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The Effect of Reynolds Number on 90° PVC Elbow Minor Loss Coefficient

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Abstract: The objective of this project is to find the effect of the Reynolds number on the 90-degree PVC elbow minor loss coefficient value. Based on Robert H. Perry & Don W. Green, (2008), the minor loss coefficient for a 90-degree elbow has a constant value of 0.75. An apparatus was built to find the relationship between these two parameters. Based on the experiment result, the value of the minor loss coefficient is inversely proportional to the Reynolds number. As the Reynold number increases, the minor loss coefficient's value decreases. At low Reynolds number, the rate of minor loss coefficient value decreasing is huge, while at high Reynolds number, the rate is small. The correlation and regression methods were applied to find the best relationship between the Reynolds number and the minor loss coefficient value. The result shows that the cubic equation was the best relationship between the Reynolds number and the minor loss coefficient value. The equation is $kL = -9 \times 10^{-14}Re^3 + 9 \times 10^{-9}Re^2 - 0.0003Re + 4.2506$ with the value of R and R^2 are 0.9775, 0.9557 respectively.

Keywords: Reynolds Number, Loss Coefficient, 90-Degree PVC Elbow

1. Introduction

Head loss in fluid flow always occurs in the piping system. There are two types of loss which are major loss and minor loss. The major loss is head loss due to pipe friction and viscous dissipation in flowing water [1]. It is also the loss of energy through friction along the length of the pipeline. Minor loss is defined as loss of energy in a piping system because of the changes in which addition of components. [2]. Minor losses are proportional to the velocity head of a pipe, which means that the higher the velocity head, the greater the losses. Minor losses may be raised by sudden expansion or contraction, pipe fittings or pipe entrance or exit. In pipe fittings, there is also loss coefficient that is dimensionless.

Another component in fluid dynamics is the Reynolds number. The ratio of viscous forces to inertial forces is known as the Reynolds number. A dimensionless number called the Reynolds number is used to group fluid systems where the influence of viscosity plays a significant role in regulating the

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velocities or the flow pattern of fluid [3]. At high Reynolds numbers, the inertial forces, proportional to the fluid density and the square of the fluid velocity, are large compared to the viscous forces. In this project, the Reynolds number and minor loss coefficient play a significant role in achieving the result.

The pipe fittings are often used in a piping system. They are used to join and redirect pipes and components to form complete plumbing systems [4]. The pipe fittings that are focused on this project are 90-degree elbow. They are used as a direction changer for the pipe from one direction to another. For a 90-degree elbow, it changes the direction of the pipe at the angle of 90°. The general minor loss coefficient value of a 90-degree elbow is 0.75.

Based on the minor loss coefficient value, it is so general and fixed. The value of the minor loss coefficient might be changed if different values of Reynolds number are applied. The objective of this project is to determine the effect of the Reynolds number on the 90-degree PVC elbow minor loss coefficient. In this project, the result of the minor loss coefficient or kL value will be influenced by the value of the Reynolds number.

This project will be done at different Reynolds numbers, and one type of elbow is used, which is PVC elbow. This project is also held at the UTHM Fluid Mechanics Laboratory, and only a 90-degree elbow will be used for this project. The fluid type will be water.

2. Methodology

The methodology of this project starts with the methodology chart that defines all the steps for this project. Figure 1 shows the methodology chart of this project.

