Losses in pipe

University o Jordan

D

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Table Index

Team "D"

- Alaa Saqr 0201373
- Omar Sowan 0204768
- Feras Takruri 0201300
- Mohammed AlSaaideh 0202057

Objectives:

To determine the variation of friction factor with Reynold's number in a pipe And find out the relationship between total head loss and flow rate for pipe bends and other common pipe fittings as well as determining the loss coefficient for several fittings such as bends, elbows, valves, sudden expansion and sudden contraction.

Introduction & Theory

In internal flows, energy losses occur due to friction (major losses) denoted by (hf) between the fluid and the pipe walls, and due to disturbances caused by fittings (minor losses) denoted by (hm). These include valves, bends, sudden and gradual contractions and expansions. The total head loss (hf), which is the sum of both major and minor losses, represents the energy lost in the system. The energy equation and the major loss formulas are represented, respectively, below.

$$\frac{P_1}{\gamma} + \alpha_1 \frac{V_1^2}{2g} + z_1 + h_p = \frac{P_2}{\gamma} + \alpha_2 \frac{V_2^2}{2g} + z_2 + h_T + h_L$$

$$h_f = f \frac{L}{D} \frac{V_m^2}{2g}$$

Where:

$L$and D are the length and diameter of the pipe.
Vm is the average velocity of the fluid.
Vm is the average velocity of the fluid.
f is the friction factor of the fluid (also called the Darcy friction factor). This factor represents the ratio between the shear stress acting at the wall and the kinetic pressure.
g is the gravity acceleration.

The friction factor depends on the type of the flow:

- For laminar flow (i.e Reynolds number Re <2300).the friction is expressed as

$$f = \frac{64}{Re}$$

The Reynolds number Re, which represents the ratio between inertia forces and viscous forces in the fluid is given by.

$$Re = \frac{\rho V D}{\mu}.$$

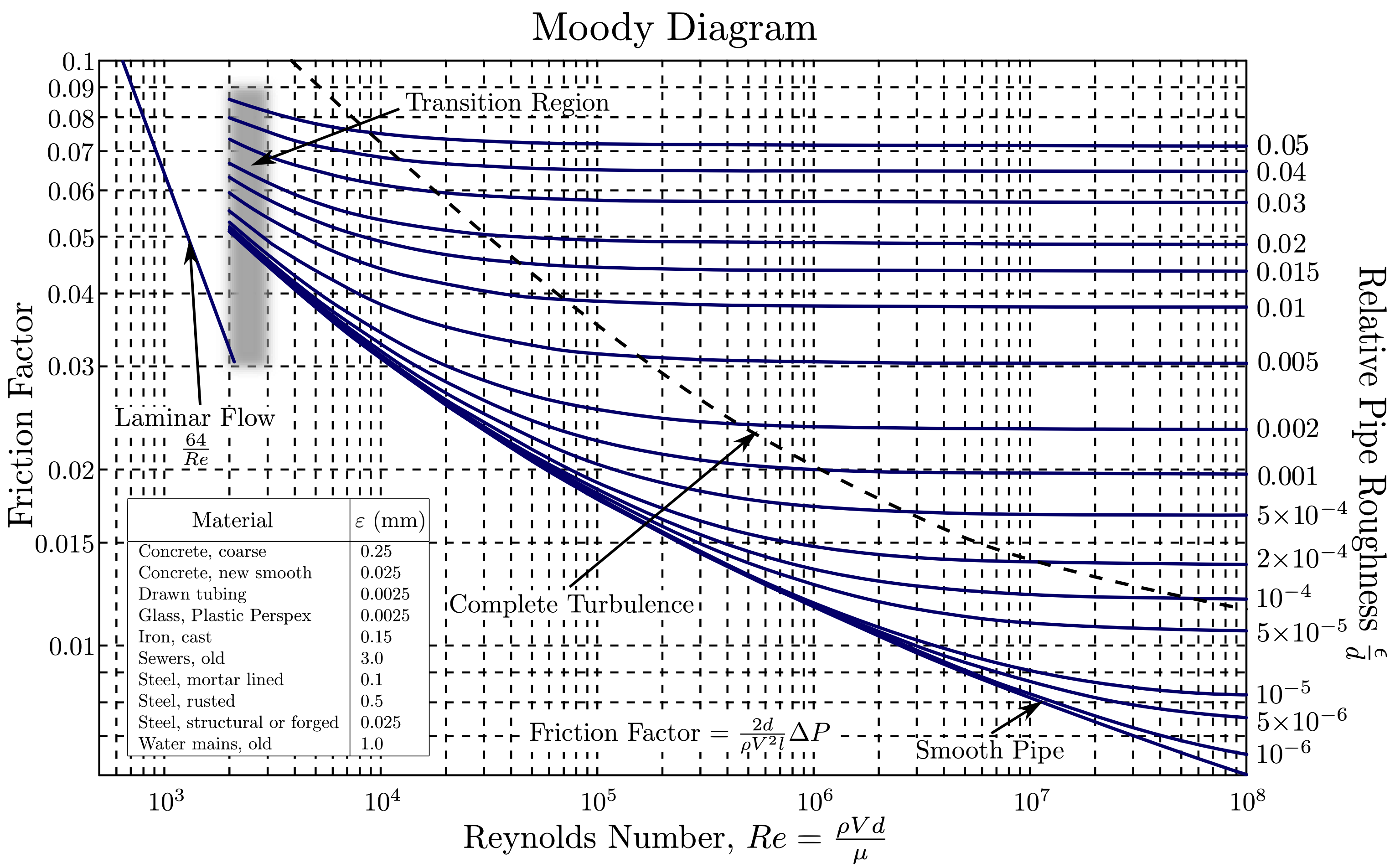
Where:

ρ is the density of the fluid.
V is the mean velocity of the fluid.
Vm is the average velocity of the fluid.
μ is the dynamic viscosity of the fluid

- For turbulent flow, (i.e Reynolds number Re>2300) , the friction factor depends on the Reynolds number and the relative roughness ε/D , and it is given by the "Colebrook equation":

$$\frac{1}{\sqrt{f}} = -2.0 \, Log\left(\frac{\varepsilon}{3.7 * D} + \frac{2.51}{R\sqrt{f}}\right)$$

This equation is plotted in the Moody diagram shown in Figure1. This diagram is a graph in nondimensional form that relates the Darcy friction factor f, Reynolds number Re, and relative roughness for fully developed flow in a circular pipe.



* The minor losses is found using the energy equation ,as shown below Apply the energy equation on a general component (valve , bend, etc.) , where state 1 represents the upstream entering the component and state 2 represents the downstream leaving the component.

$$\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + Z_2 + \frac{V_2^2}{2g} + h_L$$

If $h = P/\gamma + Z$, the equation becom

$$h_1 + \frac{V_1^2}{2g} = h_2 + \frac{V_2^2}{2g} + h_L$$

Rearranging the equation, and noting that $\Delta h = h1 - h2$ is the measured head loss, and the total head loss $hL = hf + hm$, the equation turns to

$$h_m = \Delta h + \left[\frac{V_1^2 - V_2^2}{2g}\right] - h_f$$

-If the upstream and downstream diameters are the same then $V1 = V2$, hence, the equation becomes

$$h_m = \Delta h - h_f$$

The minor head loss is expressed in terms of the loss coefficient K, which is given by $\mathbf{k} = \frac{hm}{V\ 2\ /2g}$, where v is the velocity in the smaller pipe.

Apparatus

The apparatus is shown in figure2. in the next page. It is composed of two separated hydraulic circuits: Dark Blue Circuit and Light Blue Circuit. Each circuit consists of several pipe system components. Both circuits are supplied with water from the hydraulic bench.

