MET 335W

Friction Losses in Pipes and Fittings

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Experiment Title: Friction Losses in Pipes and Fittings

Purpose:
In this lab, the loss coefficient and equivalent length of a partially opened gate valve is determined and this information is used to estimate how open the valve is.

Theoretical Considerations:
Valves restrict flow. If a valve is partially restricted, friction loss will result in a pressure drop for the system. Darcy's equation gives the energy loss due to the friction generated by the valve:

$$h_L = f\,\frac{L(v_P)^2}{D2g}$$

where

•h_L is defined as the energy loss from the system

•f = friction factor (dimensionless)

•L = length of flow stream (m or ft)

•v = average velocity of flow (m/s) or (ft/s)

•D = pipe diameter (m or ft)

The equation Q = Av, velocity of flow, is used to calculate for a given volume flow rate through a given pipe.

Valve type selection takes into consideration efficiency with the least energy loss.

Description of Apparatus:

1. H408 Fluid Friction Apparatus, with its 35 tapping points and a variety of pipes, fittings and valves (Figure 1).
2. Water collection tank (Figure 2), to include:
   a. Flow rate valve
   b. Weight beam stop
   c. Gravimetric bench
   d. Pump power button
   e. Weight platform
   f. 2 kg weight
3. Gate valve (utilized on fluid friction apparatus)
4. Digital manometer with readout display

Figure 1: H408 Fluid Friction Apparatus

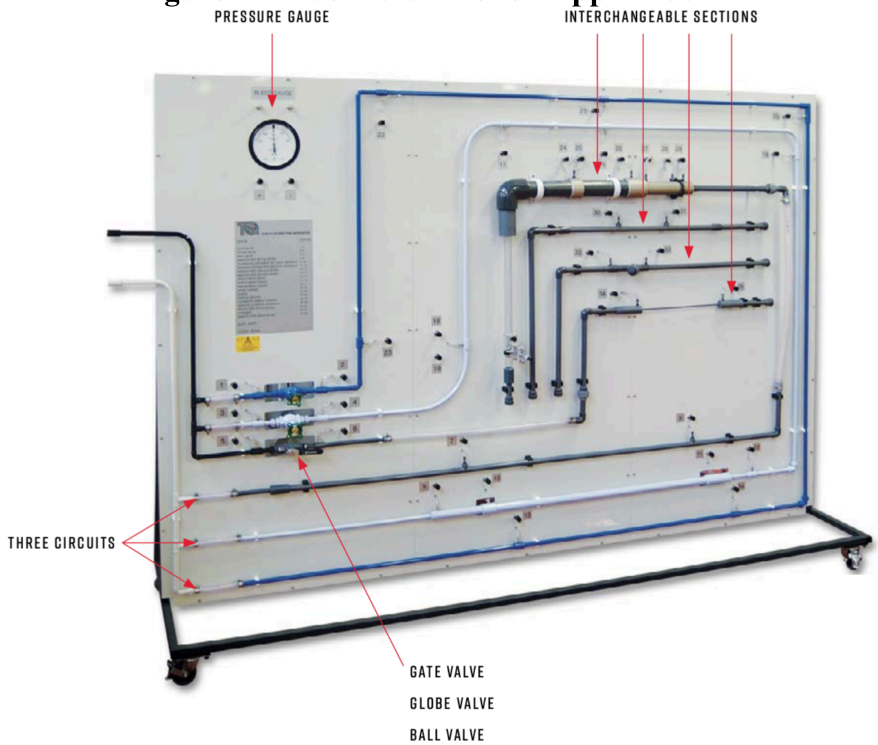
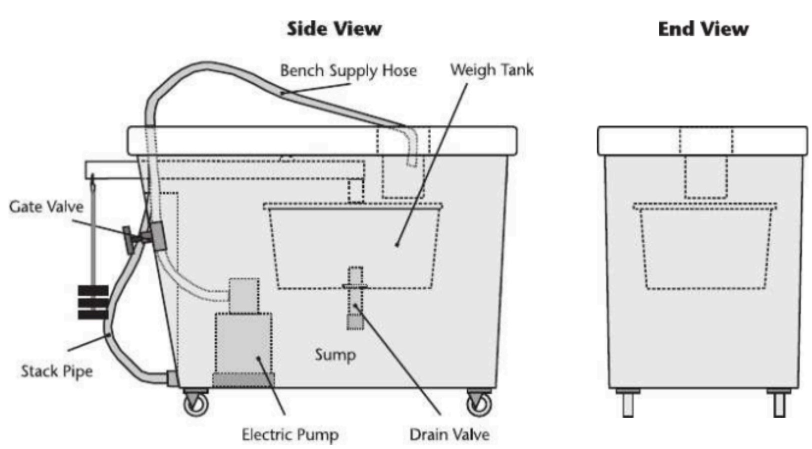