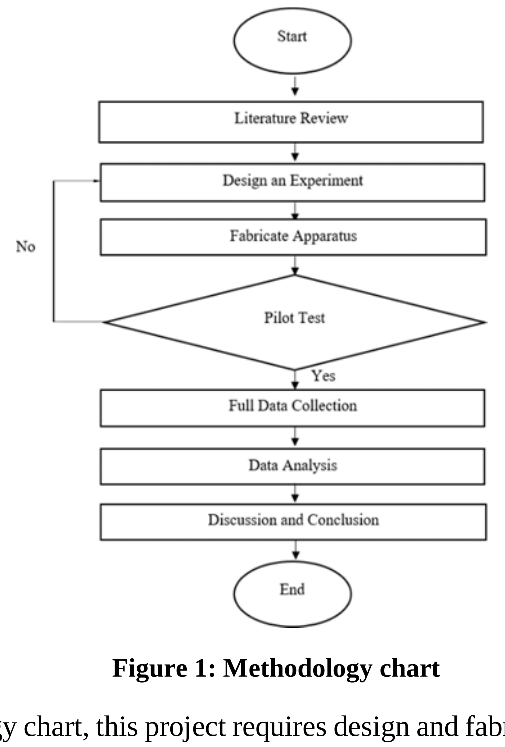

Figure 1: Methodology chart

Based on the methodology chart, this project requires design and fabricate an apparatus. Then, the apparatus is used as a model to get the data from the experiment. For the experiment part, pressure before and after the elbow which is P_1 and P_2 and time taken (t) to fill the 6-liter beaker are collected. The equation Eq. 1 to Eq. 7 were used to calculate the value of Reynolds number, Re and 90-degree elbow minor loss coefficient, k_L.

$$\frac{P_1}{\rho g} + \frac{{v_1}^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{{v_2}^2}{2g} + Z_2 + h_L \qquad \text{Eq.1}$$

$$\left(\frac{P_1}{\rho g} - \frac{P_2}{\rho g}\right) + (Z_1 - Z_2) = h_L \qquad \text{Eq.2}$$

$$h_L = k\left(\frac{v^2}{2g}\right) \qquad \text{Eq.3}$$

$$\left(\frac{P_1}{\rho g} - \frac{P_2}{\rho g}\right) + (Z_1 - Z_2) = k\left(\frac{v^2}{2g}\right) \qquad \text{Eq.4}$$

$$v = \frac{Q}{A} \qquad \text{Eq.5}$$

$$Q = \frac{\nabla}{t} \qquad \text{Eq.6}$$

$$Re_D = \frac{\rho v_{avg} D}{\mu} \qquad \text{Eq.7}$$

Equation 1 is the primary equation, which is the Energy Equation is used to calculate the value of minor loss coefficient. Then, equation 2 is the equation from the derivation of equation 1 which eliminates the parameters that are not included in the calculation. Equation 3 is the formula for minor loss calculation and equation 4 is the derivation of equation 2. Equation 5 and equation 6 are the formula to calculate the value of velocity and the flow rate of the fluid respectively. Equation 7 is the formula to calculate the Reynolds number.

Then, all the data that has been calculated will be presented in a table. After that, the Correlation and Regression method is used to identify the suitable relationship between the Reynolds number and the minor loss coefficient.

3. Results and Discussion

The pilot test was done to determine the accuracy of the apparatus in determining the value of the minor loss coefficient. From the pilot test experiment, the value of the minor loss coefficient is 1.06 when the Reynolds number is 39461 while the theoretical value is 0.75. The result shows that the apparatus can determine the value of the 90-degree elbow minor loss coefficient at different Reynolds numbers. A total of thirty-nine sets of experiments were conducted, and Table 1 shows the result.

Appendix A shows the sample of calculation for this project. Based on the value of the Reynolds number and the minor loss coefficient value, a series of graphs were plotted, and Figure 2, 3, and 4 shows the graph plotted.

