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Friction losses in pipes and fittings

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Introduction

Fluids that move through pipes are subjected to resistance. This resistance is caused by pipe roughness, pipe diameter and length. Also pipe fitting causes resistance. This leads to the two types of losses. Major loss and minor loss. Major loss came from pipe wall roughness. When the fluid touches the pipe wall, the flow velocity at the boundary will equal zero as shown in figure 1. Also, as the length of the pipe increases the pressure loss will increase because the energy is conservative. The smoother the pipe, the less resistance. Also, if fluid types turbulent flow or laminar flow. The empirical friction coefficient only depends on Reynolds number. In reality, pipe adds another resistance. That resistance will make the value of the empirical friction coefficient and theoretical friction coefficient deferent. It is important to determine the friction loss because when the flow touches the pipe wall, wall roughness will affect the flow velocity as shown in figure 1. And because of the conservation of energy principle the pressure also will be affected.

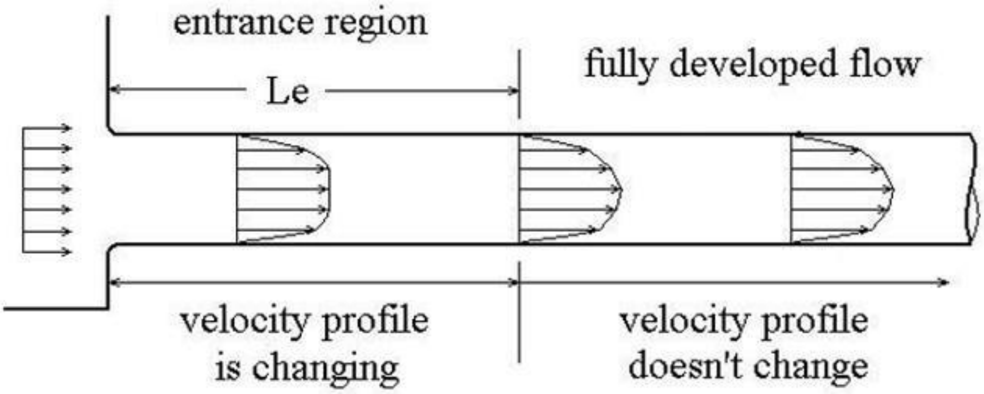


Figure 1: Flow profile inside pipe.

Elbows and valve are types of pipes fitting. They also will cause loss but a different one called minor loss. This resistance should be taken into consideration because it adds resistance to the fluid flow. Figure 2 shows the types of pipe fitting. The total head loss for the pipe is the sum of these two losses.

Figure 2: Types of pipe fittings.

Theoretical background

Losses in general are divided into categories major and minor losses. Major loss is caused by friction in fully developed flow in constant area portions. The effect of friction causes a decrease in pressure or pressure "loss" compared to the ideal, frictionless flow situation. Minor loss occurs when a fluid flow through valves, tees, elbows, etc. in addition, any frictional effects in other nonconstant area portions of the system can be classified as minor loss.

Total head loss h_{lt} is regarded as the sum of major losses h_{lj} in fully developed flow in constant area tubes and minor losses h_{ln} due to fittings, area changes and so on. Analysis of the major loss and the minor loss will be considered separately.

The steady- flow energy equation gives:

$$Z_1 + \frac{\bar{u}_1^2}{2g} + \frac{P_1}{\rho g} = Z_2 + \frac{\bar{u}_2^2}{2g} + \frac{P_2}{\rho g} + h_{lt} \quad \text{(Eq 1)}$$

Where z is the elevation head, $\bar{u}_1^2$ the mean velocity of the flow, P is the pressure, and h_{lt} is the total head loss.

