvature of bend and diameter of pipe.

Losses due to various pipes fittings (valves)

$$h_f = k\frac{v^2}{2g} \qquad \text{.... 18}$$

Where h_f = head loss due to fittings

K = value of the coefficient of fittings.

The table below gives the typical values of loss coefficients for gate and globe valves.

Table 2 Values of loss coefficients for gate and globe valves

Valve type	K
Globe valve, fully open	10.0
Gate valve, fully open	0.2
Gate valve, half open	5.6

Principles of pressure loss measurements

Pressure loss between two points at different elevations

Considering figure 4, applying Bernoulli's equation between 1 and 2, gives

$$z + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + h_L \qquad \text{.. 19}$$

But $v_1 = v_2$, $= h_L = z + \frac{p_1 - p_2}{\rho g}$ 20

Consider piezometer tubes

$$p = p_1 + \rho g[z - (x + y)] \qquad \text{.....21}$$

Also $p = p_2 - \rho g y$ 22

Giving: $x = z + \frac{(p_1 - p_2)}{\rho g}$ 23

Comparing equation (23) and (26),

$H_L = x$ ... 24

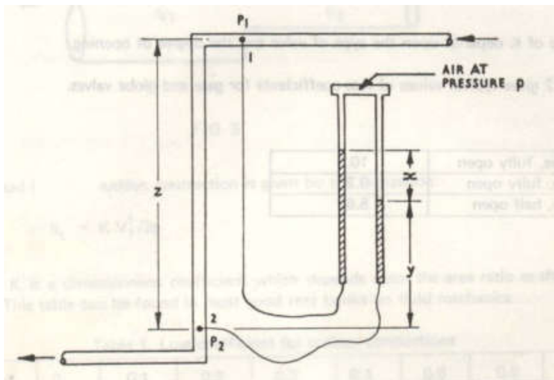


Fig 4 Pressurized piezometer tubes used for measuring the pressure difference between two points at different elevations.

Description of Apparatus

The apparatus is show diagrammatically in figure 1. there are essentially two separate hydraulic circuits, one painted dark blue and the other painted light blue, but having common inlet and outlets. A hydraulic bench is used to circulate and measure water. Each one of the two pipe circuits contains a number of pipe system components. The components in each of the circuits are as follows

Dark Blue Circuit

a. Straight pipe (12.7mm bore)
b. 90° mitre bend
c. Proprietory 90° elbow
d. Gate valve

Light Blue Circuit

e. Sudden expansion(12.7mm /25.4mm)
f. Sudden contraction(25.4mm/12.7mm)
g. 60 mm 90^o radius bend
h. 100 mm 90^o radius bend
i. 150 mm 90^o radius bend
j. Globe valve
k. Straight pipe (25.4mm bore)

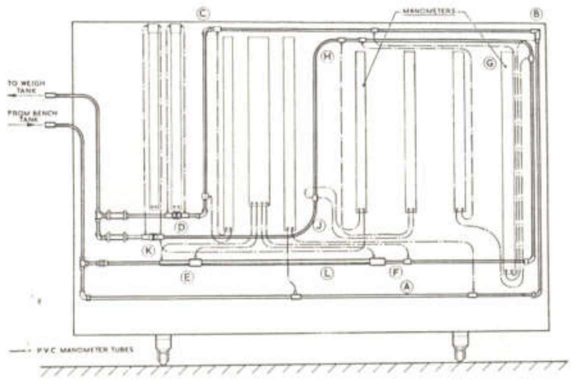


Fig 5 Diagrammatic representation of the losses in pipe apparatus.

In all cases (except the gate and globe valves) the pressure change across each of the component is measured by a pair of pressurized piezometer tubes. In the case of the valves, pressure measurement is made by U-tubes containing mercury.

Experimental Procedures

1. Open fully the water control on the hydraulic bench
2. With the globe valve closed, open the gate valve fully to obtain maximum flow through the dark blue circuit. Record the readings on the piezometer tubes and the u-tube. Measure the flow rate by timing the level rise in the volumetric tank
3. Repeat the above procedure for a total of seven different flow rates obtained by closing the gate valve, equally spaced over the full flow range.
4. With simple mercury in glass thermometer record the water temperature in the sump tank.
5. Close the gate valve; open the globe valve fully to obtain maximum flow through the light blue circuit. Record the reading s on the piezometer tubes and the u-tube. Measure the flow rate by timing the level rise in the volumetric tank
6. Repeat the above procedure for a total of ten different flow rates obtained by closing the globe valve, equally spaced over the full range.
7. With simple mercury in glass thermometer record the water temperature in the sump tank.

Note: Before switching off the pump, close both the globe valves and the gate valve. This prevents air gaining access to the system and so saves time in subsequent setting up.

CALCULATIONS AND ANALYSIS OF RESULTS

The experiment was conducted for the two sets of circuits, the dark blue circuit and the light blue circuit. For the dark blue circuit, table 3 illustrates the readings obtained.

