Journal of Positive Psychology & Wellbeing
2023, Vol. 7, No. 1, 464-475
http://journalppw.com
ISSN 2587-0130

Experimental Local Loss Coefficients (Km) Of Some Common Fittings Used In Residential Hydraulic Networks

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ABSTRACT

The loss coefficients values (Km) of hydraulic fittings produce energy losses that are related to the minor ones (hL) and are widely used in hydraulic network designs. In this work, through a loss bank, the most common fittings Km coefficients used in residential hydraulic installations in Colombia were found, such as 90° elbows, universal joints, reductions, and ball valves from ½ to 2 inches in diameter. Among the results found, it was evidenced that the smaller the diameter, the load losses, the velocity, and the loss coefficient increase. An analysis of variance (ANOVA) was performed to corroborate the results obtained and, in most cases, reliability greater than or equal to 90% was achieved.

Keywords: Loss coefficient, Accessories, Energy loss, Hydraulic bench, Hydraulic installations.

1. Introduction

In the design and construction projects of potable water conduction and distribution in Colombia, it is important to study the hydraulic behavior of accessories, so it is essential to know and apply the concepts about the hydraulic loss coefficients involved in them, to make the systems work in an efficient and optimal way. Hydraulic head losses in fittings are important when designing hydraulic systems to estimate the service pressure to be had at certain demand points (Silverio et al., 2020), A significant reduction or total loss of pressure in a distribution system's part can allow contaminants from an end user or the environment to enter the distribution system (Khaleefa et al., 2018). The hydraulic energy losses of the fluid are referred to as "Head Losses" and depend on the shape, dimensions, flow velocity, viscosity, and roughness of the conduit (Rivas and Sanchez, 2008). These head losses are due to friction between the fluid and the solid walls or by the strong dissipation of hydraulic energy that occurs when the flow is affected by a change in its direction or direction due to the components presence such as adapters, elbows, and bends, valves, bypasses, widening or sudden narrowing, bifurcations, among others. Head losses can be divided into friction head losses and local losses.

It is necessary to highlight that local or minor losses caused by the presence of different fittings are generally due to flow disturbances, so it is important the friction loss evaluation in valves and other fittings, this involves the determination of the appropriate loss or resistance coefficient Km, which can be determined experimentally and calculated with empirical equations (Russi, 2015). The individual effects of these losses commonly do not play an important role in the overall losses of the piping system but added together, they can represent serious implications in the hydraulic networks desings (Balsiguer et al., 2014).

In a piping system, local losses are numerous and are expressed as a height fraction of the velocity at nominal diameter (case valves and elbows) although, in variable diameter sections (narrowing and widening), the diameter to which such fraction is referred is almost always specified (Hechavarría, 2017). However, when in a segment of the considered conduit appears a local change of flow parameters, i.e., local change of the section, from the flow direction to the forced separation zone of the boundary layer, secondary flows with high vorticity are formed, arising appreciable shear stresses. The effect of this action manifests itself as local pressure loss. Local losses are usually expressed as a velocity loading function by an empirical coefficient "Km" (Mederos, 2012).

Some related studies with local pressure losses are based on the relationship determination of the loss coefficient Km with other dimensionless parameters. This coefficient is dimensionless and depends on additional parameters, such as Reynolds number, relative roughness, geometric relations, and the singularity type or hydraulic fitting being analyzed. For local head losses, there are few valid results, mainly because the fittings flow character is quite complicated and the way to determine the losses value is experimental (Rivas and Sanchez, 2008). The above confirms the importance and need to know and study experimentally the Km loss coefficients depending on the diameter of the fitting and its respective material since the information found is generic and scarce. With a more precise determination of Km values, it is possible to improve hydraulic designs, since the decrease in head loss translates directly into a decrease in energy consumption (Alba et al., 2008).

The main objective of this work was to define a more accurate Km value for some common fittings used in the design of residential hydraulic networks, based on their commercial diameter.

2. Methodology

2.1 General description of the methodology

To carry out this experimental research, a loss bank of PVC fittings with diameters from ½ to 2 inches was designed and built, and a comparison was made with the Km of the technical literature. The tests were executed in the facilities of the hydraulics laboratory of the Universidad del Sinú in Monteria city, Colombia. The information collected was then analyzed using statistical software.