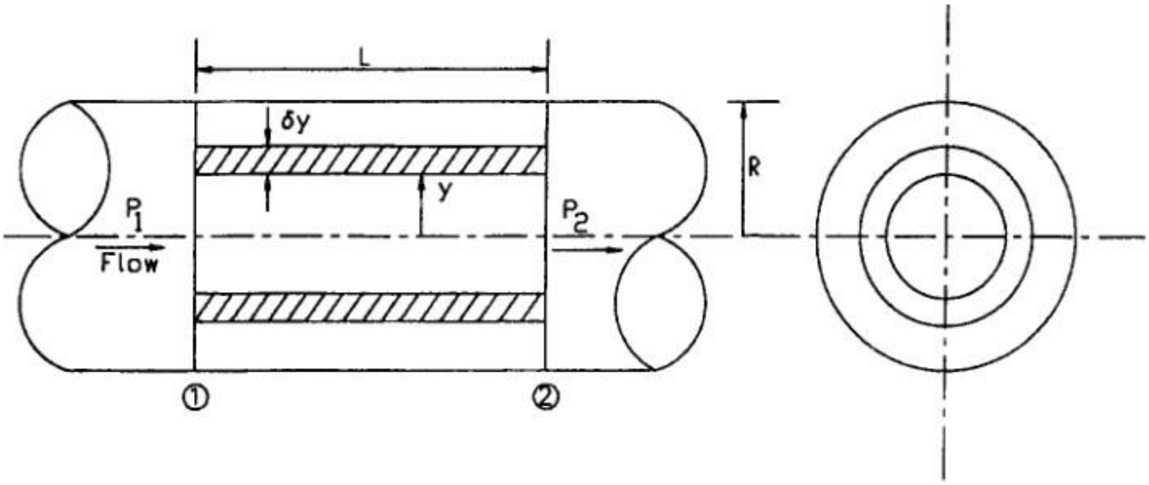


Figure 3: Schematic diagram for flow inside pipe.

Major losses

Calculation of major losses of flow through pipes depends on whether the flow is laminar or turbulent. Consider first a laminar viscous flow through round pipes as shown in fig (1).

For a horizontal pipe, the force due to viscous resistance is equal to that of pressure difference, i.e.,

$$2\pi y L(\tau) = \Delta P \pi y^2$$

Where r is the shear stress, y is the radial distance from centerline, L is the length of the pipe, and ΔP is the drop in pressure. The shear stress τ is expressed as

$$\tau = -\mu \frac{du}{dy} \qquad \text{(Eq 3)}$$

So, equation 1 becomes

$$-2\mu y L \frac{du}{dy} = \Delta P \pi y^2 \qquad \text{(Eq 4)}$$

Therefore,

(Eq 2)

$$du = -\frac{\Delta P y dy}{2\mu L} \qquad \text{(Eq 5)}$$

Integrating the above equation yields

(Eq 6)

$$u = \frac{-\Delta P y^2}{4\mu L} + c$$

Using the boundary condition of the velocity at the surface is equal to zero gives us:

$$C = \frac{Pr^2}{4\mu L}(R^2 - y^2) \qquad \text{(Eq 7)}$$

Thus, the velocity distribution has a parabolic shape. The maximum and mean flow velocities are then given as follows:

$$u_{max} = \frac{\Delta P R^2}{4\mu L} \qquad \text{(Eq 8)}$$

$$\bar{u} = \frac{\Delta P R^2}{8\mu L} \qquad \text{(Eq 9)}$$

The major loss for laminar flow becomes:

$$h_{lj} = \frac{32\mu L\bar{u}}{\rho g d^2} \qquad \text{(Eq 10)}$$

Where d is the diameter of the pipe. This equation in known as Poiseuille equation (after J.L. Poiseuille 1799-1869). The friction factor f for laminar flow is then defined as:

$$f = \frac{64}{Re_d} \qquad \text{(Eq 11)}$$

where Re_d is the Reynolds number based on the diameter of pipe.

Consider now a turbulent flow through a horizontal round pipe as shown in fig (1). The force required to overcome frictional resistance between 1 and 2 is equal to the pressure force, i.e.,

$$F = (P_1 - P_2)\frac{\pi d^2}{4} \qquad \text{(Eq 12)}$$

Experimentally, the friction resistance is found to be proportional to the wetted area and square of the velocity, or

$$F = f\pi d L\bar{u}^2 \qquad \text{(Eq 13)}$$

Where f is a friction factor dependent on the nature of the pipe surface. Equating equations 12 and 13 we have

$$(P_1 - P_2)\frac{\pi d^2}{4} = f\pi dL\bar{u}^2 \qquad \text{(Eq 14)}$$

Thus,

$$(P_1 - P_2) = \frac{4fL\bar{u}^2}{d} \qquad \text{(Eq 15)}$$

Now let w be the specific weight of the fluid, then

$$\frac{(P_1 - P_2)}{w} = \frac{4fL\bar{u}^2}{\rho g d} \qquad \text{(Eq 16)}$$

Using equation1 with the same mean velocity and same elevation, the major head loss due to friction for turbulent flow becomes

