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Effect of Reynolds Number on 90-Degree Short and Long Radius PVC Elbow Loss Coefficient

Mohamad Razlan Rosli[1], Ahmad Fu'ad Idris[1]*, Mohd Azwir Azlan[1]

[1] *Faculty of Mechanical and Manufacturing Engineering*
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, MALAYSIA

*Corresponding Author: afuad@uthm.edu.my
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Keywords

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Abstract

This study investigates the effect of the Reynolds number on the minor loss coefficients of 90-degree short and long-radius PVC elbows, which are crucial components in fluid transport systems. Experiments were conducted using a custom-fabricated setup to measure pressure drops and flow rates at varying Reynolds numbers. The findings reveal an inverse relationship between the Reynolds number and minor loss coefficients, indicating that energy losses decrease at a higher Reynolds number. Data analysis reveals that the most effective relationship between Reynolds number and loss coefficient value follows a cubic pattern. Furthermore, long-radius elbows consistently showed lower loss coefficients with a k_L value of 1.11 compared to short-radius elbows with a k_L value of 1.42 at a high Reynolds number, highlighting their greater efficiency in minimizing turbulence and pressure loss. These results contribute to the optimization of pipeline designs and provide valuable insights for creating more energy-efficient fluid transport systems in industrial applications.

1. Introduction

In fluid transport systems, energy losses arise from friction along the walls of pipes and disruptions caused by fittings, such as elbows and bends. These losses are measured using the minor loss coefficient (k_L), which plays a critical role in optimizing pipeline efficiency and ensuring effective system performance [1]. Among these fittings, 90° elbows are frequently utilized to change flow direction and come in two configurations: short-radius (SR) and long-radius (LR). While SR elbows are ideal for compact installations, LR elbows are favored for their ability to reduce turbulence and minimize pressure losses [2]. Standard references typically assign fixed k_L values of 0.3 for SR elbows and 0.2 for LR elbows [3]. However, these assumptions may oversimplify the actual relationship between flow conditions and energy losses.

The Reynolds number (Re) is a dimensionless parameter that indicates the ratio of inertial to viscous forces and significantly impacts flow behavior. However, its effect on minor loss coefficients for 90-degree elbows has not been adequately studied [4]. This research aims to explore how the Re influences the k_L for SR and LR PVC elbows by analyzing pressure drops and flow rates under different conditions. The experimental results will offer new insights into the dynamic behavior of minor loss coefficients, challenging traditional assumptions and contributing to the development of more efficient pipeline designs. These findings have practical implications for industries where fluid transport efficiency is crucial, including water distribution, chemical processing, and HVAC systems.

2. Methodology

The methodology chart outlines the flow of project activities, and the procedures involved. It serves as the theoretical framework for the chosen method [5]. Figure 1 illustrates the flowchart for this project.