In order to obtain the loss coefficients for Km fittings, 18 flow rates were used, taking 6 measurements per fitting for each flow rate. From these data, the 10 most significant flow rates were selected considering parameters such as local hydraulic head loss per fitting (hL) and velocity (V), obtaining the most accurate Km and discarding the most distant or atypical data.

2.2 Materials and equipment

To determine the Km loss coefficients, equipment and materials were used to take measurements. Figure 1 shows the equipment used.

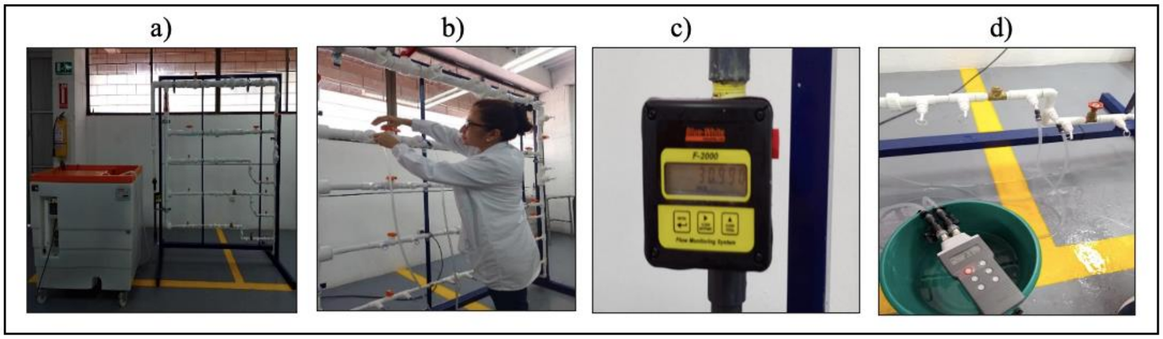

Figure 1. Materials and equipment used in the laboratory tests: a) Hydraulic bench and leakage bench, b) Measurement taker, c) Flowmeter, and d) Digital manometer.

Figure 1a shows the hydraulic bench and the storage tank that internally has a hydraulic pump to lift and propel water to the loss bank of fittings. Figure 1b shows the measurement of accessories in the loss bank. Figure 1c shows the Blue White digital flow meter (Reference F2000), used to measure the flow rate in L/min. Finally, Figure 1d shows the Comark digital manometer, used to measure the losses of the accessories.

Figure 2 shows a general scheme of the loss bank used for taking readings.

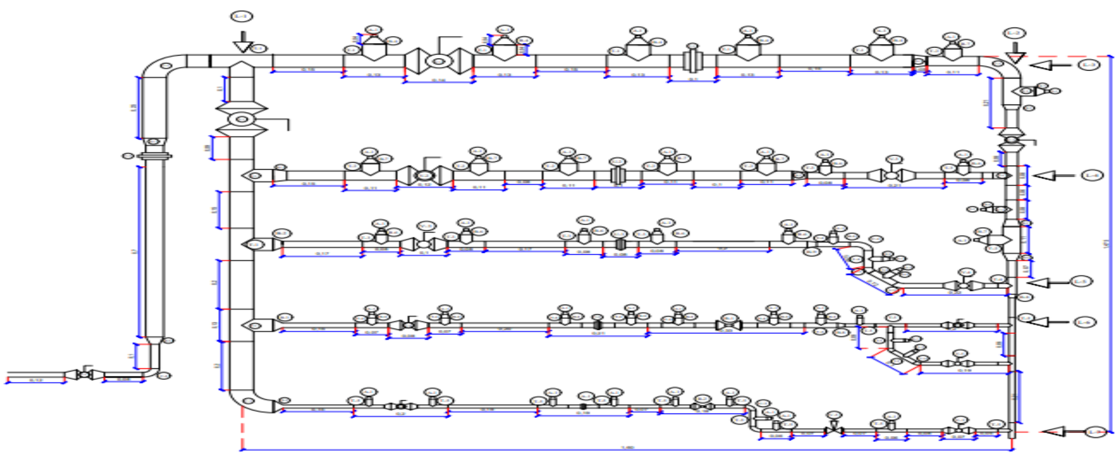

Figure 2. General schematic of the accessory loss bank.