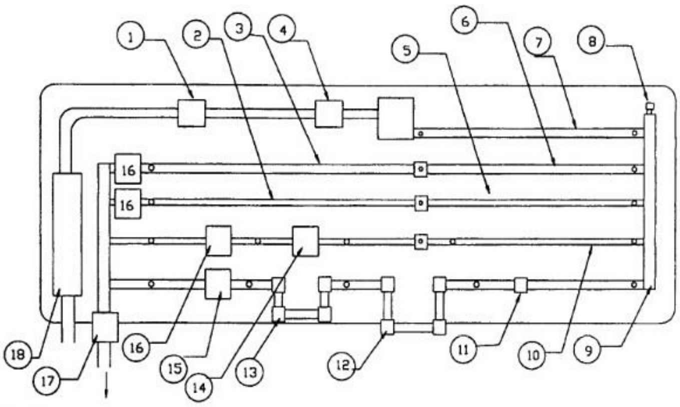
$$h_{lj} = \frac{4fL\bar{u}^2}{2gd} \qquad \text{(Eq 17)}$$

Minor losses

The flow in a piping system may be required to pass through a variety of fittings and bends. These losses are considered minor losses. The minor head loss is expressed as

$$h_{lj} = k\frac{\bar{u}^2}{2g} \qquad \text{(Eq 18)}$$

Where K is the loss coefficient. By measuring the velocity and the pressure drop across the component and using equation 18, the loss coefficient K can be determined.



1. VENTURI
2. PIPE WITH ROUGHENED SURFACE (I/D=23.5 MM)
3. PIPE WITH ROUGHENED SURFACE (I/D = 25 MM)
4. ORIFICE
5. PIPE WITH SMOOTH SURFACE (I/D=13.3 MM)
6. PIPE WITH SMOOTH SURFACE (I/D=14 MM)
7. ANNULAR PIPE
8. VENT VALVE
9. INLET HEADER
10. PIPE WITH SMOOTH SURFACE
11. PITOT STATIC PROBE
12. 90° BEND
13. ELBOWS
14. STRAINER
15. GATE VALVE
16. BALL VALVE
17. DRAIN VALVE
18. FLOWMETER

Experimental setup

Figure 4: Schematic diagram for measuring friction losses in pipe and fittings.

The Cussons P5160 Friction losses in pipes and fittings apparatus, Fig 4, enables the Friction losses in a range of pipe lengths and fittings to be determined experimentally. The apparatus consists of five sections of pipeline containing pipes of various diameters and internal finishes with a range of standard pipeline fittings. The materials used for the pipework and most fittings are unplasticized P.V.C to minimize corrosion problems.

Water is fed from external pressurized supply to the supply header of the apparatus via variable area flowmeter, a venturi, an orifice, and an annular section of pipework. From the supply header, four pipelines are connected along the length of the apparatus to drain connection. The topmost of these pipelines consists of 1-meter length of 23.5 mm I/D smooth pipe in series with a 1-meter length of 25 mm I/D pipe with specially roughened internal surface of the tube and gives a roughness factor of approximately 0.02. The pipeline is then connected to the drain connection via a ball valve. Fitted under the ball valve. The second pipeline is similar to the topmost pipeline, and it consists of a 1-meter length 13.5 mm I/D smooth pipe and 1-meter of 14.4 mm rough pipe. The third pipeline contains a 1-meter section of 8.5 mm I/D pipe, strainer, and a ball valve. Fitted under the ball valve handle is calibrated scale which enables experiments on relationships between pressure drop and valve opening angle to be carried out.

The lowest pipeline contains a sudden enlargement from a 13.3mm pipe to a 23.5 mm pipe, a section of pipeline containing a pitot-static probe, a sudden contraction from 23.5 mm pipe to 13.3 pipe, two U bends which are constructed from pipe fittings (one from small radius bends and one from elbows), and an angle set valve with a calibrated scale under the control wheel. The drain is connected to the water outlet pipe by a 23.5mm ball valve. Each length of pipe and each test fitting is provided with both upstream and downstream self-sealing manometer connection. These enable the supplied manometers to be connected across them and the pressure drop across the test sample to be measured. The fluid used in the manometer is either water or mercury.

Experimental procedure

1- Connect the inlet of the variable area flow meter to an external pressurized supply.
2- Connect the water outlet from the drain valve to a suitable drain.
3- Open all the valves on the unit except the vent valve.
4- Turn on the water supply and allow water to flow through the apparatus.
5- Close the water outlet valve slightly to provide some back pressure.
6- Open the vent valve and allow air to escape until water starts to flow through the valve, then close the valve.
7- Press down the center spindle of the non-return manometer connection fitted opposite the pilot-static probe entry and allow any trapped air to escape.
8- Close the angle seat valve.
9- Close the ball valves on the other pipelines starting at the bottom and working up to the top.
10- Open the ball valve on the line containing the component required for the test.
11- Adjust the water flow rate to that required for the test. When requiring high flow rates use the large 18 mm diameter orifice.

