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Effect of Reynolds Number on Minor Loss Coefficient for 3 Different Brands of Ball Valves

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Abstract

This research objective was to determine the effect of Reynolds number on the valve loss coefficient for three different brands of ball valves. An apparatus was designed and fabricated to investigate the relationship between the minor loss coefficient and Reynolds number. The apparatus with a ball valve was used to conduct an experiment, collecting around forty raw data for each brand of ball valve. From raw data, the equations related to fluid flow were used to determine the value of the Reynolds number and minor loss coefficient of a ball valve. The analysed results from the experiment showed that the value of the minor loss coefficient is inversely proportional to the Reynolds number for three different brands of ball valves. Different geometries of ball valves result in different minor loss coefficients. Correlation and regression methods were applied to determine the best relationship between the minor loss coefficient and the Reynolds number. The result showed all three ball valves have a strong negative correlation between two variables and a cubic regression model was identified as the best model to describe the relationship for each of the ball valves.

1. Introduction

Fluid flow through a pipe is fundamental in fluid dynamics and crucial for various engineering applications, as it involves transporting fluids and gases under pressure through interconnected piping networks. Pipes are essential for transporting fluids, whether liquid or gas, under pressure from one place to another [1]. Piping systems, comprising pipes, fittings, valves, flanges, gaskets, bolts and other components can exhibit different types of flow: laminar, turbulent and transitional which can be determined by the Reynolds number, a dimensionless parameter used to predict the flow regime [2]. Friction between fluid particles and pipe surfaces leads to major losses, while components like valves cause minor losses, both contributing to the total head loss in a system. According to the established reference book "Fundamentals of Fluid Mechanics", 7th ed, the loss coefficient value of a fully open ball valve is K_L= 0.05 and is commonly considered independent of Reynolds number [3]. However, practical experience shows that the loss coefficient of valves varies with different Reynolds numbers, highlighting a discrepancy between theoretical assumptions and observed behavior. Additionally, the loss coefficient varies across different brands of valves due to unique design features, materials and geometries; these brand-specific variations are not reflected in standard reference data [4]. These differences can only be determined throughout the experiment.

The main research objective is to determine the effect of Reynolds number on valve loss coefficient for three different brands of ball valves. Besides that, this research also investigates the influence of the Reynolds number on the minor loss coefficient for different brands of ball valves, determining if brand variations affect the minor loss coefficient, as differences in valve geometry may result in different coefficients. This research only focuses on loss coefficients of three different brands of ball valves and design and development of an apparatus for valve pressure difference and flow rate collection. The experiment will be conducted at different Reynolds numbers in the Fluid Mechanic Laboratory, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia and the fluid used during the experiment is water.

2. Methodology

The design phase of the experiment began with creating drawings to assess the feasibility of fabricating the necessary apparatus. These design drawings were then translated into a physical apparatus. The design process involved considerations such as measuring the pressure of fluid flow before and after a ball valve, determining the fluid flow rate in a specific cross-sectional area per unit of time and ensuring that the fluid flow can fully fill the system. The general structure of the designed apparatus was referred to the previous research [5].

The fabrication of the apparatus was divided into two parts which are fabricating the board stand to hold the testing apparatus and fabricating the necessary testing apparatus itself. This process involved the use of tools and machinery available in laboratory of Universiti Tun Hussein Onn Malaysia as well as additional components that needed to be purchased. After the fabrication process, a fabricated apparatus was produced and designed to collect raw data from the experiment for further analysis.

The pilot test involves conducting a small scale, preliminary trial or experiment using the fabricated apparatus. The purpose of the pilot test was to confirm that the fabricated apparatus could obtain valid results before moving to full data collection. Maintenance was performed to address any issue such as water leakage. The validation of results was carried out by comparing them to the established reference book and previous research [3][6].

After the pilot test, full data collection was conducted to collect the required raw data. In order to determine the variables, the required raw data are temperature of the water during the experiment (T), the height of water in the transparent hoses before (h_1) and after (h_2) a ball valve, the time taken (t) for water to fill 9 litres volumetric tank (∇) and the pipe's inner diameter before the ball valve (D_{in}). Each ball valve was conducted around forty times with different Reynolds numbers.