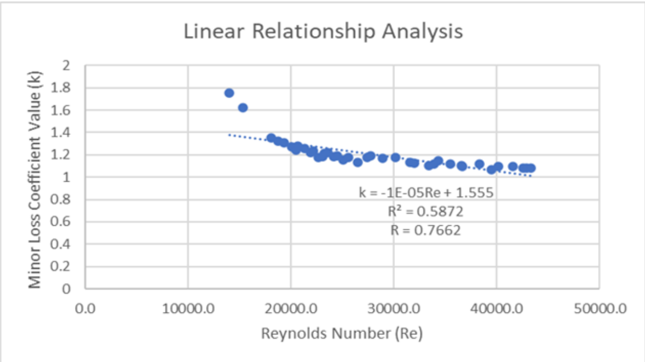

Figure 2: Graph linear equation analysis

Table 1: Data analysis

No.	h_1 (m)	h_2 (m)	Volume (l)	t (s)	P_1 (Pa)	P_2 (Pa)	Flowrate, Q, $\left(\frac{m^3}{s}\right)$	Velocity, V, $\left(\frac{m}{s}\right)$	Re	k_L
1	0.429	0.360	6	27.72	4196	3521	0.000216	0.57	14022	1.754
2	0.434	0.362	6	25.36	4245	3541	0.000237	0.62	15327	1.620
3	0.443	0.366	6	21.52	4333	3580	0.000279	0.73	18062	1.348
4	0.448	0.369	6	20.75	4382	3609	0.000289	0.76	18732	1.321
5	0.453	0.372	6	20.12	4431	3638	0.000298	0.78	19319	1.306
6	0.458	0.375	6	19.36	4480	3668	0.000310	0.82	20077	1.268
7	0.461	0.377	6	18.93	4509	3687	0.000317	0.83	20533	1.241
8	0.465	0.379	6	18.79	4548	3707	0.000319	0.84	20686	1.278
9	0.469	0.381	6	18.22	4587	3726	0.000329	0.87	21333	1.254
10	0.472	0.383	6	17.77	4616	3746	0.000338	0.89	21874	1.218
11	0.477	0.386	6	17.52	4665	3775	0.000342	0.90	22186	1.232
12	0.480	0.389	6	17.13	4695	3805	0.000350	0.92	22691	1.178
13	0.483	0.390	6	16.87	4724	3814	0.000356	0.94	23041	1.187
14	0.487	0.392	6	16.75	4763	3834	0.000358	0.94	23206	1.214
15	0.492	0.395	6	16.47	4812	3863	0.000364	0.96	23600	1.217
16	0.497	0.399	6	16.10	4861	3902	0.000373	0.98	24142	1.183
17	0.501	0.401	6	15.87	4900	3922	0.000378	0.99	24492	1.189
18	0.505	0.404	6	15.52	4939	3951	0.000387	1.02	25045	1.156
19	0.512	0.407	6	15.18	5008	3981	0.000395	1.04	25606	1.179
20	0.517	0.410	6	14.67	5057	4010	0.000409	1.08	26496	1.135
21	0.525	0.411	6	14.20	5135	4020	0.000423	1.11	27373	1.174
22	0.530	0.413	6	14.01	5184	4039	0.000428	1.13	27744	1.189
23	0.538	0.416	6	13.45	5262	4069	0.000446	1.17	28899	1.167
24	0.551	0.421	6	12.89	5389	4118	0.000465	1.22	30155	1.177
25	0.560	0.425	6	12.30	5477	4157	0.000488	1.28	31601	1.131
26	0.569	0.432	6	12.14	5565	4225	0.000494	1.30	32018	1.125
27	0.580	0.437	6	11.65	5673	4274	0.000515	1.36	33364	1.100
28	0.590	0.442	6	11.47	5771	4323	0.000523	1.38	33888	1.118
29	0.601	0.447	6	11.32	5878	4372	0.000530	1.39	34337	1.150
30	0.613	0.455	6	10.96	5995	4450	0.000547	1.44	35465	1.115
31	0.628	0.464	6	10.64	6142	4538	0.000564	1.48	36531	1.105
32	0.635	0.471	6	10.61	6211	4607	0.000566	1.49	36635	1.099
33	0.655	0.477	6	10.14	6406	4665	0.000592	1.56	38333	1.117
34	0.665	0.485	6	9.85	6504	4744	0.000609	1.60	39461	1.069
35	0.684	0.495	6	9.68	6690	4841	0.000620	1.63	40154	1.099
36	0.704	0.505	6	9.35	6886	4939	0.000642	1.69	41572	1.094
37	0.720	0.516	6	9.14	7042	5047	0.000656	1.73	42527	1.078
38	0.730	0.523	6	9.07	7140	5115	0.000662	1.74	42855	1.081
39	0.741	0.530	6	8.97	7247	5184	0.000669	1.76	43333	1.083