Using the water manometers:

1- Hook the manometers on the manometer rail adjacent to the component under test
2- Connect the two inlet pipes of the manometer to the required tapping’s.
3- Open the vent valve and open the balancing valve on the manometer and vent the manometer tubes of all air.
4- Close the vent valve.
5- Fix the pressures pump onto the manometer and pressurize the manometer until the water levels in the tubes are at the zero level.
6- Close the balancing valve.
7- Measure the pressure drop across the two tapping’s by the difference of height.

8- If required, the pressurization of the manometers can be released by opening the vent valve.

Using the Mercury Manometer:

1- Hook the manometer on the rail adjacent to the component under test.
2- Connect the inlet pipes of the manometer to the required tapping's.
3- Open the two transport valves on the manometer tubes.
4- Open the vent valve fully and vent all the air from the manometer tubes and connecting pipes.
5- Half close the valve and check whether the two mercury columns are of the same height.
6- Completely close the vent valve.
7- Measure the difference in the height of the two columns.
8- To convert this height into an equivalent height of water multiply the height of mercury by 12.6 this figure considers the effects of the two water columns above the mercury.

Results and discussion

This experiment focused on measuring the major friction coefficient which occurs because of the natural type of surface. And measuring the minor loss in pipe which caused of pipe fitting. Table (1) shows the results of the experiment runs to measure the pressure drop for smooth pipes with different diameters. The first column represents volume flow rate in [L/min]. While the second represents the same flow rate as [m^3/s]. The third column represents the average velocity of the fluid. The fourth column represents the pressure drop in [mm H_2O]. The fifth column represents Reynolds number. The sixth column represents the experimental friction coefficient, and the last column represents theoretical friction.

Smooth Pipe, Diameter = 10 mm						
Flow Rate		Average velocity	Pressure Drop	Reynolds Number	Exp. Friction Factor	Friction Factor
[L/min]	[m^3/s]	[m/s]	[mm H_2O]	(Re)	(f_{exp})	(f_{emp})

33	0.00055	7.00282	4630	70028.2	0.018524	0.019425
28	0.00047	5.98423	3438	59842.3	0.018836	0.020204
24	0.0004	5.09296	2621	50929.6	0.019826	0.021035
20	0.00033	4.20169	1934	42016.9	0.021494	0.022071
16	0.00027	3.43775	1315	34377.5	0.021831	0.023207
12	0.0002	2.54648	817	25464.8	0.024720	0.025015
Smooth Pipe, Diameter = 17 mm						Eq 2
Flow Rate		Average velocity	Pressure Drop	Reynolds Number	Exp. Friction Factor	Friction Factor
[L/min]	[m^3/s]	[m/s]	[mm H_2O]	(Re)	(f_{exp})	(f_{emp})
72	0.0012	5.28681	2037	89875.77	0.024308	0.018251
60	0.001	4.40567	1332	74896.39	0.022889	0.019102
50	0.00083	3.65671	1016	62164.07	0.025343	0.020013
40	0.00067	2.9518	680	50180.6	0.026031	0.021113
30	0.0005	2.20284	392	37448.28	0.026944	0.022716
20	0.00033	1.45387	182	24715.79	0.028719	0.025202
Rough Pipe, Diameter = 17 mm						Eq 3
Flow Rate		Average velocity	Pressure Drop	Reynolds Number	Exp. Friction Factor	Pipe Roughness Ratio
[L/min]	[m^3/s]	[m/s]	[mm H_2O]	(Re)	(f_{exp})	(ε/D)
47	0.00078	3.45111	10138	58668.87	0.283911	0.011726
40	0.00067	2.93712	7283	49931.04	0.281588	0.011726
34	0.00057	2.49655	5250	42441.35	0.280948	0.011726
28	0.00047	2.05598	3556	34951.66	0.28059	0.011726
22	0.00037	1.61541	2230	27461.97	0.285028	0.011726
16	0.00027	1.17485	1165	19972.45	0.281519	0.011726

Figure 5 shows the relation between the friction factor and Reynold's number for both diameters experimentally and theoretically. It can be seen that as Reynolds number increases the friction factor decreases, and the bigger the diameter the greater the friction factor. Also, the pressure drop increases as the flow rate is increase, it is noticed that 17-mm diameter smooth pipe has the highest flow rate value and the lowest pressure drop. Moreover, the 10-mm diameter smooth pipe has the lowest flow rate value. And this relates to the inlet cross sectional area of each type. Furthermore, the experimental friction factor for 17-mm-diameter is larger than the empirical one and the experimental friction factor for the 10-mm-diameter is smaller than the empirical one.