A comprehensive data analysis was then performed to generate the research's required results. The variables were determined using Equations 1 and 2. Equation 1 represents the equation used to determine the Reynolds number while Equation 2 represents the equation used to determine the minor loss coefficient. The variables were plotted on a scatter diagram and both correlation and regression methods were applied to investigate the relationship between the variables. Three types of regression models were compared which are linear, quadratic and cubic.

$$\mathrm{Re} = \frac{\rho V D}{\mu} \tag{1}$$

$$K_L = \frac{2g}{V^2}\left(h_1 - h_2\right) \tag{2}$$

Finally, a discussion has been conducted to address the challenges encountered in completing this research and the results obtained. Then, a brief conclusion was presented to summarize the findings and outcomes as well as providing suggestions for improvements for this study and direction for future studies.

3. Results and Discussion

3.1 Designed and Fabricated Apparatus

The general structure of the designed apparatus is shown in Fig 1. The design was inspired by a study of previous research. In this research, the feasibility of the designed apparatus was verified and supported by the previous research [5]. This is because the raw data that could have been successfully collected by the previously researched testing equipment was the same as the raw data required for this research. The only difference was in the testing fitting used.

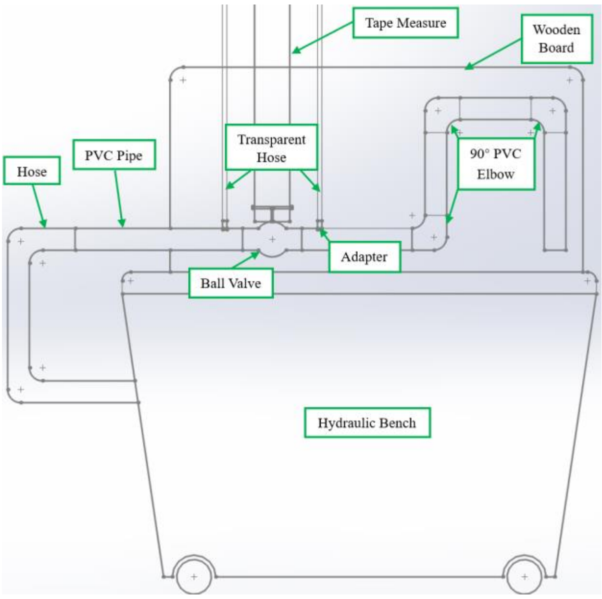


Fig 1 *Designed testing apparatus*

3.2 Pilot Test

The pilot test was done to determine the accuracy of the fabricated apparatus in determining the value of minor loss coefficient for a ball valve. The pilot test was conducted at 25 ℃ of water temperature, resulting in a water density of 997 kg/m^3 and a dynamic viscosity of 0.891×10^{-3} kg/ms. Fig 2 shows the first pilot test result.

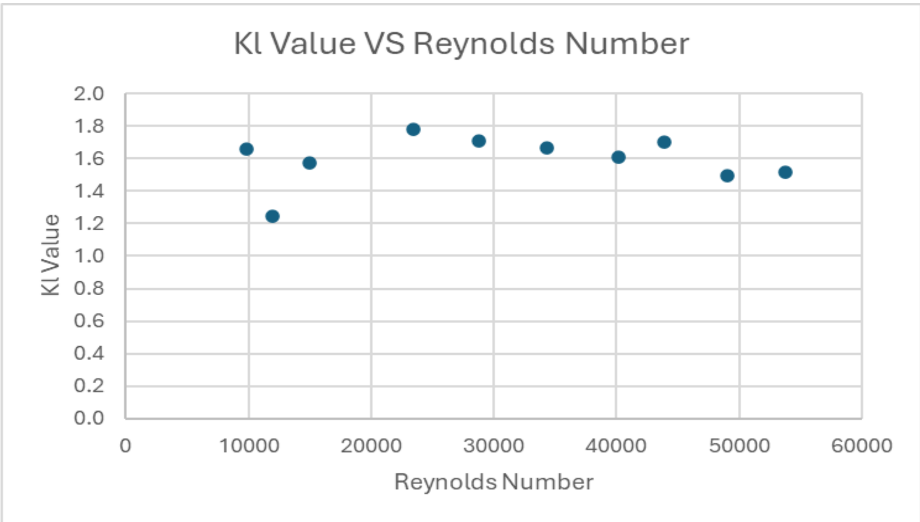


Fig 2. *Graph K_L value against Reynolds number for pilot test*

The first pilot result illustrated that the pattern graph differed from other research even though the minor loss coefficient value was close to the value in the research [6]. Consequently, a modification in the data collection process was implemented, which involved waiting for the water inside the manometers to stabilize before taking further measurements. After the improvement, the second pilot test result is shown in Fig 3.