Figure 2: Water Collection Tank



Step-by-Step Procedures:

1. The black start switch controlling power to the pump (located on the water collection tank) was pressed to start the flow of water through the pipe network.
2. The red flow valve on the gravimetric bench was rotated counterclockwise, opening the valve to its maximum flow rate.
3. To ensure there was no water in the water collection tank, the gravimetric bench beam was lifted up to allow any excess water to drain out, and then the drain valve was closed.
4. The gravimetric bench beam was then returned to its original downward position.
5. The weight beam stop was slid to the left to act as a stop for the gravimetric bench beam.
6. Once the weigh tank inside the water collection tank refilled, the beam lifted upward to rest against the weight beam stop in a horizontal position.
7. The 2 kg weight was added to the weight platform, bringing the beam back down to its starting position.
8. A timer was immediately started in order to time how long it would take for the weigh tank to refill and lift the beam up to the weight beam stop again.
9. The timer was stopped immediately as the beam rose horizontally, resting against the weight arm stop again.
10. The time was recorded in the data sheet.
11. The downstream pressure head reading on the digital manometer was recorded (in inches) on the data sheet.
12. The upstream pressure head reading on the digital manometer was recorded (in inches) on the data sheet.
13. The red flow rate valve on the gravimetric bench was rotated clockwise one turn to slightly reduce the flow rate of the water to the pipe network.
14. The excess 2 kg weight was removed from the weight platform, causing the beam to return to its original resting position at the bottom.
15. The weight beam stop was slid out of the way and the beam was lifted all the way up to drain all water from the water collection tank, and the beam lowered to the bottom again.
16. The weight beam stop was slid to the left to act as a stop for the gravimetric bench beam.
17. Once again, the weigh tank inside the water collection tank refilled, the beam lifted upward to rest against the weight beam stop in a horizontal position.
18. The 2 kg weight was added to the weight platform, bringing the beam back down to its starting position.
19. A timer was immediately started in order to time how long it would take for the weigh tank to refill and lift the beam up to the weight beam stop again.
20. The timer was stopped immediately as the beam rose horizontally, resting against the weight arm stop again.
21. The time was recorded in the data sheet.
22. The downstream pressure head reading on the digital manometer was recorded (in inches) on the data sheet.
23. The upstream pressure head reading on the digital manometer was recorded (in inches) on the data sheet.
24. Again, the red flow rate valve on the gravimetric bench was rotated clockwise one turn to slightly reduce the flow rate of the water to the pipe network.