The components in each of the circuits are as follow:

Dark Blue Circuit (DBC)

1. Gate Valve (D)
2. Standard Elbow Bench (C) radius = 12.7 mm
3. 90 degree Miter Bend (B)
4. Straight Pipe : length = 914.4 mm

Small diameter = 13.6 mm

Large diameter = 26.2 mm

Pipe material is copper: (ε = 0.0015 mm)

Light Blue Circuit (LBC)

1. Globe Valve (K)
2. Sudden Expansion (E)
3. Sudden Contraction (F)
4. 150 mm radius 90 degree bend (J), R/d = 11.1 4
5. 100 mm radius 90 degree bend (H) , R/d = 7.4 6. 60 mm radius 90 degree bend (G) , R/d = 3.7 .

In all components (except the gate and globe valves), the pressure drop across each of the components is measured by a pair of pressurized piezometer tubes containing water. In the case of the valves, the pressure drop is measured using a U-tube manometer containing mercury.

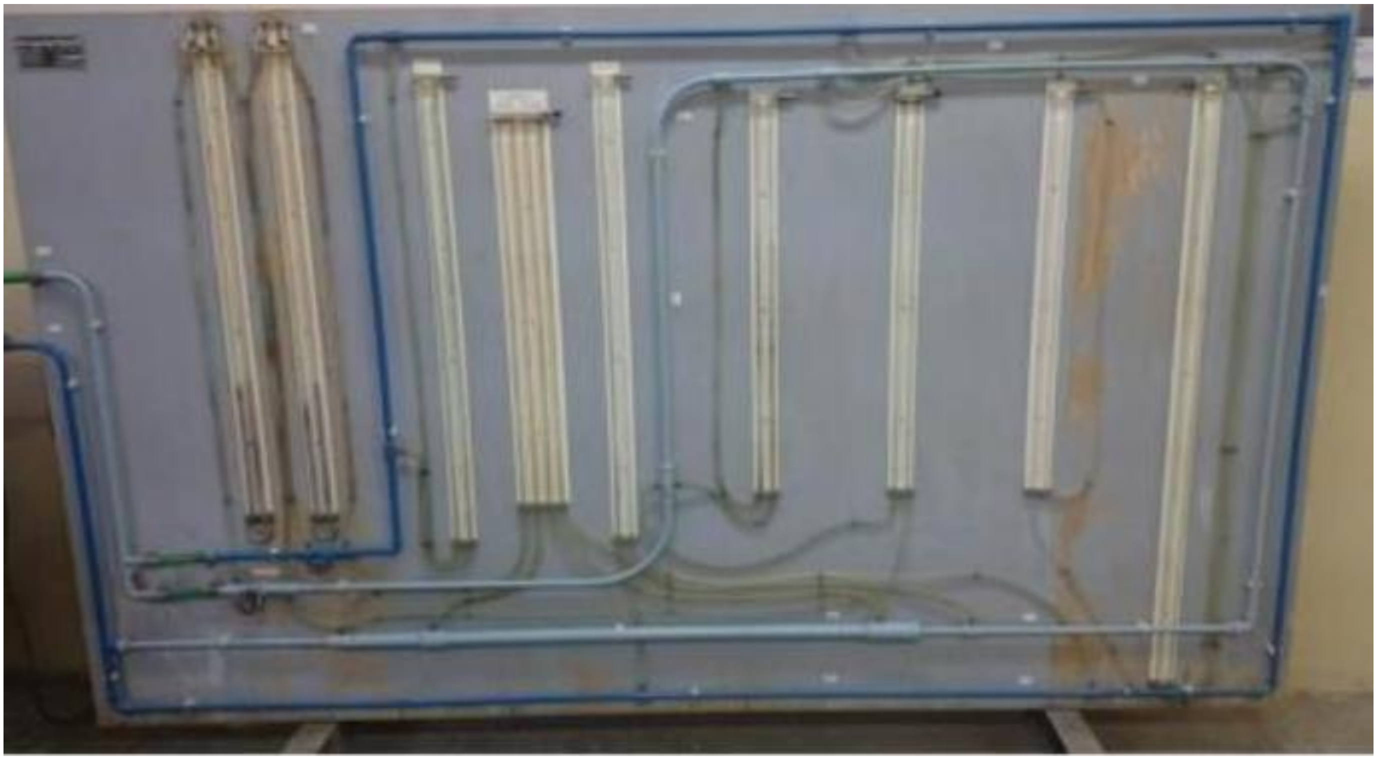


Figure 1: The apparatus of the experiment

Procedure

(1) Before performing the experiment, the trapped air in the two circuits must be expelled out. Hence, first, close the globe valve and open the gate valve. Switch on the bench pump and open the bench supply valve to allow water to flow in the dark blue circuit.

(2) Close the gate valve and allow for the trapped air to be expelled into the top of the manometer tubes. Check that all manometer readings show zero pressure difference.

(3) Open the gate valve and then open the bled screws at the top of the mercury U tube. Make sure that all air bubbles have been expelled, then close the bleed screws.

(4) Close the gate valve and open the globe valve to repeat the previous steps for the light blue circuit.

(5) To start with the experiment, open fully the bench supply valve. Close the globe valve and open fully the gate valve to allow for maximum flow rate through the dark blue circuit.

(6) Record the manometer readings across the straight pipe in the dark blue circuit.

(7) Measure the flow rate by measuring the time required to collect the water in the bench weighing tank.