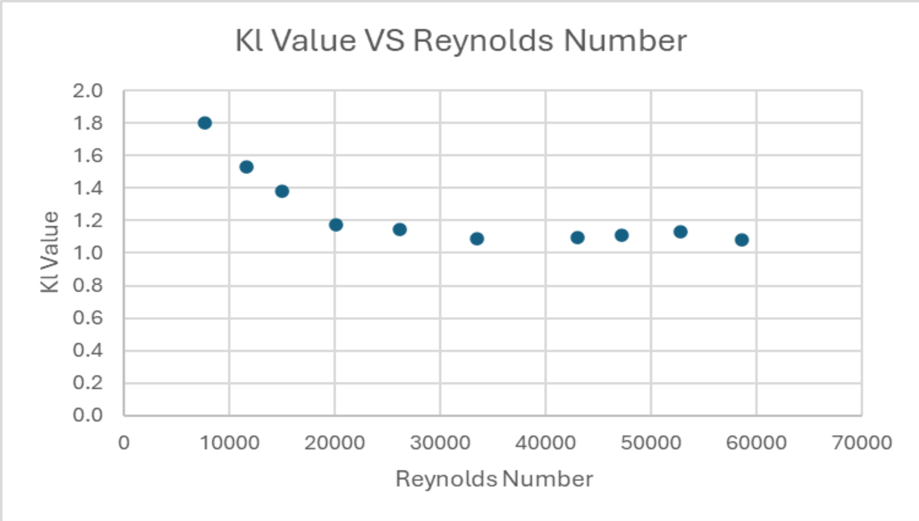


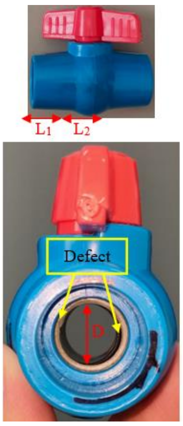
Fig 3 *Graph K_L value against Reynolds number for pilot test after improvement*

The improved pilot test result showed the same pattern graph as the previous research which is inversely proportional. The minor loss coefficient for a ball valve in the pilot test was 1.091 at a Reynolds number of 33492 compared to 1.19 in the previous research at a Reynolds number of 34629. This comparison indicates only a slight difference between the pilot test results and the previous research [6]. Hence, the fabricated apparatus can be used to determine the minor loss coefficient for a ball valve under varying Reynolds numbers.

3.3 Data Analysis

There are three brands of ball valves were tested in this research which are Brand A is COD, Brand B is PRO and Brand C is Marksman. Table 1 shows the brand of each ball valve. The collected raw data were converted to the desired data by applying the fluid flow equation especially energy, head loss, continuity, flow rate and Reynolds number equation. Appendix A shows a sample of calculation for this research by using the first (NO 1) collected raw data for ball valve brand A. The analysed data for ball valve brand A is shown in Table 2 while the analysed data for ball valve brand B and C is shown in Appendix B. Afterward, the analysed Reynolds number and minor loss coefficient for the three different brands of the ball valves were presented using graph plotting as shown in Fig 4.