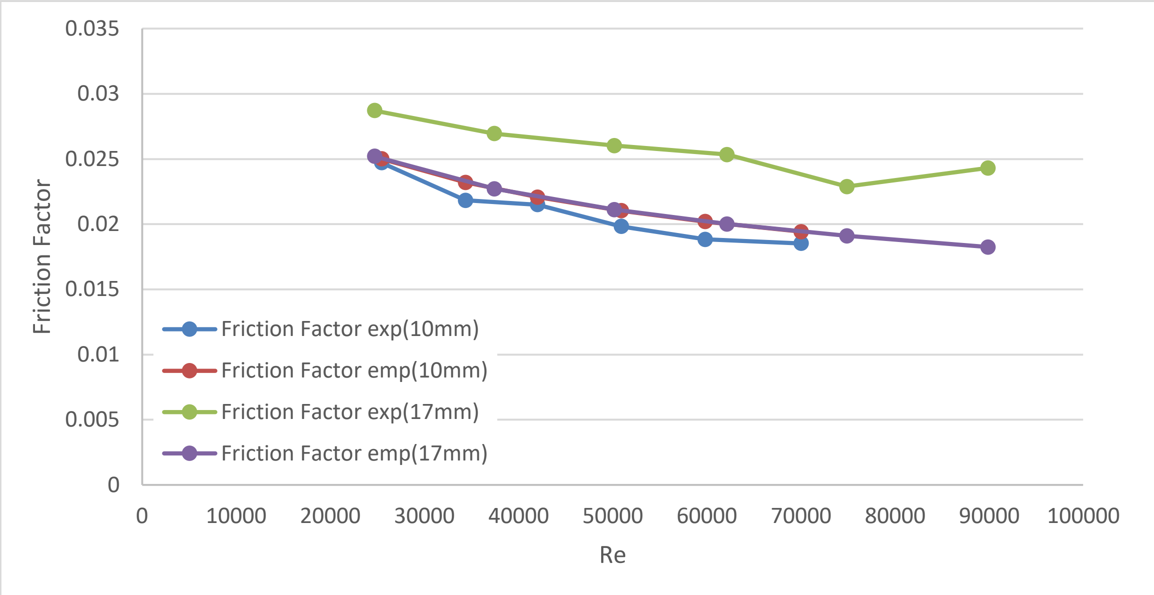


Figure 5: Comparison of smooth pipes.

Figure 6 represents the relation between the experimental friction factor for both rough and smooth pipes with a constant diameter d = 17 mm versus Reynolds number

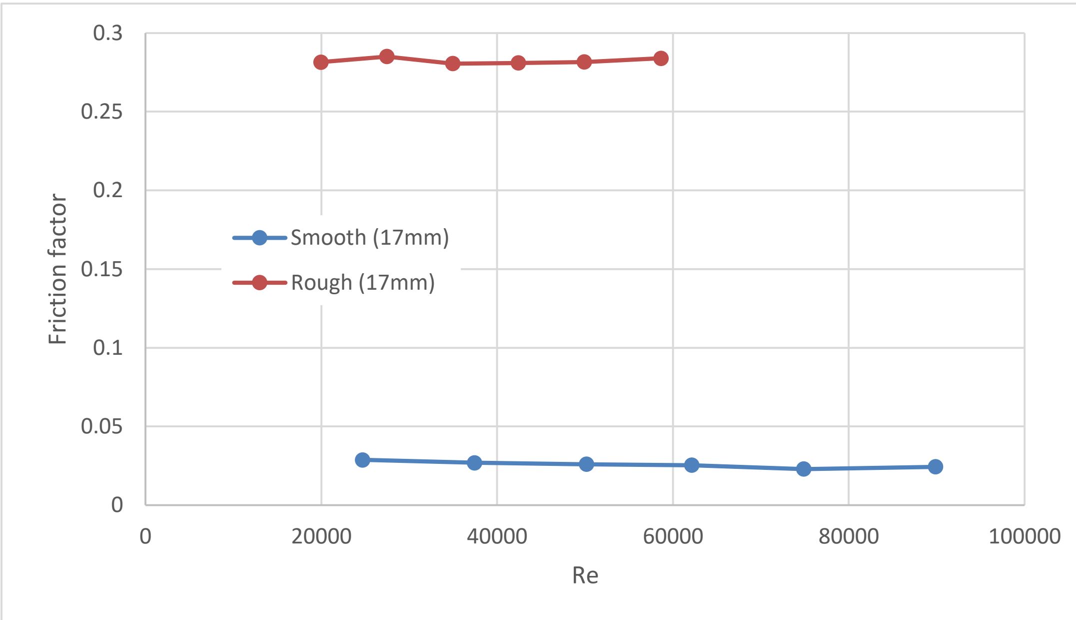


Figure 6: Comparison of smooth pipe and rough pipe.