2.3 Statistical analysis

An ANOVA analysis of variance was performed with the data obtained, using STATGRAPHICS Centurion software which is a powerful data analysis tool that combines a wide range of analytical procedures with interactive graphics (STATGRAPHICS Centurion net, 2014). With this analysis, the Km coefficients for accessories were chosen, which presented lower losses and better performance. In addition, the coefficient of determination (R^2) was determined; this coefficient is the specific measure that quantifies the intensity of the linear relationship between two variables in a correlation analysis (Martínez, 2005). When the correlation coefficient (R) is greater than 0.8, the predictive and experimental values are highly correlated; similarly, an R2 close to 1 indicates that the model values fit very well and are close to the values found experimentally. An R2 of 0.65 to 0.75 implies outstanding performance, while an R2 of less than 0.50 indicates poor performance (Feria et al., 2022). In addition to ANOVA, a multiple range analysis was performed to determine the variability of the data with respect to its mean value, in this case of diameters. Plots hL vs $V^2/2g$ were made to obtain the percentage of reliability, K vs Diameter plots, to obtain the general equation and the coefficient of determination R^2.

3. Results and discussion of results

3.1 Regular PVC 90° Ell

For the Km coefficient of the regular PVC 90° Ell, we worked with diameters of 1½, ¾, and ½ inches. The average Km was calculated according to the results achieved for each diameter. Table 1 shows a summary of the Km results obtained for 90° Ell with different diameters.

Table 1. Summary of Regular PVC 90° Ell calculations

Nominal ϕ (Inches)	Flow (m^3/s)	hL (m.c.a)	Velocity (m/s)	Km	Mean Km
1½	0.00083	0.0100	0.56	0.64	0.65
	0.00087	0.0107	0.58	0.62	
	0.00091	0.0137	0.61	0.72	
	0.00098	0.0133	0.65	0.61	
3/4	0.00076	0.1253	1.73	0.82	0.79
	0.00083	0.1373	1.90	0.74	
	0.00087	0.1510	1.98	0.75	
	0.00091	0.1933	2.09	0.87	
	0.00098	0.1927	2.24	0.75	
1/2	0.00076	0.3367	2.91	0.78	0.82
	0.00083	0.4250	3.20	0.81	
	0.00087	0.4607	3.33	0.81	
	0.00091	0.5580	3.52	0.89	
	0.00098	0.5920	3.77	0.82	
Km= 0.76 ± 0.09*					

*Mean ± Standard deviation

Table 2 shows the results of the ANOVA performed for the Km of the 90° ell.

Table 2. ANOVA for Km per Diameter (inches)

Source	Sum of Squares	DF	Mean Squares	F-Reason	P-Value
Between groups	0.0732179	2	0.0366089	14.87	0.0007
Intra groups	0.027075	11	0.00246136		
Total (Corr.)	0.100293	13			

Since the P-value is less than 0.05, there is a statistically significant difference in the mean Km between one Diameter and another, at the 95.0% confidence level. To determine which means are significantly different from others, Fisher's Multiple Range tests were applied. Table 3 shows the results of the multiple-range test.

Table 3. Multiple Range Tests for Km by Diameter (inches)

Contrast	Sig.	Difference	+/- Boundaries
1/2 - 3/4		0.036	0.0690615
1/2 - $1\frac{1}{2}$	*	0.1745	0.0732508
3/4 - $1\frac{1}{2}$	*	0.1385	0.0732508

In Table 3, it is established that between diameters ½ to ¾ inch, there are no significant differences. Between diameters ½ to 1½ inches and between diameters ¾ to 1½ inches, there are significant differences. From these results, Figure 4 was projected. It shows the behavior of Km as a function of 90° elbow diameter.