Table 1 *Brand of each ball valve*

Brand	COD	PRO	Marksman
Name	Brand A	Brand B	Brand C
Material	PVC	PVC	PVC
Image			
Dimension	L_1 = 23mm L_2 = 25mm D = 14mm	L_1 = 22mm L_2 = 25mm D = 13mm	L_1 = 20mm L_2 = 27mm D = 14mm
Defect	None	Poor finishing and ball of ball	None

	valve was shifted in fully open

Table 2 *Completed raw data analysis for ball valve Brand A*

No	Height 1, $h_1(m)$	Height 2, $h_2\ (m)$	Time Taken, $t\ (s)$	Volume, $\forall\ (L)$	Pipe Inner Diameter, $D_{in}\ (cm)$	Flow Rate, $Q\ \left(\frac{m^3}{s}\right)$	Velocity, $V\ \left(\frac{m}{s}\right)$	Reynolds Number, Re	Minor Loss Coefficient, K_L
1	0.256	0.244	87.89	9	19	0.000102	0.361	7679	1.805
2	0.271	0.254	72	9	19	0.000125	0.441	9373	1.716
3	0.286	0.267	67.23	9	19	0.000134	0.472	10038	1.672
4	0.309	0.286	58.53	9	19	0.000154	0.542	11530	1.534
5	0.329	0.306	57.84	9	19	0.000156	0.549	11668	1.498
6	0.349	0.319	47.76	9	19	0.000188	0.665	14130	1.332
7	0.366	0.331	45.06	9	19	0.000200	0.704	14977	1.384
8	0.376	0.339	43.19	9	19	0.000208	0.735	15625	1.344
9	0.407	0.364	39.77	9	19	0.000226	0.798	16969	1.324
10	0.426	0.378	37.22	9	19	0.000242	0.853	18132	1.295
11	0.448	0.395	35.28	9	19	0.000255	0.900	19129	1.285
12	0.468	0.412	33.69	9	19	0.000267	0.942	20032	1.238
13	0.487	0.427	31.45	9	19	0.000286	1.009	21458	1.156
14	0.516	0.451	30.16	9	19	0.000298	1.052	22376	1.151
15	0.555	0.479	27.97	9	19	0.000322	1.135	24128	1.158
16	0.581	0.501	27.02	9	19	0.000333	1.175	24976	1.137
17	0.606	0.522	26.66	9	19	0.000338	1.191	25314	1.163
18	0.629	0.541	25.88	9	19	0.000348	1.227	26077	1.148
19	0.671	0.574	24.72	9	19	0.000364	1.284	27300	1.154
20	0.705	0.6	23.69	9	19	0.000380	1.340	28487	1.147
21	0.753	0.639	22.58	9	19	0.000399	1.406	29888	1.132
22	0.796	0.673	21.79	9	19	0.000413	1.457	30971	1.137
23	0.845	0.717	20.73	9	19	0.000434	1.531	32555	1.071
24	0.879	0.741	20.15	9	19	0.000447	1.575	33492	1.091
25	0.913	0.768	19.88	9	19	0.000453	1.597	33947	1.116
26	0.966	0.811	19.03	9	19	0.000473	1.668	35463	1.093
27	1.022	0.859	18.63	9	19	0.000483	1.704	36225	1.102
28	1.119	0.934	17.4	9	19	0.000517	1.824	38785	1.091
29	1.174	0.962	16.23	9	19	0.000555	1.956	41581	1.087
30	1.223	1.002	15.88	9	19	0.000567	1.999	42498	1.085
31	1.302	1.074	15.69	9	19	0.000574	2.023	43012	1.093
32	1.528	1.26	14.5	9	19	0.000621	2.189	46542	1.097
33	1.715	1.442	14.44	9	19	0.000623	2.198	46736	1.108
34	1.833	1.554	14.3	9	19	0.000629	2.220	47193	1.111
35	1.919	1.636	14.09	9	19	0.000639	2.253	47897	1.094
36	1.964	1.666	13.71	9	19	0.000656	2.315	49224	1.091
37	2.056	1.712	12.86	9	19	0.000700	2.468	52478	1.108
38	2.101	1.745	12.79	9	19	0.000704	2.482	52765	1.134
39	2.183	1.801	12.21	9	19	0.000737	2.600	55271	1.109

40	2.272	1.867	11.76	9	19	0.000765	2.699	57386	1.091
41	2.334	1.914	11.52	9	19	0.000781	2.755	58582	1.085