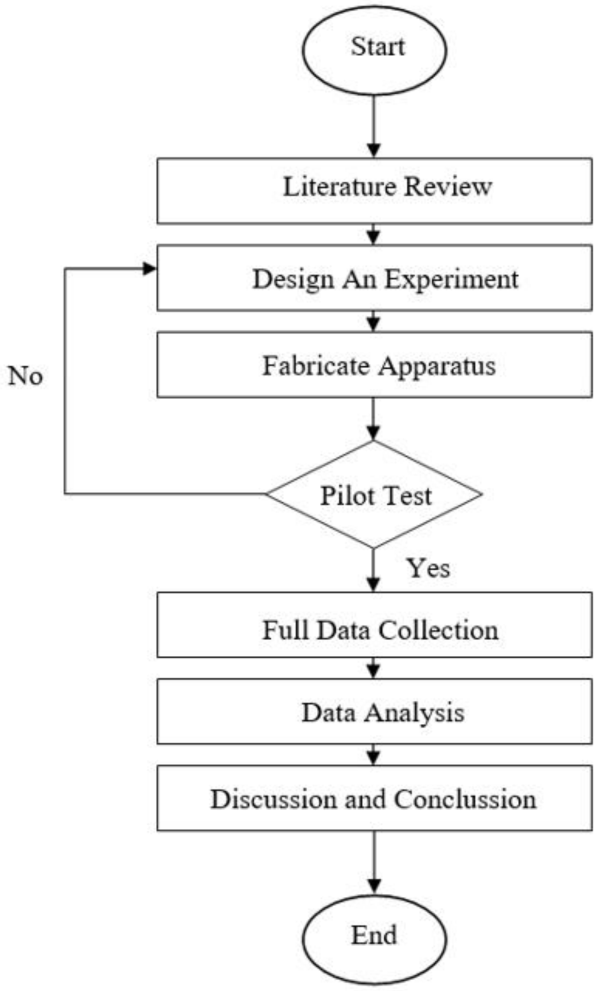


Fig.1 *Methodolody flowchart of this project*

A comprehensive literature review was conducted to establish the theoretical foundation for this study. Key topics explored included fluid dynamics, k_L, Re, and the behavior of 90-degree elbows in pipeline systems. The review involved analyzing academic papers, technical references, and industry standards [1][3]. Insights gained from the literature highlighted the lack of detailed studies on the effect of Re on the k_L of 90-degree SR and LR elbows. This gap served as the primary motivation for designing the experimental framework to investigate these parameters systematically.

The experimental setup was designed to measure pressure drops and flow rates across SR and LR 90-degree PVC elbows under varying flow conditions. The apparatus included two separate pipeline systems, a hydraulic bench to regulate water flow, U-tube manometers for pressure measurements, and a beaker for volume collection. Specific design considerations ensured minimal disturbances to fluid flow and precise alignment of components. In this project, the feasibility of the design apparatus was verified and supported by the previous research [6][7]. Adhesives were applied to secure pipe connections and prevent leaks, while a custom-built support system maintained the stability of the apparatus. The design phase also accounted for the inclusion of LR elbows, which required additional procurement through online vendors due to their unique specifications. Fig. 2 illustrates the design of the experimental setup for the project.

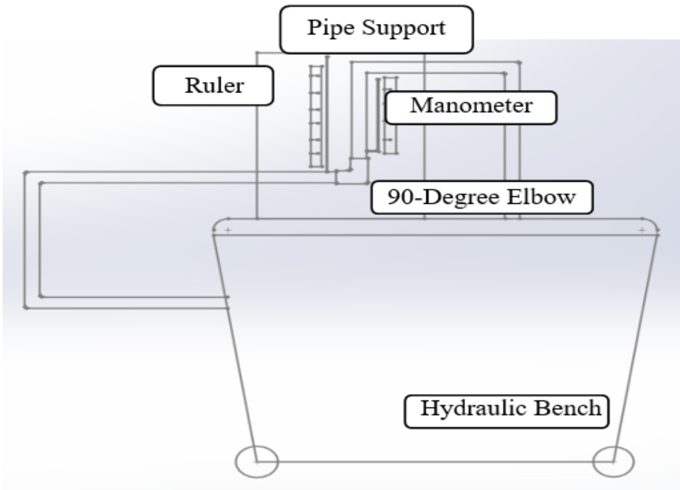


Fig. 2 *Design of the experiment setup*

The fabrication process involved assembling and validating the components of the experimental setup. Materials such as PVC pipes, SR and LR elbows, and other accessories were sourced from local suppliers and the university's laboratory resources. Tools such as a hacksaw, drilling machine, and adhesives were employed to construct the pipeline systems. A pilot test was conducted to verify the apparatus by pumping water through the system and observing pressure readings. Issues such as leaks and air bubbles in the manometer were identified and rectified to ensure accurate data collection. The validation of the results was carried out by comparing them to the established reference book and previous research [3][7].

Once the apparatus was validated, experiments were conducted by varying Re through flow rate adjustments on the hydraulic bench. For each condition, manometer readings before (h_1) and after (h_2) the elbow, as well as the time taken to collect a fixed volume of water, were recorded. These measurements were repeated for both SR and LR elbows across multiple Re ranges to ensure data accuracy and reproducibility. The raw data were systematically documented, including fluid velocity, Re, and pressure drops. This process produced a comprehensive dataset for further analysis of the k_L.