25. The excess 2 kg weight was removed from the weight platform, causing the beam to return to its original resting position at the bottom.
26. The weight beam stop was slid out of the way and the beam was lifted all the way up to drain all water from the water collection tank, and the beam lowered to the bottom again.
27. The weight beam stop was slid to the left to act as a stop for the gravimetric bench beam.
28. Once again, the weigh tank inside the water collection tank refilled, the beam lifted upward to rest against the weight beam stop in a horizontal position.
29. The 2 kg weight was added to the weight platform, bringing the beam back down to its starting position.
30. A timer was immediately started in order to time how long it would take for the weigh tank to refill and lift the beam up to the weight beam stop again.
31. The timer was stopped immediately as the beam rose horizontally, resting against the weight arm stop again.
32. The time was recorded in the data sheet.
33. The downstream pressure head reading on the digital manometer was recorded (in inches) on the data sheet.
34. The upstream pressure head reading on the digital manometer was recorded (in inches) on the data sheet.
35. The entire process was repeated exactly the same until 8 sets of data had been collected and recorded on the data sheet, completing with the red flow valve rotated incrementally each time until reaching a point of being fully closed.
36. Once securing the red flow valve in the fully closed position to stop all water flow to the pipe network, the 2 kg weight was removed from the weight platform.
37. The gravimetric bench arm was lifted to drain out any water left in the water collection tank.
38. The red pump power "off" switch was pressed, turning off electric power to the system.
39. This completed the Friction Losses in Pipes and Fittings experiment.

Recorded Data Table:

Table 1. Recorded Data:

Tank Valve Position (red knob)	Time to Fill Tank (seconds)	Upstream Head, h_2 (location 2) (inches of H_2O)	Downstream, h_1 (location 1) (inches of H_2O)
1	31	34.8	12.5
2	33	34.6	12.6
3	34	34.3	12.7
4	37	34.3	14.0
5	41	31.3	14.2
6	43	30.8	15.4
7	48	30.3	17.7
8	57	29.5	19.3

Sample Calculations:

Mass Flow Rate = $\frac{6 \text{ kg of water}}{31 \text{ seconds}}$ = 0.194 kg/s

Volumetric Flow Rate, Q = $\frac{\text{Mass Flow Rate of } H_2O}{\text{Density of } H_2O} = \frac{0.194 \text{ kg/s}}{997 \text{ kg/m}^3} = 0.000194 \text{ m}^3/\text{s}$

Velocity through pipe containing test valve, $V_p = \frac{Q}{A_P}$ where $A_P = \frac{\pi D_P^2}{4}$

- ➔ Area of the Pipe, AP = $\frac{\pi (0.0136 \text{ m})^2}{4} = 0.000145 \text{ m}^2$

- ➔ Velocity through the pipe = $\frac{0.000194 \text{ m}^3/\text{s}}{0.000145 \text{ m}^2} = 1.34 \text{ m/s}$

Velocity through pipe squared divided by twice gravity, $\frac{(V_P)^2}{2g}$

> $\frac{(1.34 \text{ m/s})^2}{(2)(9.81 \text{ m/s}^2)} = \frac{1.7956 \text{ m}^2/\text{s}^2}{19.62 \text{ m/s}^2} = 0.0915 \text{ m}$

Resistance Coefficient for the tested Gate Valve, $K = \frac{h_L}{\frac{(V_P)^2}{2g}} = \frac{0.566 \text{ m}}{0.0915 \text{ m}} = 6.18$

Reynolds number at the pipe inlet, NR $= \frac{\rho VD}{\eta} = \frac{[1000 \text{ kg/m}^3][1.34 \text{ m/s}][0.0136 \text{ m}]}{[0.001002 \text{ kg/(m)(s)}]} = 18187.62$

Relative roughness of the pipe, given $\varepsilon = 3 \times 10^{-7}$ m, $\frac{D}{\varepsilon} = \frac{0.0136 \text{ m}}{0.0000003 \text{ m}} = 45333.33$

The fully turbulent friction factor, $\mathbf{f_T}$, given by Moody diagram is 0.0265

Calculating our gate valve's equivalent length, we use $\frac{Le}{D} = \frac{K}{f_T} = \frac{6.18}{0.0265} = 233.21$

Calculated Data Table:

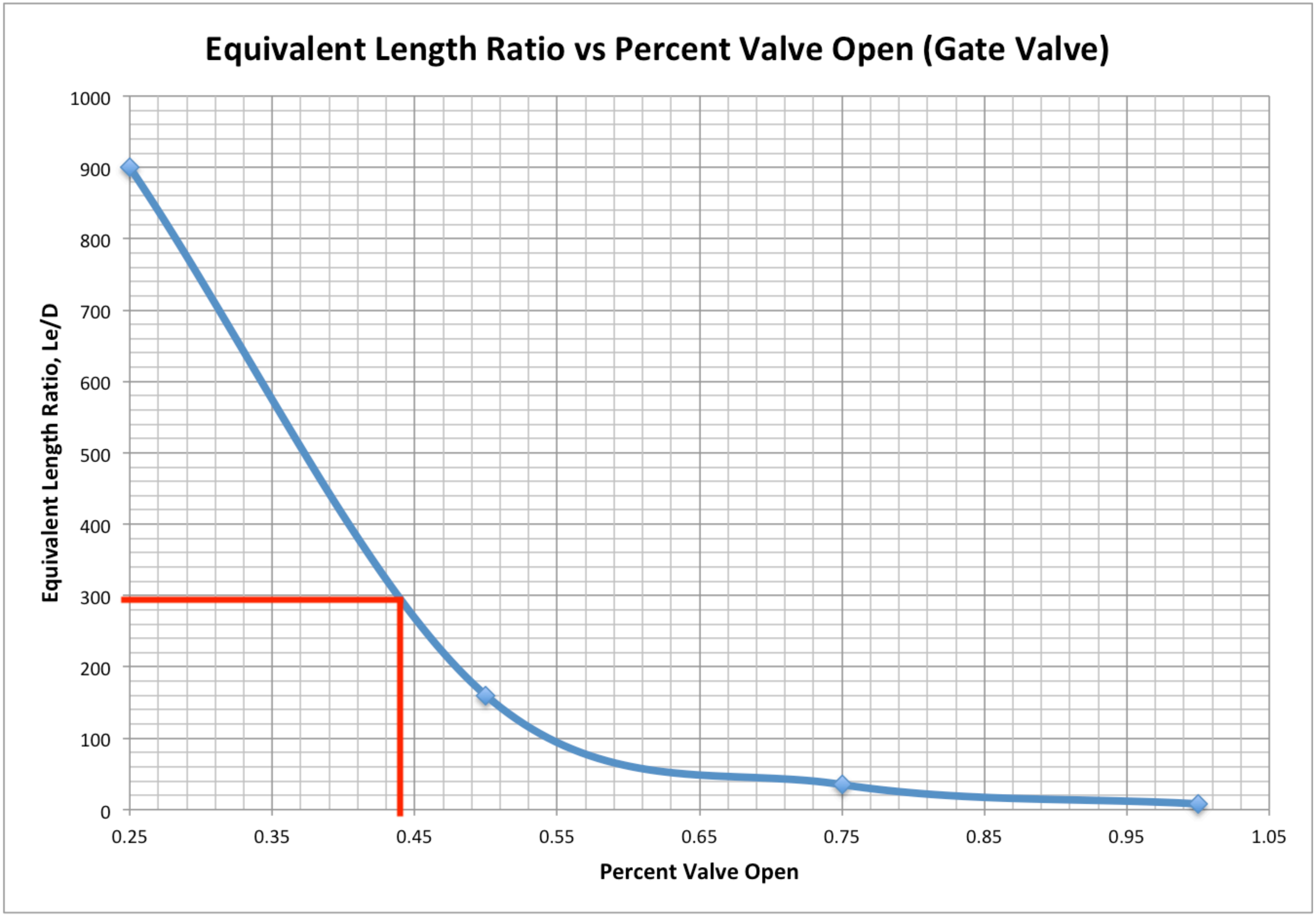
Table 2. Calculated Data:

Tank Valve Position (red knob)	Time to Fill Tank (seconds)	Upstream Head, h_2 (location 2) (inches H_2O)	Downstream Head, h_1 (location 1) (inches H_2O)	Energy Loss, $h_L = h_2 - h_1$ (inches H_2O)	Energy Loss, $h_L = h_2 - h_1$ (m of H_2O)	Mass Flow Rate, $\dot{m}$ (kg/s)
1	31	34.8	12.5	22.3	0.566	0.194
2	33	34.6	12.6	22.0	0.559	0.182
3	34	34.3	12.7	21.6	0.548	0.176
4	37	34.3	14.0	20.3	0.516	0.162
5	41	31.3	14.2	17.1	0.434	0.146
6	43	30.8	15.4	15.4	0.391	0.140
7	48	30.3	17.7	12.6	0.320	0.125
8	57	29.5	19.3	10.2	0.259	0.105

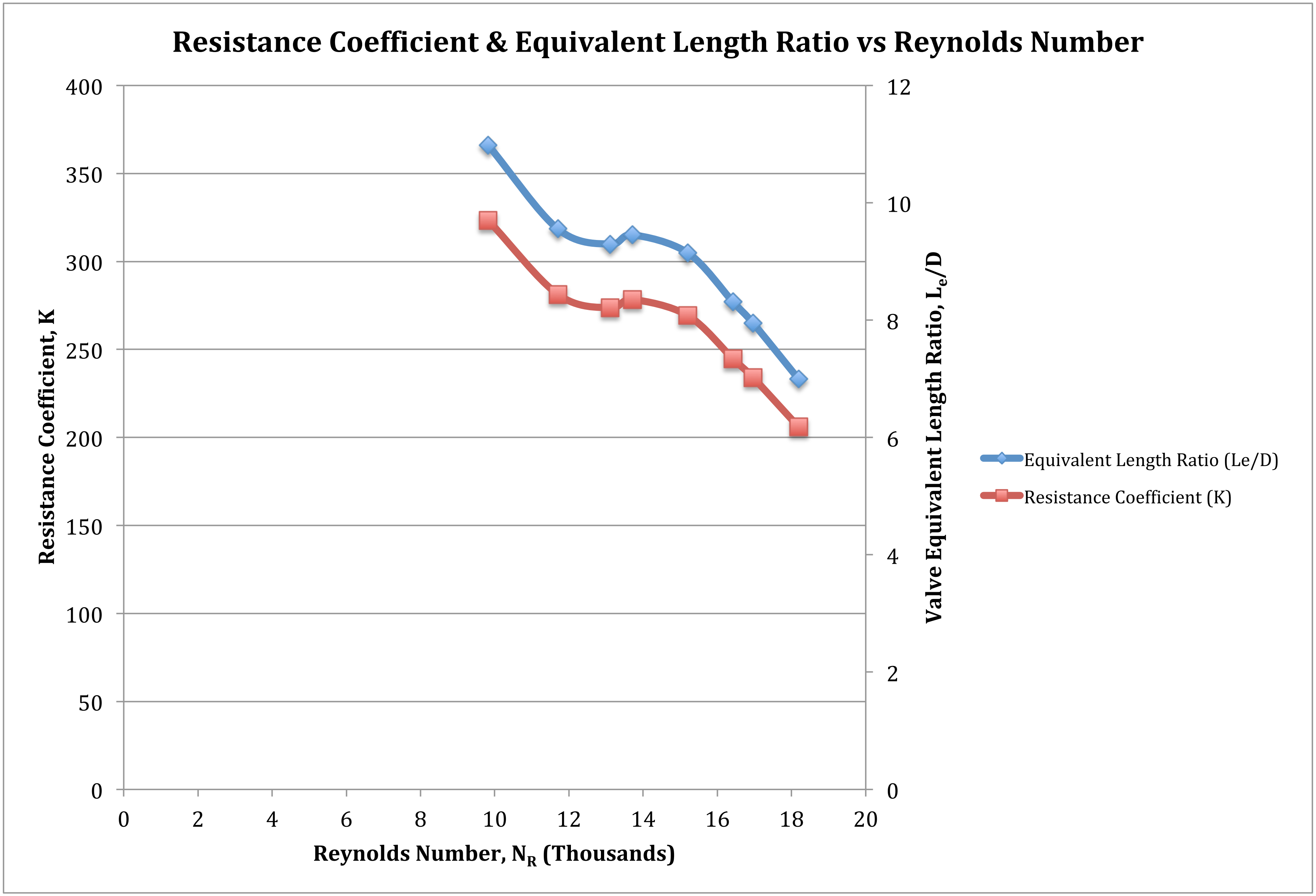
Table 2. Calculated Data (continued):