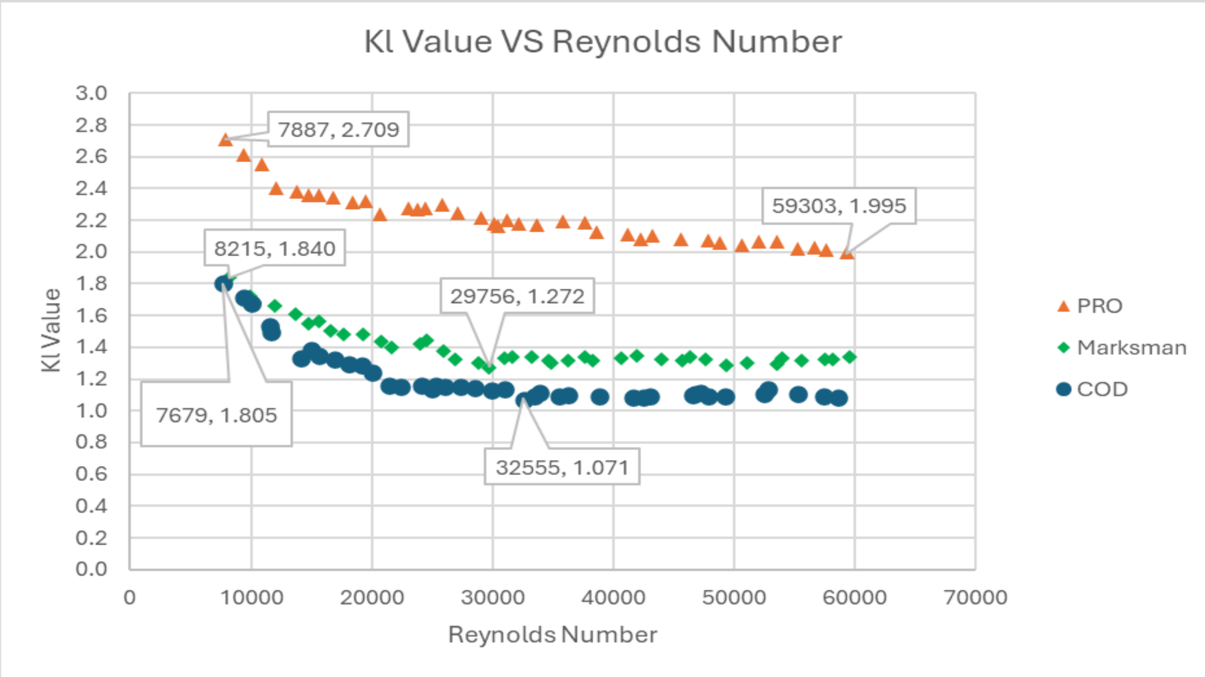
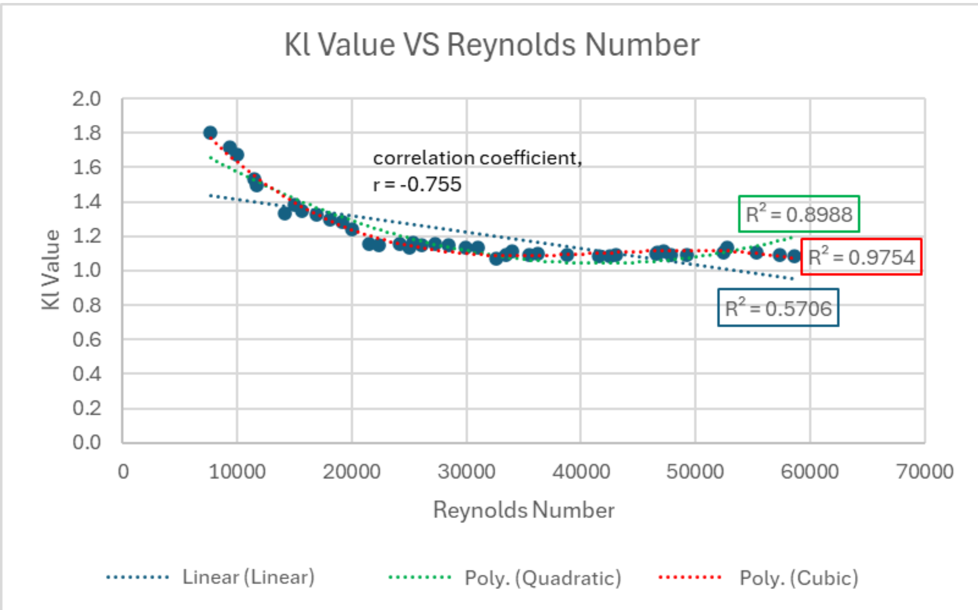
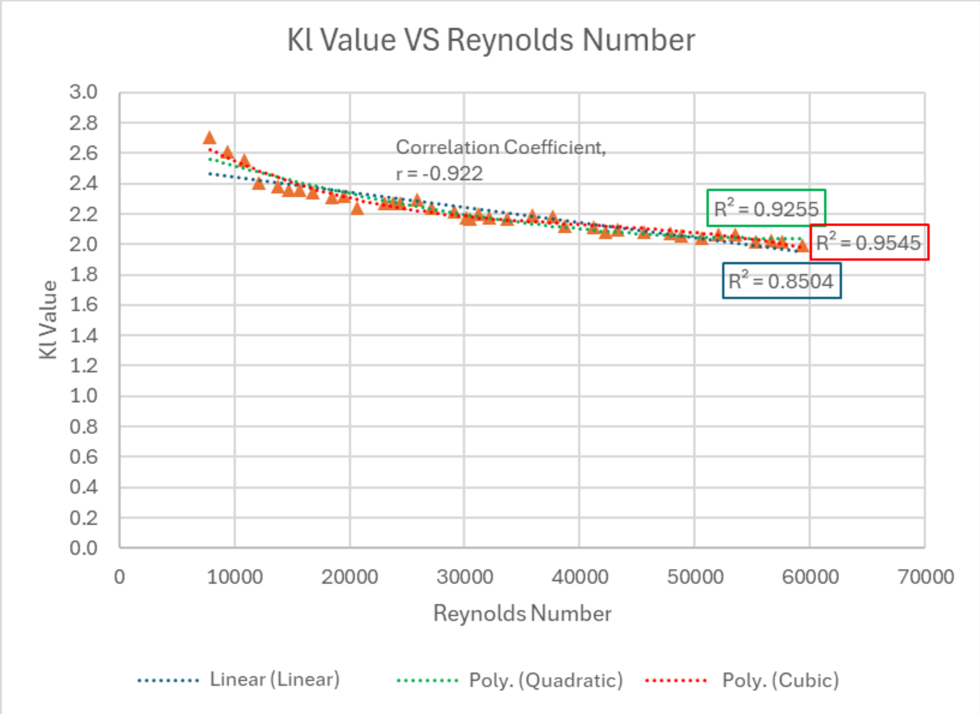