The collected data were analyzed using key fluid mechanics equations, such as the energy equation and minor loss formula. Calculations yielded values for Re and k_L , which were compared against theoretical benchmarks and existing literature. Graphs were plotted to visualize the relationship between Re and k_L , revealing an inverse correlation. The findings confirmed that LR elbows exhibited lower k_L values than SR elbows, aligning with prior studies. These results contribute to the understanding of loss coefficients in pipeline systems and offer practical insights for improving the efficiency of fluid transport designs.

3. Result and Discussion

3.1 Data Analysis

This project tested two types of elbows: SR and LR elbows. Table 1 presents the specifications for each type. The raw data collected were processed into a more useful format by applying fluid flow equations, particularly those related to energy, head loss, continuity, flow rate, and Re. The sample analyzed data is illustrated in Table 2 for SR elbow, while the analyzed data for the LR elbow is found in Appendix A. Furthermore, the Re and k_L t for both elbows were illustrated using graphs, as shown in Fig. 3.

Table 1 *Type of Elbow*

Type	Short Radius	Long Radius
Image		
Dimension	OD = 15mm	OD = 15mm
Thickness	2 mm	2 mm

Table 2 *Data analysis results for 90-degree short radius elbow*

Height, h_1 (m)	Height, h_2 (m)	Volume ∇ (l)	Time, t (s)	Pressure, P_1 (Pa)	Pressure, P_2 (Pa)	Flow Rate, Q (m^3/s)	Velocity, v (m/s)	Reynolds Number, Re	Loss Coefficient, k_L
0.52	0.445	6	47.8	5086	4352	0.000125	0.452	9512	6.53
0.53	0.446	6	37.9	5184	4362	0.000158	0.570	11997	4.65
0.54	0.448	6	33.5	5282	4382	0.000179	0.645	13573	4.01
0.55	0.45	6	30.13	5379	4401	0.000199	0.717	15091	3.55
0.56	0.453	6	28.6	5477	4431	0.000209	0.756	15898	3.44
0.57	0.455	6	27.3	5575	4450	0.000219	0.792	16655	3.38
0.58	0.458	6	25.4	5673	4480	0.000236	0.851	17901	3.12
0.59	0.46	6	22.6	5771	4499	0.000265	0.956	20119	2.64
0.6	0.462	6	20.9	5868	4519	0.000287	1.034	21755	2.40
0.61	0.464	6	19.5	5966	4538	0.000307	1.108	23317	2.22
0.62	0.465	6	19	6064	4548	0.000315	1.138	23931	2.24
0.63	0.466	6	18.6	6162	4558	0.000322	1.162	24445	2.28
0.64	0.468	6	18.2	6260	4577	0.000329	1.188	24982	2.30
0.65	0.47	6	18	6357	4597	0.000333	1.201	25260	2.35
0.66	0.472	6	17.4	6455	4616	0.000344	1.242	26131	2.30
0.67	0.474	6	17.2	6553	4636	0.000348	1.257	26435	2.35
0.68	0.476	6	16.5	6651	4656	0.000363	1.310	27556	2.25
0.69	0.477	6	16.2	6749	4665	0.000370	1.334	28067	2.27
0.7	0.48	6	15.8	6846	4695	0.000379	1.368	28777	2.23
0.71	0.483	6	15.7	6944	4724	0.000382	1.377	28961	2.28
0.72	0.485	6	15.3	7042	4744	0.000392	1.413	29718	2.24
0.73	0.488	6	14.7	7140	4773	0.000408	1.470	30931	2.13
0.74	0.491	6	14.6	7238	4802	0.000410	1.480	31143	2.17
0.75	0.494	6	12.8	7335	4832	0.000468	1.689	35522	1.71
0.76	0.496	6	12.6	7433	4851	0.000476	1.715	36086	1.71
0.77	0.499	6	12.5	7531	4881	0.00048	1.729	36375	1.73
0.78	0.501	6	12	7629	4900	0.0005	1.801	37890	1.65
0.79	0.505	6	11.8	7727	4939	0.000508	1.832	38532	1.63
0.8	0.508	6	11.6	7824	4969	0.000517	1.863	39197	1.61
0.81	0.512	6	11.2	7922	5008	0.000535	1.930	40597	1.53
0.82	0.514	6	11	8020	5027	0.000545	1.965	41335	1.52
0.83	0.517	6	10.91	8118	5057	0.000549	1.981	41676	1.53
0.84	0.52	6	10.7	8216	5086	0.000560	2.020	42494	1.51
0.85	0.523	6	10.5	8313	5115	0.000571	2.058	43303	1.47
0.86	0.526	6	10.31	8411	5145	0.000581	2.096	44101	1.45
0.87	0.528	6	10.27	8509	5164	0.000584	2.105	44273	1.47
0.88	0.532	6	10.17	8607	5203	0.000589	2.125	44708	1.47
0.89	0.536	6	9.91	8705	5242	0.000605	2.181	45881	1.42