(8) Reduce the opening of the gate valve to reduce the mass flow rate and repeat steps 6 & 7 until you have about 5 sets of readings.

(9) Close the gate valve and open fully the globe valve to allow for maximum flow rate through the light blue circuit.

(10) Record the manometer readings across the straight pipe in the light blue circuit.

(11) Measure the flow rate by measuring the time required to collect the water in the bench weighing tank.

(12) Reduce the opening of the globe valve to reduce the mass flow rate and repeat steps 10& 11 until you have about 5 sets of readings.

Data collection

table (1.a) readings from the dark

#	Mass (Kg)	Time (S)	$\Delta h = h_f$ (m)
1	7.5	31.0	0.280
2	7.5	33.0	0.245
3	7.5	35.6	0.221
4	7.5	38.4	0.196
5	7.5	53.3	0.110

table(1.b) calculation of friction factor f

#	m° (kg/s)	v (m/s)	Re	flow type	$f_{exp.}$	$f_{the.}$	relative error(ε%)
1	0.241935484	1.665454	12583.42906	turbulent	0.029457407	0.029158	1.028512534
2	0.227272727	1.564517	11820.797	turbulent	0.029208353	0.029642	1.463380144
3	0.210674157	1.450255	10957.48036	turbulent	0.030662345	0.030247	1.373056712
4	0.1953125	1.344507	10158.49742	turbulent	0.031639647	0.03087	2.492167234
5	0.140712946	0.96865	7318.692324	turbulent	0.034210562	0.033813	1.1757091

table (2) readings from the light blue circuit

#	M (kg)	Time (S)	Manometer readings and differential heads (mm water)																U-tube (mm Hg)		
			Expansion			Contraction			Bend J			Bend H			Bend G			Globe valve			
			7	8	Δh	9	10	Δh	11	12	Δh	13	14	Δh	15	16	Δh	h_1	h_2	Δh
1	7.5	32.8	350	390	-40	380	185	195	702	480	222	438	197	241	402	203	199	337	294	43
2	7.5	35.2	353	394	-41	382	196	186	698	490	208	440	210	230	427	194	233	350	282	68
3	7.5	38.2	360	394	-34	384	230	154	692	516	176	442	250	192	425	230	195	371	260	111
4	7.5	42.6	370	399	-29	390	261	129	688	537	151	445	285	160	430	262	168	393	240	153
5	7.5	54.8	382	398	-16	392	315	77	674	578	96	446	344	102	423	318	105	428	205	223