Tank Valve Position (red knob)	Volumetric Flow Rate, Q (m^3/s)	Pipe Velocity, V_P (m/s)	Pipe Velocity, $\frac{(V_p)^2}{2g}$ (m/s)	Resistance Coefficient (K)	Reynolds Number (N_R)	Friction Factor (f_T)	Equivalent Length Ratio $\frac{L_e}{D}$
1	0.000194	1.34	0.0915	6.18	18187.62	0.0265	233.21
2	0.000182	1.25	0.0796	7.02	16966.07	0.0265	264.91
3	0.000176	1.21	0.0746	7.34	16423.15	0.0265	276.98
4	0.000162	1.12	0.0639	8.08	15201.59	0.0265	304.90
5	0.000146	1.01	0.0520	8.35	13708.58	0.0265	315.09
6	0.000140	0.966	0.0476	8.21	13111.37	0.0265	309.81
7	0.000125	0.862	0.0379	8.44	11699.80	0.0265	318.49
8	0.000105	0.724	0.0267	9.70	9826.74	0.0265	366.04

Graph 1: Equivalent Length Ratio vs Percent Valve Open (Gate Valve)



Graph 2: Resistance Coefficient & Equivalent Length Ratio vs Reynolds Number



Discussion of Results and Conclusions:

From the Mott-Untener 7th Edition text, the accepted Gate Valve Position and Equivalent Length (L/D) is depicted in the table below:

Gate Valve Position	Equivalent Length (L/D)
Wide open	8
¾ open	35
½ open	160
¼ open	900

Our average for L/D was 298.68. Graph One, Equivalent Length versus Percent Valve Open, correlates this to the Gate Valve being open at 44%. That is, our gate valve position was between a quarter and half open. The data above shows that as the gate valve opening gets smaller, its equivalent length increases. Gate valves are used when minimum restriction is desired. When the valve is wide open the gate is fully drawn up into the valve, so the flow is able to proceed in a space the size of the duct. This keeps the pressure low and the flow from being restricted.

For each of our gate openings, our calculated friction factor was fairly constant. For a constant friction factor, it was also shown that as our Reynolds number decreased, our equivalent length, L_e/D increased. Thus, as our fluid approaches a more laminar behavior, it must overcome a resistance by a larger equivalent length.

Glass tubing, which is very smooth, has a very small value of roughness; relative roughness, D/ε, approaches infinity. We used plastic tubing which is very near glass in smoothness ($\varepsilon = 3 \times 10^{-7}$). Our relative roughness was high at 45333. Given our relative roughness of D/ε, and Reynolds number, our friction factor, f_T, was low at 0.0265.

Graph 2, Resistant Coefficient & Equivalent Length versus Reynolds Number, also provides that the increase in Reynolds number, with each increase in the gate valve opening, the equivalent length decreases. Furthermore, the resistance coefficient, K, also decreases with increasing Reynolds number. The slight dip between Reynolds number of 10000 to 140000 was noted.

Sources of error in this lab, could be attributed to the gravimetric bench, which we used to determine the mass flow rate. It seemed like the draining of the tank, watching for the beam to get horizontal and then coordination of the stop clock was a bit problematic and not in sync.