Readings from the Dark Blue Circuit

From the above table, it is required to calculate the head loss for the standard elbow bend, straight pipe and mitre by subtracting h_2 from h_1, h_4 from h_3 and h_6 from h_5, respectively and comparing the measured values with the theoretical values from equations (15) and (3) respectively.

Table 3 Values for dark blue circuit

Test	Flow rate		Discharge	Piezometer readings (mm) water (Δh)		
				Stand. elbow	Straight	Mitre
	Qty (l)	t(sec)	Q (l/s)	1 2	3 4	5 6
1	10	35.3	0.283	543	293	520
2	10	48.6	0.206	303	160	280
3	15	81.70	0.184	265	144	240
4	15	98.70	0.152	202	110	185
5	20	151.2	0.132	148	89	132
6	20	190.2	0.105	95	70	85
7	25	292.8	0.085	66	40	60

The discharge Q is calculated by dividing the quantity (liters) by the time (seconds), and then a graph of log h_L against log Q will be plotted. This will help us to obtain the relationship between the straight pipe head loss and the volume flow rate. Also the Reynolds number for each flow is calculated, to ascertain that the flow is turbulent, i.e. Re>2000, then the friction factor f is calculated and the relationship between the friction factor and the Reynolds number is obtained by plotting a graph of log f against log Re. the results gotten will be compared with the literature given equations (i.e. $f = 0.04\ Re^{-0.16}$ for $4000<Re<10^7$ and $f = 0.079\ Re^{-1/4}$ for $4000<Re<10^5$) And finally, discuss the head losses in 90^o mitre and standard elbow bend.

Calculations and Results For Dark Blue Circuits

Parameters

Temperature of fluid, Θ = 20^o c, v = 1/100 stoke

H_L between tapping 1 and 2 = 743 – 200 = 543mm = 0.543m

H_L between tapping 3 and 4 = 778 – 485 = 293mm = 0.293m

H_L between tapping 5 and 6 = 1175 – 655 = 520mm = 0.520m

Diameter of small pipe, D_1 = 12.7 mm = 0.0127m

Length of straight pipe, L = 0.914m

Cross sectional area of the pipe, A $= \frac{\pi}{4} D^2 =$ 0.7854×0.0127^2

$= 1.27 \times 10^{-4} m^2$

Velocity of flow in the small pipe, v_1 $= \frac{Q}{A} = \frac{0.28\ 3}{1.27 \times 10^{-4}} \times 10^{-3}$

= 2.22m/s

Velocity head, $\frac{v_1^2}{2g} = \frac{2.22}{19.62} = 0.113$

Renold number, Re $= \frac{VD}{v} = \frac{2.22 \times 0.0127}{0.01 \times 10^{-4}}$

$= 2.8 \times 10^4$

Friction factor, f $= \frac{h_L g D}{2LV^2}$

from equation (2.3)

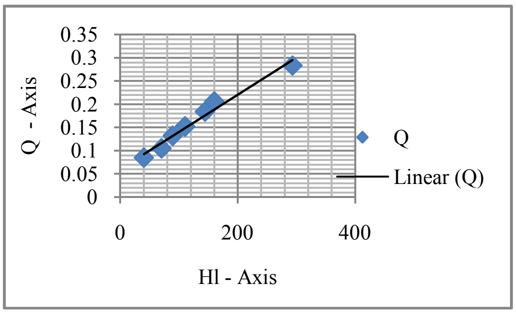
$= \frac{0.293 \times 9.8\ 1 \times 0.0127}{2 \times 0.914 \times 2.22^2} = 0.00405$

The table below shows computed values for head losses and discharge. The values were gotten the same way the values for tapping between h_1 and h_2 to tapping h_5 and h_6 were derived. The tables below shows detailed values for the parameters needed. The values were calculated using the same steps as shown above.

Table 4 Measured results for discharge and losses

H_L	Q	Log H_L	Log Q
293	0.283	2.467	-0.548
160	0.206	2.204	-0.686
144	0.184	2.158	-0.735
110	0.152	2.041	-0.818
89	0.132	1.950	-0.879
70	0.105	1.845	-0.979
40	0.085	1.602	-1.070

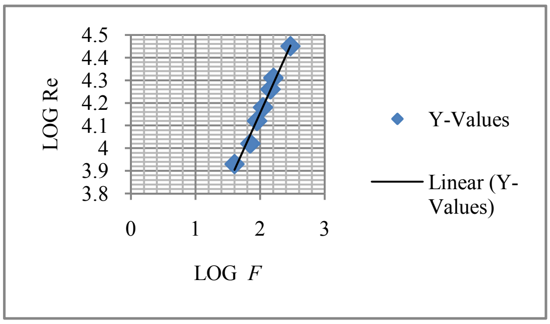
When the graph of Q was plotted against H_L, a linear graph was obtained, indicating that as the discharge decreases, the head loss also decreases