Fig 4 *Graph K_L value against Reynolds number for three different brands of ball valves*

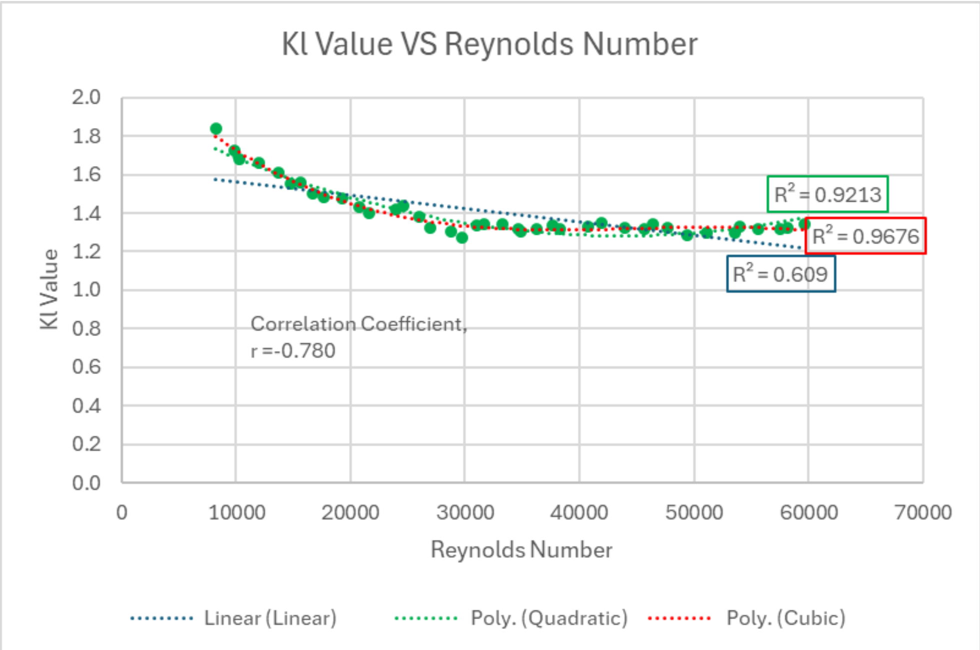
The plotted graph shows that the pattern graph for three of the ball valves was inversely proportional. Furthermore, correlation and regression methods were applied to determine types of correlation and the fittest regression model between the minor loss coefficient and Reynolds number. Both methods allow for direct analysis of the relationship between the two variables using the default functions in Microsoft Excel. Figure 5 shows the correlation coefficient (r) for linear relationship and R-squared (R^2) values for linear, quadratic and cubic regression models