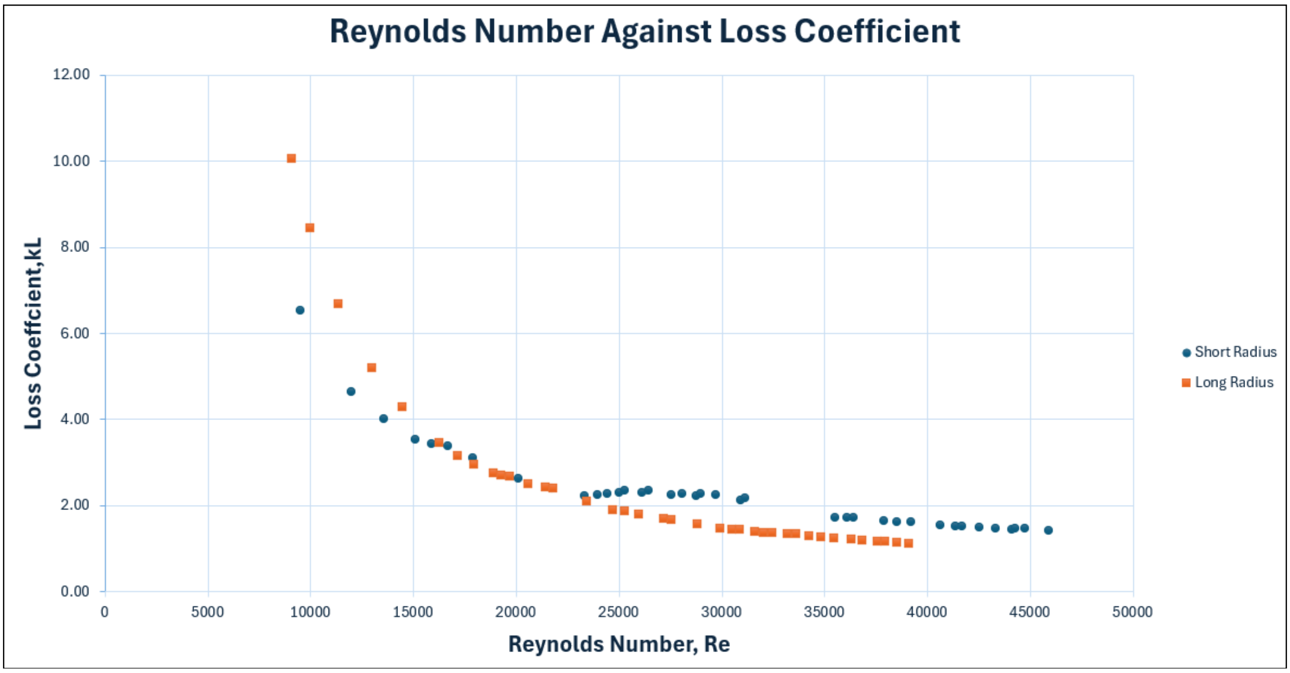
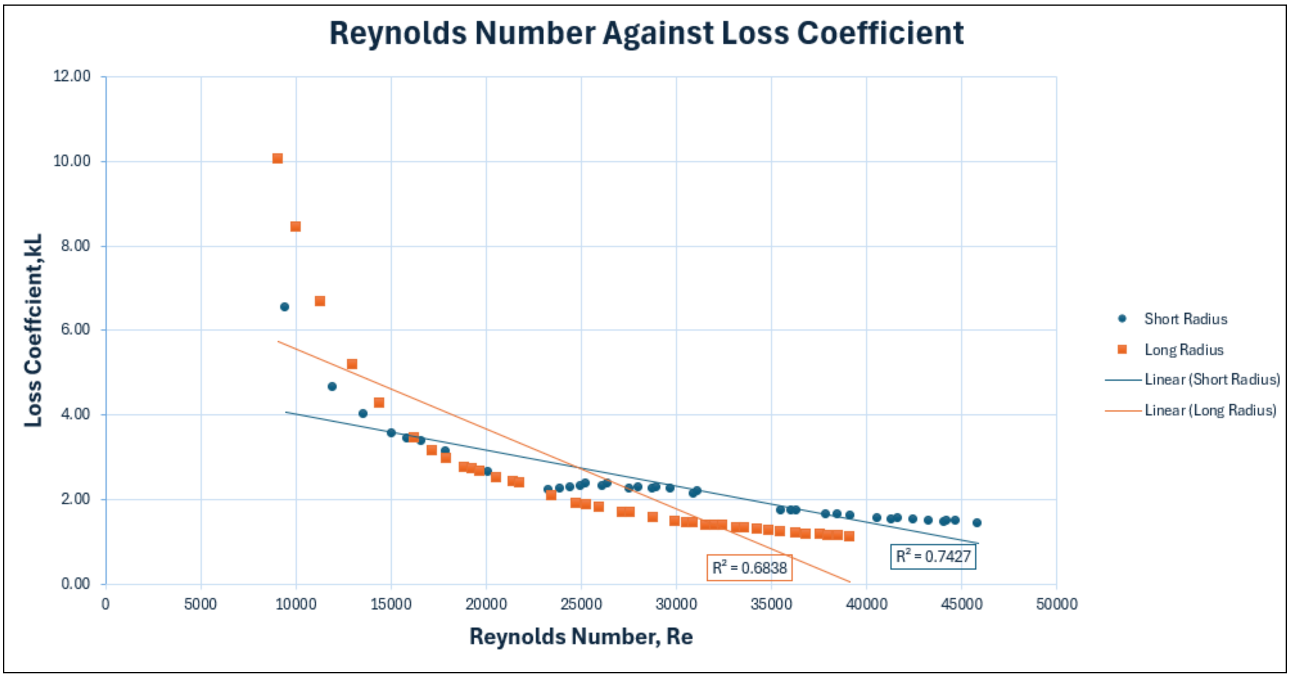