table (3) Results for light blue circuit

#	η 13.6mm	η 26.2mm	Re	f	Head losses for different fittings (mm water)														U-tube (m Hg)		
					Expansion			Contraction			Bend J			Bend H			Bend G		Globe valv		
					Δh	h_f	h_m	Δh	h_f	h_m	Δh	h_f	h_m	Δh	h_f	h_m	Δh	h_m	Δh	h_f	h
1	1.6	0.42	11893	0.02959	-40	0	77.1	195	0	77.9	222	11.4	211	241	17.1	224	199	171	43	0	4
2	1.5	0.40	11082	0.03016	-41	0	60.7	186	0	84.3	208	10.1	198	230	15.1	215	233	208	68	0	6
3	1.4	0.36	10212	0.03083	-34	0	52.3	154	0	67.7	176	8.75	167	192	13.1	179	195	173	111	0	1
4	1.2	0.33	9157	0.03176	-29	0	40.4	129	0	59.6	151	7.25	144	160	10.9	149	168	150	153	0	1
5	0.9	0.25	7118	0.03408	-16	0	26	77	0	35	96	4.7	91.3	102	7.05	95	105	93.3	223	0	2

table (4) The minor loss coefficient 'K'

fitting type	test no.						std. value (theoretical)	relative error
	1	2	3	4	5	avg.		
expansion	0.610646855	0.55347715	0.562210298	0.54002648	0.57373339	0.568019	0.55	3.276151649
contraction	0.616763541	0.768925592	0.726687209	0.79573714	0.774612649	0.736545	0.345	113.4913698
bend J	1.667764525	1.805049373	1.796423285	1.92020564	2.018106007	1.84151	0.247	645.5505126
bend H	1.773119327	1.959732509	1.921296423	1.99202566	2.098789606	1.948993	0.342	469.8809077
bend G	1.350326791	1.895178006	1.859559135	2.00208933	2.061220505	1.833675	0.16	1046.04672
globe valve	0.3405074	0.620161286	1.192230194	2.04371833	4.929199455	1.825163	10	81.74836667

Calculations

* Sample of calculations:

1.) dark blue circuit (trial "1")

$$* \dot{m} = \frac{m}{t} = \frac{7.5\ Kg}{31\ sec.} = 0.2419\ Kg/sec.$$

$$* V = \frac{(\dot{m})}{(\rho)(A)} = \frac{(0.2419\ Kg/sec.)}{\left(\frac{\pi}{4} * (0.0136m)^2\right)(1000\ Kg/m^3)} = 1.665\ m/s$$

$$* Re = \frac{(\rho)(V)(D)}{(\mu)} = \frac{(1000\ Kg/m^3)(1.665\ m/s)(0.0136m)}{(0.0018\ Kg/(m.s))} = 12,583$$

∴ turbulent flow

$$* \; f_{exp.} = \frac{(h_f)(D)(2g)}{(L)(V^2)} = \frac{(0.28\,m)(0.0136\,m)(2 * 9.81\,m/s^2)}{(0.9114\,m)(1.665\,m/s)^2} = 0.02946$$

$$* \; \frac{1}{\sqrt{f_{th}}} = (-1.8) * \log \left[\frac{9.6}{Re} + \left(\frac{(\varepsilon/D)}{3.7} \right)^{1.11} \right]$$

$$\frac{1}{\sqrt{f_{th}}} = (-1.8) * \log \left[\frac{9.6}{(12,583)} + \left(\frac{\left(\frac{0.0000015\,m}{0.0136\,m}\right)}{3.7} \right)^{1.11} \right]$$

$$f_{th} = 0.029158$$

$$* \; \text{Relative error } (\varepsilon\%) = \left| \frac{f_{exp.} - f_{th}}{f_{th}} \right| \times 100\%$$

$$\varepsilon\% = 1.03\%$$

2.) light blue circuit (trial "1") :