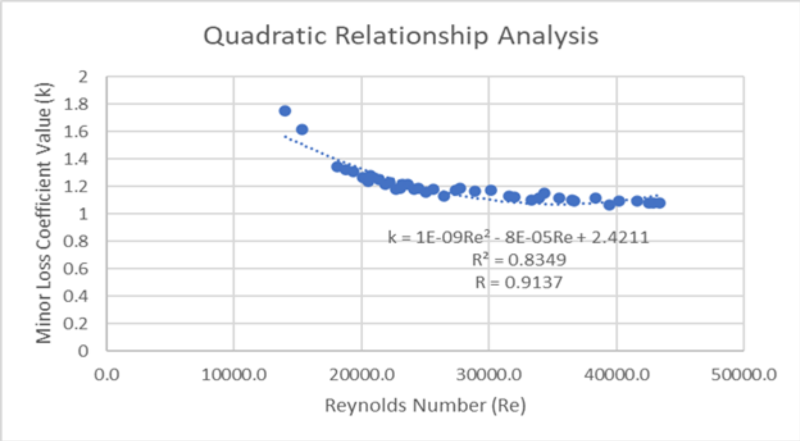

Figure 3: Graph quadratic equation analysis

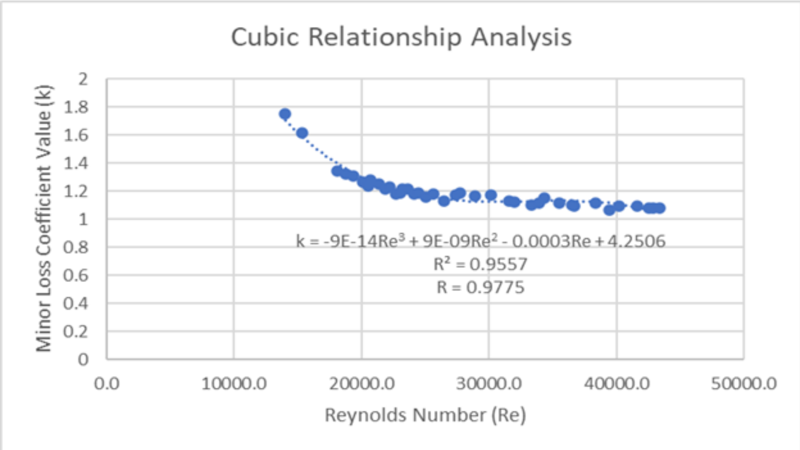

Figure 4: Graph cubic equation analysis

The Correlation and Regression method was used to determine the best graph representing the relationship between the Reynolds number and the minor loss coefficient. Based on the value of R and R, the best-fit graph is cubic analysis. The equation for this graph is $kL = -9 \times 10^{-14}Re^3 + 9 \times 10^{-9}Re^2 - 0.0003Re + 4.2506$ with the value of R, and R^2 is 0.9775, 0.9557 respectively. Based on this graph, the value of the Reynolds number is inversely proportional to the value of the minor loss coefficient of the 90-degree elbow. At low Reynolds numbers, the rate of minor loss coefficient value decreasing is huge, while at high Reynolds numbers, the rate is small.

4. Conclusion

In conclusion, the objective of this project was achieved. The effect of the Reynolds number on the minor loss coefficient of 90-degree PVC elbow can be determined. Based on the experiment result, the value of the minor loss coefficient is inversely proportional to the value of the Reynolds number. The greater the value of the Reynolds number, the smaller the minor loss coefficient value. Based on the experiment data, the best relationship to describe the relationship between the Reynolds number and the loss coefficient is the cubic equation. The equation is represented as $k = -9 \times 10-14Re3 + 9 \times 10-9Re2 - 0.0003Re + 4.2506$ with the value of R, and $R2$ is 0.9775, 0.9557 respectively. The result of this project shows that the minor loss coefficient value of the 90-degree elbow depends on the value of the Reynolds number.

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Appendix A (Optional)

The calculation part started with the calculation of the system's flow rate. As example, the calculation for data no. 1 is shown below.

$$Q = \frac{\nabla}{t}$$

$$Q = \frac{6 \times 10^{-3}}{27.72} = 0.00022\ \frac{m^3}{s}$$

Next, calculate the cross-sectional area of pipe,

$$A = \pi r^2$$

$$= \pi\ (0.022)^2$$

$$= 0.00038\ m^2$$

Next, calculate the velocity of the fluid,

$$V = \frac{Q}{A}$$

$$Q = \frac{0.00022}{0.00038} = 0.57\ \frac{m}{s}$$

After that, calculate the value of pressure 1 and 2 using height 1 and 2,

$$P_1 = \rho g h_1$$

$$P_1 = (997)(9.81)(0.429)$$

$$P_1 = 4195.86\ kPa$$

$$P_2 = \rho g h_2$$

$$P_2 = (997)(9.81)(0.36)$$

$$P_2 = 3521\ kPa$$

Derivation of energy equation, substitute the value of h_L with the minor loss formula,

$$\left(\frac{P_1}{\rho g} - \frac{P_2}{\rho g}\right) + (Z_1 - Z_2) = k\left(\frac{v^2}{2g}\right)$$

Then, substitute all the value that have been calculated before,

$$k = 0.0165$$

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