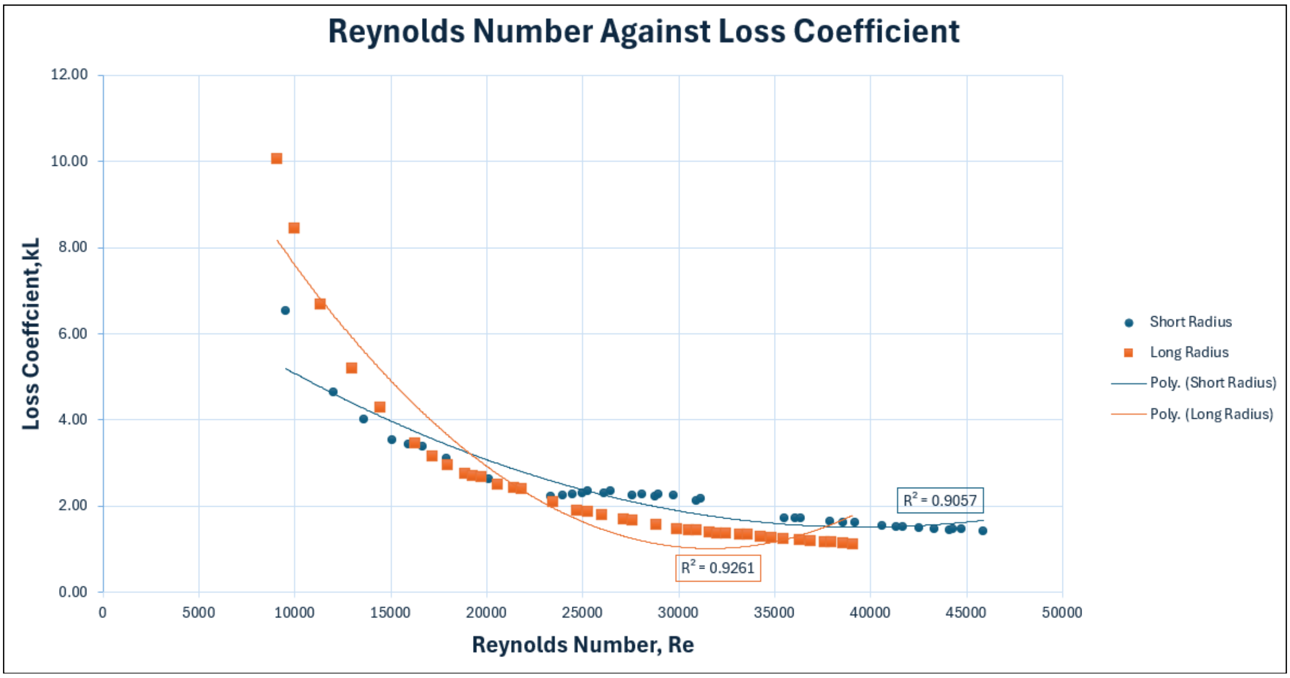