This figure compares the experiment friction factor and Reynold's number for smooth and rough pipes of the same diameters. It can be seen that the rough pipe has a higher value of losses than the smooth pipe as Reynold's number increases. Also, the values for both pipes are fluctuating.

Table 2 presents the results of the experiment runs to calculate the pressure drop for gate valve and globe valve at a constant diameter of 25 [mm]. The table consists of 4 columns and 8 rows. The first column represents the flow rate divided into two units [L/min] and [m^3/s]. The second column represents the average velocity in [m/s]. The third column for the pressure drop in [mm H2O]. The Last column represents the loss coefficient (K) for both values.

Gate Valve with diameter = 25 [mm]				
Flow rate		Average Velocity	Pressure Drop	Loss Coefficient
[L/min]	[m^3/s]	[m/s]	[mm H_2o]	(k)
72	0.0012	2.44462	137	0.449777
60	0.001	2.03718	94	0.444394
50	0.00083	1.69765	65	0.442503
40	0.00067	1.35812	41	0.436121
30	0.0005	1.01859	25	0.472759
20	0.00033	0.67906	12	0.51058
Globe Valve with diameter = 25 [mm]				
Flow rate		Average Velocity	Pressure Drop	Loss Coefficient
[L/min]	[m^3/s]	[m/s]	[mm H_2o]	(k)
72	0.0012	2.44462	1890	6.196934
60	0.001	2.03718	1325	6.264062
50	0.00083	1.69765	925	6.297156
40	0.00067	1.35812	600	6.382252
30	0.0005	1.01859	340	6.429528
20	0.00033	0.67906	153	6.509897

Figure 7 shows the effect of the variation of the volumetric flow rate on the loss coefficient for both the gate and the globe valve.

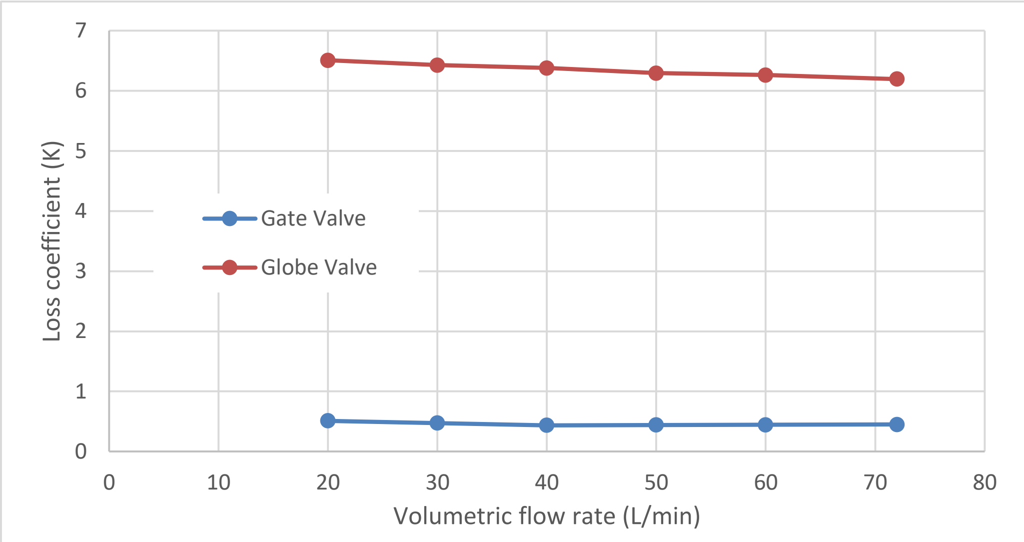


Figure 7: The effect of flow rate on loss coefficient for gate valve and globe valve.