Graph of H_L against Q

Table 5 Values for the graph of Re against f

F	Re	Log f	Log Re
0.00405	28194	-2.39	4.45
0.00416	20574	-2.38	4.31
0.00467	18415	-2.33	4.26
0.00521	15240	-2.28	4.18
0.00561	13208	-2.25	4.12
0.00692	10541	-2.16	4.02
0.00607	8509	-2.22	3.93



Graph of friction factor log *f* against log Re

Table 6 Reading for light blue circuit

Test	Flowrate Qty (l)	Flowrate T(sec)	discharge Q (l/s)	Piezometer readings(mm) water: Expansion 7 8	Contraction 9 10	100 mm bend 11 12	150 mm bend 13 14	50 mm bend 15 16
1	10	35.3	0.283	174	290	296	325	257
2	10	48.6	0.206	31	152	164	181	178
3	15	81.70	0.184	28	131	115	156	155
4	15	98.70	0.152	15	96	108	115	113
5	20	151.2	0.132	10	69	82	87	84
6	20	190.2	0.105	10	47	57	60	60
7	25	292.8	0.085	5	31	41	40	45

Calculations for light blue circuit

Parameters

Diameter D_2 = 25.4mm = 0.0254m

Cross sectional area, $A_2 = \frac{\pi}{4} \times \mathbf{0.0254}^{2} = 5.07 \times 10^{-4}\ m^2$

For the velocity at the large pipe bore

$V_2 = \frac{A_1 V_1}{A_2} = \frac{1.27\times10^{-4}\times2.22}{5.07\times10^{-4}} = 0.56$m/s

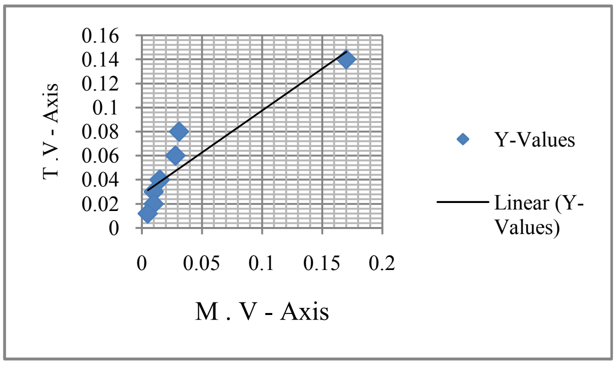
Velocity head for the larger pipe $= \frac{v_2^2}{2g} = \frac{0.56^2}{19.62} = 0.016$

Theoretical value for expansion

$\frac{(v_1^2 - v_2^2)}{2g} = \frac{2.7556}{19.62} = 0.14$m

Table 7 Values for measured and theoretical values of head loss

Measured values (M.V)	Theoretical values (T.V)
0.17	0.14
0.031	0.08
0.028	0.06
0.015	0.04
0.01	0.03
0.01	0.02
0.005	0.012



Graph of m.v against t.v for sudden expansion

Table 8 Total head losses at various rates of flow.

Q	V_1	V_2	$V_1^2/2g$	$V_2^2/2g$	Loss of head Δh in mm: expansion	Contraction	100m m bend	150mm bend	50mm bend
l/s	m/s	m/s	m	m	mm	mm	mm	m	M
0.283	2.22	0.56	0.113	0.028	174	290	296	325	257
0.206	1.62	0.40	0.082	0.020	31	152	164	181	178
0.184	1.45	0.36	0.074	0.018	28	131	115	156	155
0.152	1.20	0.30	0.061	0.015	15	96	108	115	113
0.132	1.04	0.26	0.053	0.013	10	69	82	87	84
0.105	0.83	0.21	0.042	0.012	10	47	57	60	60
0.085	0.67	0.18	0.034	0.0092	5	31	41	40	45

DISCUSSION OF RESULTS

For the enlargement, equation (15) provides a theoretical value for the head loss, in this case,

$$h_{exp} = \frac{(v_1 - v_2)^2}{2g} = \frac{(2.22 - 0.56)^2}{19.62} = 0.14m$$

The measured value is 0.17m; the value is within range.

If the Reynold's number is above 2 X 10^3, the flow is possibly partly laminar and partly turbulent or wholly turbulent. For each pipe, the Reynolds number was found to be above this number.The results of this experiment show that the theoretical frictional losses and experimental frictional losses are closely linked and the difference could mainly be contributed towards experimental errors that were reproduced in the results.

CONCLUSION

The major objective of this research work was to carry out a theoretical and experimental comparison of the losses in piping system. The objective was achieved in two phases. The first phase involved doing a literature review of the equations currently being used and selecting the ones to be used in calculating for the losses theoretically. The second phase was running an experiment and comparing the values obtained, with the values calculated from the selected equations. The following conclusions were made

a. The calculations are extremely sensitive to variations in the pipe diameter.
b. The actual velocity, Reynolds number and equivalent pipe roughness are inversely proportional to diameter, whilst the friction factor is proportional to the diameter.

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