Fig. 3 *Graph k_L value against Re for both elbow*

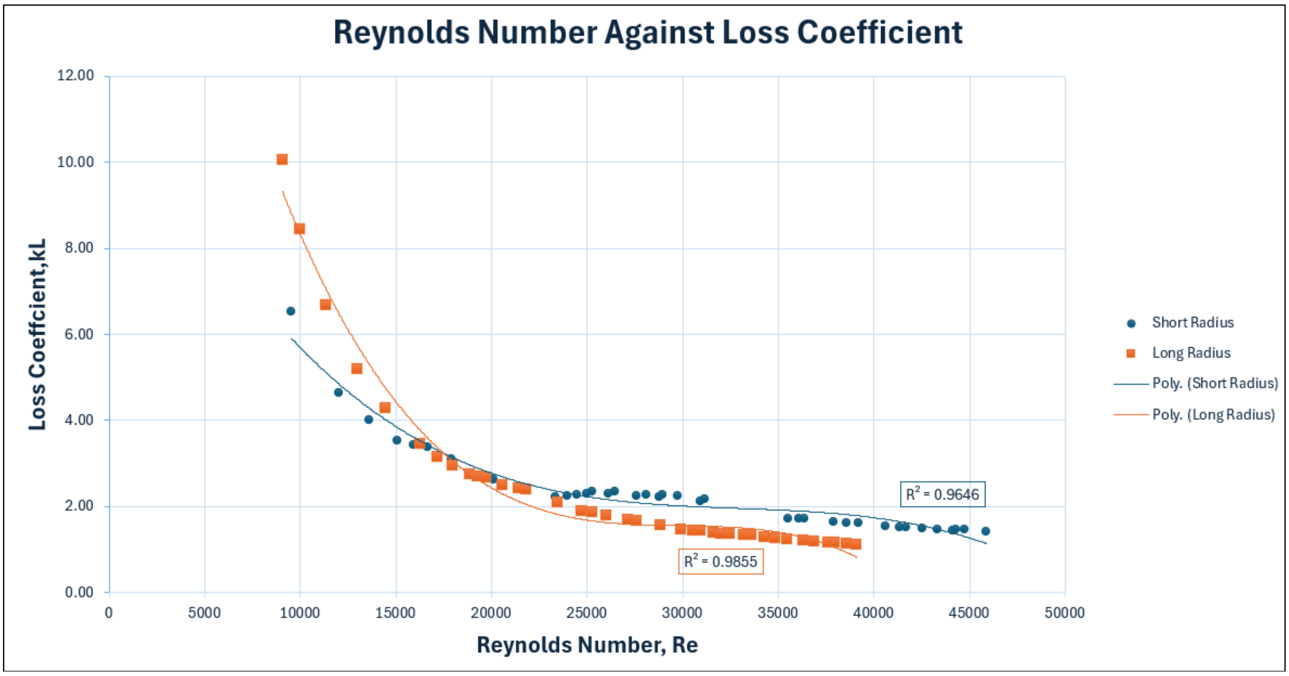
Both correlation and regression methods are used to identify the most effective relationship between two variables. These methods allow for direct analysis using the default functions in Microsoft Excel. Figure 4(a), (b), and (c) illustrate the relationships of linear, quadratic, and cubic models.