$$* \; \dot{m} = \frac{m}{t} = \frac{7.5\,Kg}{32.8\,sec} = 0.2286\,Kg/sec.$$

$$* \; V(D = 0.0136\,m) = \frac{\dot{m}}{\rho A} = \frac{(0.2286\,Kg/s)}{(1000\,Kg/m^3)\left(\frac{\pi}{4} * (0.0136\,m)^2\right)} = 1.574\,m/s$$

$$* \; V(D = 0.0262\,m) = \frac{\dot{m}}{\rho A} = \frac{(0.2286\,Kg/s)}{(1000\,Kg/m^3)\left(\frac{\pi}{4} * (0.0262\,m)^2\right)} = 0.424\,m/s$$

* $$Re = \frac{(\rho)(V)(D)}{(\mu)} = \frac{(1000\ Kg/m^3)(1.574\ m/s)(0.0136 m)}{(0.0018\ Kg/(m.s))} = 11,892$$

∴ turbulent flow

* $$\frac{1}{\sqrt{f_{th.}}} = (-1.8) * \log\left[\frac{(6.9)}{Re} + \left(\frac{(\varepsilon/D)}{3.7}\right)^{1.11}\right]$$

$$\frac{1}{\sqrt{f_{th.}}} = (-1.8) * \log\left[\frac{(9.6)}{(11,892)} + \left(\frac{\left(\frac{0.00\ 000\ 15 m}{0.0136 m}\right)}{3.7}\right)^{1.11}\right]$$

$$f_{th.} = 0.0295$$

1.

expansion

* $\Delta h = (h_7) - (h_8) = -40\ mm$

* $\Delta Ke = \dfrac{(V_1)^2 - (V_2)^2}{2g} = \dfrac{(1.574\ m/s)^2 - (0.424\ m/s)^2}{2(9.81\ m/s^2)} = 0.117\ m = 117\ mm$

* $h_m = (\Delta h) + (\Delta Ke) = (-40\ mm) + (117\ mm) = 77\ mm$

2.

Contraction

* $\Delta h = (h_9) - (h_{10}) = 195\ mm$

* $\Delta Ke = \dfrac{(V_1)^2 - (V_2)^2}{(2g)} = \dfrac{(0.424\ m/s)^2 - (1.574\ m/s)^2}{(2 * 9.81\ m/s^2)} = -0.117\ m = -117\ mm$

* $h_m = (\Delta h) + (\Delta K) = (195\ mm) + (-117\ mm) = 78\ mm$

3.

Bend (J)

* $\Delta h = (h_{11}) - (h_{12}) = (702\ mm) - (480\ mm) = 222\ mm$

* $h_f = \dfrac{(f)(v^2)(L)}{(2g)(D)} = \dfrac{(0.0296)(1.574\ m/s)^2(0.9144\ m)}{(2 * 9.81\ m/s^2)(0.3\ m)} = 0.01139\ m = 11.39\ mm$

dia. of the bend (D)

* $h_m = (\Delta h) - (h_f) = (222\ mm) - (11.39\ mm) = 210.61\ mm$

4. # Bend (H)

* $\Delta h = (h_{13}) - (h_{14}) = (438\,mm) - (197\,mm) = 241\,mm$

* $h_f = \dfrac{(f)(v^2)(L)}{(2g)(D)} = \dfrac{(0.0296)(1.574\,m/s)^2(0.9144\,m)}{(2*9.81\,m/s^2)(0.2\,m)} = 0.01708\,m = 17.08\,mm$

* $h_m = \Delta h - h_f = (241\,mm) - (17.08\,mm) = 223.92\,mm$

5. # Bend (G)

* $\Delta h = (h_{15}) - (h_{16}) = (402\,mm) - (203\,mm) = 199\,mm$

* $h_f = \dfrac{(f)(v^2)(L)}{(2g)(D)} = \dfrac{(0.0296)(1.574\,m/s)^2(0.9144\,m)}{(2*9.81\,m/s^2)(0.12\,m)} = 0.02848\,m = 28.48\,mm$