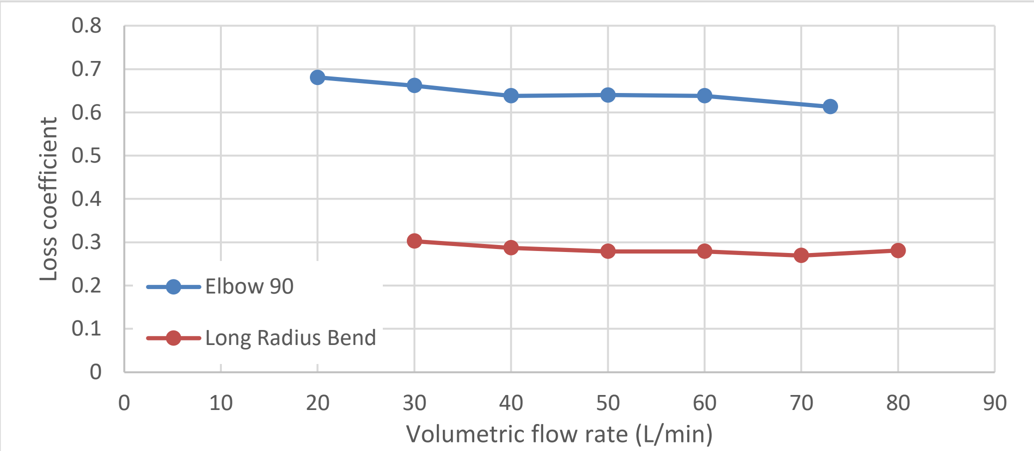
This figure represents the comparison between the fitting pipes. The loss coefficient in gate and global valve does not change with the flow rate. Also, it is obvious that the globe valve has a loss coefficient (K) higher than gate valve's coefficient.

Table 3 presents the calculation for the gate valve elbow 90 and long radius bend at constant diameters. It consists of 4 columns. The first column represents the flow rate divided into two units [L/min] and [m3/s]. The second column represents the average velocity in [m/s]. The third column for the pressure drop in [mm H2O]. The Last column represents the loss coefficient (K) for both values.

Elbow 90° with diameter = 25 [mm]				
Flow rate		Average Velocity	Pressure Drop	Loss Coefficient
[L/min]	[m^3/s]	[m/s]	[mm H_2o]	(k)
73	0.00122	2.47857	192	0.613194
60	0.001	2.03718	135	0.638225
50	0.00083	1.69765	94	0.639927
40	0.00067	1.35812	60	0.638225
30	0.0005	1.01859	35	0.661863
20	0.00033	0.67906	16	0.680774
Long radius bend with diameter = 25 [mm]				
Flow rate		Average Velocity	Pressure Drop	Loss Coefficient

[L/min]	[m^3/s]	[m/s]	[mm H_2o]	(k)
80	0.00133	2.70945	105	0.280625
70	0.00117	2.3835	78	0.269379
60	0.001	2.03718	59	0.278928
50	0.00083	1.69765	41	0.279117
40	0.00067	1.35812	27	0.287201
30	0.0005	1.01859	16	0.302566

Figure 8 shows the relation between loss coefficient for 90 degrees elbow and long radius bend versus volume flow rate.



This figure shows the comparison between two fitting pipes. It is noticed that the loss

Figure 8: The effect of flow rate on loss coefficient for 90 elbow valve and long radius valve.

coefficient for both 90 degrees elbow and long radius bend do not change with the flow rate as it is constant throughout the different flow rates. From the plot it is obvious that 90 degree elbow has a loss coefficient greater than long radius bend's coefficient.

From all previous tables it can obtained that as the flow rate increases the pressure drop also increases. Therefore, the value of average velocity will increase with increasing the flow leading to have reduction in loss coefficient values.

Conclusion

In conclusion, through this experiment, the experimental values for major and minor head losses are calculated. Major head losses are caused by the frictional force and minor head losses are caused by the loss coefficient of the various pipe fittings. The results of the experiment indicate that the friction losses are dependent upon the velocity. Head loss (H_L) increases with increasing velocity (U). major head losses decrease with increasing pipes diameter. The Reynolds number depends on the average velocity through the pipe, the pipe diameter and kinematic viscosity. The loss coefficient values differ by different pipe fittings. Loss coefficient depends on velocity through pipes and minor head losses. The loss coefficient increases when the velocity decreases. The loss coefficient increases when the pressure drop increases. The pressure drop is measured by differential digital manometer. friction factor depends on Reynolds number. To avoid errors, the calculations must be accurate.