(a)



(b)



(c)

Fig. 4 *(a) Linear relationship analysis; (b) quadratic relationship analysis; (c) Cubic relationship analysis*

3.2 Discussion

The experimental results demonstrate a consistent inversely proportional relationship between Re and the k_L for both 90-degree SR and LR PVC elbows. As the Re increases, the k_L decreases, indicating improved flow efficiency and reduced energy losses at higher Re. This trend supports theoretical principles and aligns with findings from prior studies that reported similar behaviors for fittings in pipeline systems [6][7]. The reduction in turbulence and pressure drops at higher Re is particularly pronounced in LR elbows due to their smoother curvature.

Analysis of the data for each apparatus reveals that the most effective relationship between Reynolds number and loss coefficient value follows a cubic pattern with R^2= 0.9646 for SR elbow and R^2= 0.9855 for LR elbow. When comparing the two elbow types, LR elbows consistently exhibited lower k_L across all Reynolds numbers, especially at high Reynolds numbers, with a k_L value of 1.11. In contrast, SR elbows had a k_L value of 1.42. This outcome is attributed to the gradual directional change offered by LR elbows, which minimizes flow disturbances and turbulence. In contrast, the sharper turn in SR elbows creates higher resistance, resulting in greater energy losses. These results validate the efficiency of LR elbows for applications where energy optimization is critical, despite their larger spatial requirements.

Small deviations from theoretical values were observed, particularly at higher Re, likely due to limitations in the experimental setup. Potential sources of error include minor leaks, alignment inaccuracies, or the assumption that major losses in the system were negligible. However, the observed trends and relationships remained consistent with theoretical predictions, confirming the reliability of the experimental approach.

These findings provide valuable insights into the design of efficient pipeline systems. Understanding the impact of Re on k_L allows for more accurate predictions of pressure losses, aiding in the selection of appropriate fittings for specific flow conditions. This study emphasizes the advantage of LR elbows in reducing energy losses, making them a preferred choice in systems requiring high efficiency.

4. Conclusion

In conclusion, the objective of this project was achieved which provided useful information about the k_L for 90-degree short and long radius elbow. Experimental results revealed a clear inverse relationship between Re and k_L, with higher Re leading to lower energy losses. The findings confirmed that LR elbows consistently exhibited lower k_L than SR elbows due to their smoother curvature, which minimizes turbulence and pressure drops. These results validate existing theoretical models while providing practical insights into the design of efficient pipeline systems.

The study highlights the importance of considering Re variations when evaluating the performance of pipeline components. By demonstrating the advantages of LR elbows in reducing energy losses, this research supports their use in applications prioritizing efficiency, despite their larger spatial requirements. The outcomes contribute to a better understanding of flow dynamics in fittings and offer guidance for optimizing pipeline systems in industries such as water distribution, chemical processing, and HVAC.