(a)



(b)



(c)

Fig 5 *(a) Correlation coefficient and linear, quadratic, cubic analysis for ball valve Brand A; (b) Correlation coefficient and linear, quadratic, cubic analysis for ball valve Brand B; (c) Correlation coefficient and linear, quadratic, cubic analysis for ball valve Brand C*

Based on Figure 6, the value of correlation coefficient (r) for three of the ball valves are -0.755 (Brand A), -0.922 (Brand B) and -0.780 (Brand C). Besides that, the regression analysis indicates that the highest R-squared (R^2) value for each brand of ball valves is achieved with cubic regression models. The R-squared (R^2) value for cubic regression model is 0.9754 for Brand A, 0.9545 for Brand B and 0.9676 for Brand C.

3.4 Discussion

The designed testing apparatus used simple manometers made from transparent hoses and adapters connected to PVC pipes, replacing expensive pressure gauges and unsuitable U-tube manometers. The design changed the water direction upward to fully fill the pipes. This is because a fully filled piping system ensures the accurate application of fluid dynamic equations [7]. Challenges during fabrication included creating holes in the body board and PVC pipes without causing cracks which required careful drilling and sanding.

In the pilot test, high pressure water leakage at joint points was addressed using a mixture of 502 glue and baking soda to reduce the curing time and strengthen the bond while white seal tapes were used for easily changeable ball valve connections [8]. Air bubbles in the manometers causing inaccurate readings were removed by flicking. Afterward, a five minute interval was allowed for each data point to stabilize the water in the manometers, reducing fluctuations during data measurement.

The relationship between the minor loss coefficient and Reynolds number was inversely proportional for all ball valve brands. Correlation and regression analyses showed strong negative linear relationships with cubic regression models providing the best fit. The correlation coefficients for the three brands were all smaller than -0.7, indicating a strong negative linear relationship [9]. R-squared values for cubic models were 97.54% for Brand A, 95.45% for Brand B and 96.76% for Brand C was the highest compared to linear and quadratic models. This confirms that the cubic regression model was the best fit for the data of both variables.

By comparing three of the ball valves, the ball valve Brand C had the highest ball length which result in the highest minor loss coefficient under good finishing. Furthermore, ball valve Brand B with poor finishing and the ball of the ball valve was shifted in fully open condition had the highest minor loss coefficient value compared to ball valve brands A and C. Thus, the different geometries of ball valves will give different minor loss coefficient values.

4. Conclusion

In conclusion, the objective of this research was achieved which provided useful information about the minor loss coefficient of ball valves for designing efficient piping systems. The experimental results revealed a clear dependency of the minor loss coefficient on the Reynolds number of the flowing fluid and showing an inversely proportional relationship across three brands of ball valves. Plotted graphs demonstrated strong negative linear relationships and cubic regression models identified as the most suitable for describing this relationship. Furthermore, it was observed that the different geometries of ball valves result in various minor loss coefficient values. The analysed results were close to the previous research but different from the established reference book.

Recommendations for improvement include increasing the amount of data collected to improving the accuracy of regression models, replacing manometers with pressure gauges for easier and more robust readings and considering the use of threaded end ball valves to ensure better water flow. Future studies could explore higher Reynolds numbers, test different materials and types of ball valves and investigate the impact of varying valve openings on minor loss coefficients.

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