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Appendix

The velocity of the nozzle exit U_n

$$U_n = \frac{V}{A_{Nozzle}} = \frac{V}{\frac{\pi d^2}{4}} = \frac{4x\frac{32}{(1000x60)}}{22/7x(1000)^2} = 6.787\ m/s$$

The velocity when the water hits the vane

$$U_o = \sqrt{U_n^2 - 2gs} = \sqrt{(6.787)^2 - 2x9.81x0.035} = 6.74\ m/s$$

The rate of momentum

$$\dot{m}U_o = \frac{32}{(60)x6.74} = 3.595\ N$$

The theoretical force F_{th} for each type of vane

$$F_{hemispherical} = 2\dot{m}U_o = 2x3.595 = 7.19\ N$$

$$F_{conical} = 1.5\dot{m}U_o = 1.5x3.595 = 5.3925\ N$$

$$F_{flat} = \dot{m}U_o = 3.595\ N$$

$$F_{angled} = 0.87\dot{m}U_o = 0.87x3.595 = 3.1276\ N$$

The actual force F_a, for the hemispherical vane

$$F_{a.hemispherical} = \frac{m_j\ x\ g\ x\ y}{y_v} = \frac{\frac{600}{1000}x9.81x169/1000}{150/1000} = 6.63156\ N$$

The percentage loss in the impact force for the hemispherical vane

$$\%loss = \left|\frac{F_{th} - F_a}{F_{th}} x100\right| = \left|\frac{7.19 - 6.63156}{7.19} x100\right| = 7.77\%$$

Data sheets

A7 – Determination of Head Losses in Pipes and Fitting

Table A7.1 Data for Determination of Friction Factor (f) for pipes

	Smooth Pipe		Pipe Diameter = 10 mm		
#	Flow rate	Pressure Drop	Reynolds Number	Friction Factor	
	L/min	[mm H20]		emperical	exp
1	33	4635	70028.2	0.0192	0.0185
2	28	3443	59417.8	0.0199	0.0191
3	24	2626	50929.6	0.0206	0.0199
4	20	1940	42441.3	0.0215	0.0211
5	16	1320	33953.1	0.0226	0.0225
6	12	822	25464.8	0.0243	0.0249

	Smooth Pipe		Pipe Diameter = 17mm		
#	Flow rate	Pressure Drop	Reynolds Number	Friction Factor	
	L/min	[mm H20]		emp	exp
1	72	2042	89875.7	0.01823	0.0244
2	60	1447	74896.4	0.01895	0.0249
3	50	1021	62413.7	0.01972	0.0253
4	40	685	49931	0.02072	0.0265
5	30	397	37448.2	0.02213	0.0273
6	20	187	24965.5	0.02437	0.0289

	Rough Pipe		Pipe Diameter = 17mm	
#	Flow rate	Pressure Drop	Reynolds Number	Friction Factor
	L/min	[mm H20]		
1	47	10143	58668.9	0.01999
2	40	7288	49931	0.02072
3	34	5254	42441.3	0.02150
4	28	3561	34951.7	0.02249
5	22	2234	27462	0.02382
6	16	1170	19972.4	0.02576

Table A7.2 Data for Determination of Loss coefficient (K) for fittings.

	Type of Fitting : Gate Valve			Pipe Diameter = 25 mm
#	Flow rate	Pressure Drop		K
	L/min			
1	72	143		0.4695
2	60	99		0.4680
3	50	70		0.4765
4	40	46		0.4893
5	30	27		0.5106
6	20	13		0.5531
	Type of Fitting : Globe Valve			Pipe Diameter = 25. mm
#	Flow rate	Pressure Drop		K
	L/min			
1	72	1895		0.62214
2	60	1301		0.61506
3	50	927		0.63108
4	40	608		0.64733
5	30	332		0.62782
6	20	155		0.65949
	Type of Fitting : Elbow 90 °			Pipe Diameter = 25 mm
#	Flow rate	Pressure Drop		K
	L/min			
1	73	197		0.62916
2	60	140		0.66186
3	50	99		0.67396
4	40	65		0.69408
5	30	36		0.68078
6	20	17		0.72332
	Type of Fitting : Long Radius Bend			Pipe Diameter = 25 mm
#	Flow rate	Pressure Drop		K
	L/min			
1	80	103		0.27390
2	70	81		0.28133
3	60	60		0.28365
4	50	45		0.30635
5	40	29		0.30847
6	30	17		0.32148

Nomenclature

d = Diameter of the pipe

f = Friction Factor

h_{ij} = Major head loss

h_{ln} = Minor head loss

h_{lt} = Total head loss

Re_d = Reynolds number based on the diameter of pipe

K = Loss Coefficient

L = Length of the pipe

P = Pressure

$\bar{u}$= Mean flow velocity

y = Radial distance from the centerline

Z = elevation

τ= Shear stress