Acknowledgement

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Appendix A: Analysed Raw Data

Appendix B: Completed raw data analysis for 90-degree LR elbow

Height, h_1 (m)	Height, h_2 (m)	Volume $\forall$ (l)	Time, t (s)	Pressure, P_1 (Pa)	Pressure, P_2 (Pa)	Flow Rate, Q (m^3/s)	Velocity, v (m/s)	Reynolds Number, Re	Loss Coefficient, k_L
0.558	0.453	6	50.19	5458	4431	0.0001195	0.431	9059	10.05
0.562	0.455	6	45.5	5497	4450	0.0001319	0.475	9993	8.43
0.566	0.457	6	40.1	5536	4470	0.0001496	0.539	11339	6.69
0.57	0.459	6	35	5575	4489	0.0001714	0.618	12991	5.20
0.574	0.461	6	31.5	5614	4509	0.0001905	0.686	14434	4.29
0.578	0.463	6	27.96	5653	4528	0.0002146	0.773	16262	3.45
0.582	0.465	6	26.5	5692	4548	0.0002264	0.816	17158	3.16
0.586	0.466	6	25.34	5731	4558	0.0002368	0.853	17943	2.97
0.59	0.467	6	24.1	5771	4568	0.000249	0.897	18866	2.76
0.594	0.468	6	23.6	5810	4577	0.0002542	0.916	19266	2.71
0.598	0.469	6	23.1	5849	4587	0.0002597	0.936	19683	2.67
0.602	0.47	6	22.12	5888	4597	0.0002712	0.977	20555	2.51
0.608	0.47	6	21.22	5947	4597	0.0002828	1.019	21427	2.42
0.612	0.471	6	20.87	5986	4607	0.0002875	1.036	21786	2.40
0.614	0.472	6	19.41	6005	4616	0.0003091	1.114	23425	2.09

0.618	0.474	6	18.4	6044	4636	0.0003261	1.175	24711	1.91
0.622	0.474	6	18	6084	4636	0.0003333	1.201	25260	1.88
0.626	0.476	6	17.51	6123	4656	0.0003427	1.234	25967	1.80
0.63	0.477	6	16.75	6162	4665	0.0003582	1.290	27145	1.69
0.634	0.477	6	16.5	6201	4665	0.0003636	1.310	27556	1.68
0.638	0.479	6	15.78	6240	4685	0.0003802	1.370	28814	1.56
0.642	0.48	6	15.2	6279	4695	0.0003947	1.422	29913	1.47
0.646	0.481	6	14.9	6318	4704	0.0004027	1.451	30516	1.45
0.65	0.482	6	14.72	6357	4714	0.0004076	1.468	30889	1.44
0.654	0.483	6	14.4	6396	4724	0.0004167	1.501	31575	1.40
0.658	0.485	6	14.2	6436	4744	0.0004225	1.522	32020	1.38
0.662	0.485	6	14.01	6475	4744	0.0004283	1.543	32454	1.38
0.666	0.486	6	13.7	6514	4753	0.000438	1.578	33188	1.34
0.67	0.487	6	13.54	6553	4763	0.0004431	1.596	33581	1.33
0.674	0.488	6	13.27	6592	4773	0.0004521	1.629	34264	1.30
0.678	0.489	6	13.05	6631	4783	0.0004598	1.656	34841	1.28
0.682	0.491	6	12.82	6670	4802	0.000468	1.686	35467	1.25
0.686	0.492	6	12.52	6709	4812	0.0004792	1.726	36316	1.21
0.69	0.494	6	12.34	6749	4832	0.0004862	1.752	36846	1.19
0.694	0.495	6	12.1	6788	4841	0.0004959	1.786	37577	1.16
0.698	0.496	6	11.98	6827	4851	0.0005008	1.804	37953	1.16
0.702	0.498	6	11.8	6866	4871	0.0005085	1.832	38532	1.13
0.706	0.501	6	11.63	6905	4900	0.0005159	1.858	39096	1.11

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