* $h_m = (\Delta h) - (h_f) = (199\,mm) - (28.48\,mm) = 170.52\,mm$

Globe valve

* $\Delta h = (h_1) - (h_2) = (337\,mm) - (294\,mm) = 43\,mm$

* $h_m = \Delta h = 43\,mm$

note:

- contraction & expansion → $h_f = 0$
- for all bends (J & H & G) → $\Delta KE = 0$
- globe valve → $h_f = \Delta KE = 0$

3.) Minor loss coefficient $\underline{\underline{K}}$ (trial "1")

★ expansion → $K = \frac{(2g)(hm)}{(V^2)} = \frac{(2 * 9.81\ m/s^2)(0.077\ m)}{(1.574\ m/s)^2} = 0.61$

★ contraction → $K = \frac{(2g)(hm)}{(V^2)} = \frac{(2 * 9.81\ m/s^2)(0.078\ m)}{(1.574\ m/s)^2} = 0.62$

★ Bend "J" → $K = \frac{(2g)(hm)}{(V^2)} = \frac{(2 * 9.81\ m/s^2)(0.21\ m)}{(1.574\ m/s)^2} = 1.66$

★ Bend "H" → $K = \frac{(2g)(hm)}{(V^2)} = \frac{(2 * 9.81\ m/s^2)(0.224\ m)}{(1.574\ m/s)^2} = 1.77$

★ Bend "G" → $K = \frac{(2g)(hm)}{(V^2)} = \frac{(2 * 9.81\ m/s^2)(0.171\ m)}{(1.574\ m/s)^2} = 1.35$

★ Globe valve → $K = \frac{(2g)(hm)}{(V^2)} = \frac{(2 * 9.81\ m/s^2)(0.043\ m)}{(1.574\ m/s)^2} = 0.34$

Result and discussion

1) Tables
2)

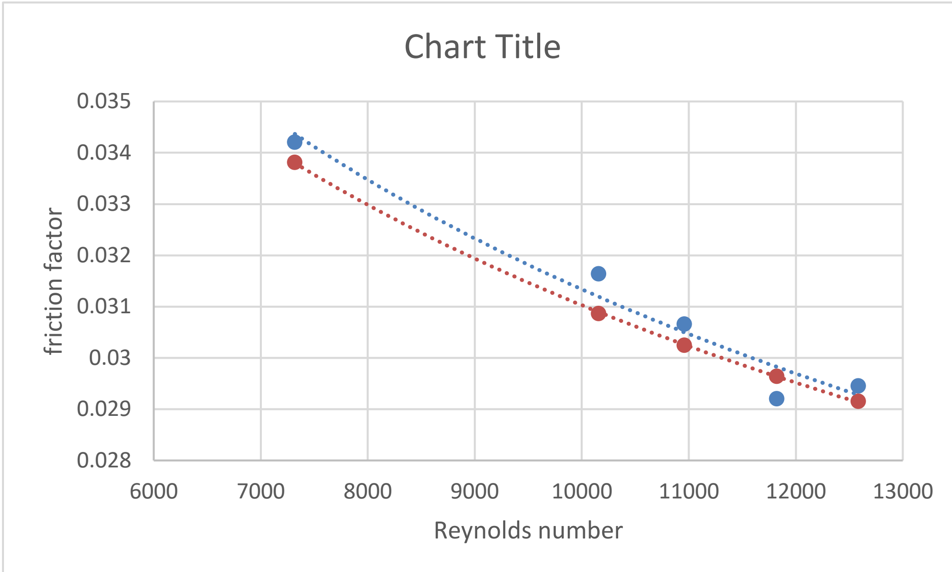


Figure 2. Plot of the relationship between Reynolds number and the friction factor

3) The loss coefficient shows little variation, as evidenced by the close values in Table 4. However, some discrepancies exist due to potential experimental and data recording errors. This reinforces the concept that the loss coefficient is primarily determined by the component's geometry**.**

4) Most of the obtained value of K are close to the standard data.