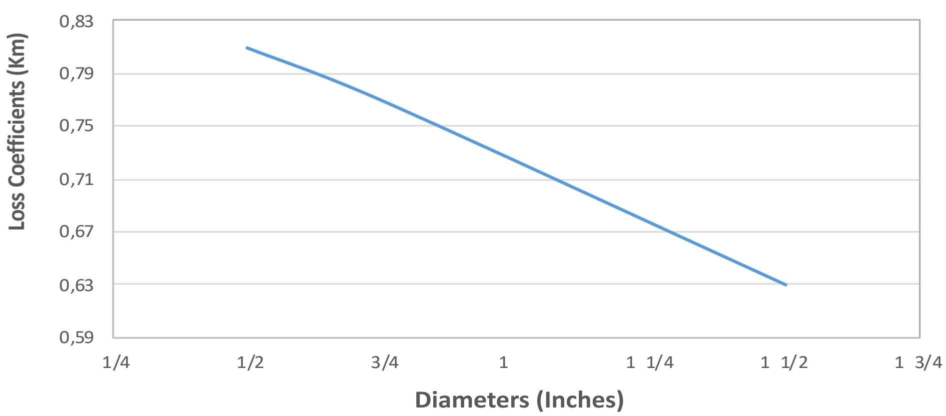

Figure 3. Regular PVC 90° Elbow: General loss coefficient Km vs Diameter.

The Km results (1½", Km=0.63; ¾", Km=0.75; ½", Km=0.81) are very similar to those reported by Cameron (2017), which ratifies that the Km coefficient in 90° Elbows depends on the diameter of this fitting.

3.2 PVC Reductions

To obtain the Km coefficients of the Reductions of diameters from 2 to 1½ inches, 1½ to 1 inch, and ¾ to ½ inches experimental tests were performed, the results of which are described den Table 4.

Table 4. Summary of reduction calculations.

Accessory	Nominal ϕ (Inches)	Flow (m^3/s)	hL (m.c.a)	Velocity (m/s)	Km	Mean Km
Reductions of 2 to 1½ inches	1½	0.00083	0.0020	0.56	0.13	0.13
		0.00087	0.0020	0.58	0.12	

		0.00098	0.0030	0.65	0.14	
Reductions of 1½ to inches	1	0.00076	0.0120	1.06	0.21	0.21
		0.00083	0.0140	1.16	0.20	
		0.00087	0.0150	1.21	0.20	
		0.00091	0.0170	1.28	0.20	
		0.00098	0.0213	1.37	0.22	
Reductions of 3/4 to 1/2 inches	1/2	0.00076	0.0920	2.91	0.21	0.22
		0.00083	0.1133	3.20	0.22	
		0.00087	0.1167	3.33	0.21	
		0.00091	0.1440	3.52	0.23	
		0.00098	0.1580	3.77	0.22	
Km = 0.19 ± 0.04*						

*Mean ± Standard deviation

In the ANOVA analysis, the diameter groups 2 to 1½ inches; 1½ to 1 inch; ¾ to ½ inch were related. Table 5 shows the results of this ANOVA.

Table 5. ANOVA for Km by Diameter (inches)

Source	**Sum of Squares**	**DF**	**Mean Squares**	**F-Reason**	**P-Value**
Between groups	0.0158769	2	0.00793846	99.23	0.0000
Intra groups	0.0008000	10	0.00008000		
Total (Corr.)	0.0166769	12			

According to the results in Table 5, there is a statistically significant difference between one diameter level and another, at the 95% confidence level. Table 6 presents the multiple-range test for the different diameter levels of the Reductions.

Table 6. Multiple Range Tests for Km by Diameter (inches) for Reductions

Contrast	**Sig.**	**Difference**	**+/- Boundaries**
1/2 - 1		0.012	0.0126043
1/2 - 1 1/2	*	0.088	0.0145542
1 - 1 1/2	*	0.076	0.0145542

In the contrast ranges between diameters ½ to 1 inch, there is no significant difference. Between diameters ½ to 1½ inches, the significant difference is low despite the difference in diameter levels. Finally, for the contrast range between 1 to ½ inches, it is low because of the diameter levels achievement. Based on these results, Figure 4 was elaborated, where it is possible to appreciate the behavior of the Km loss coefficient as a function of the larger diameter of the PVC reductions.

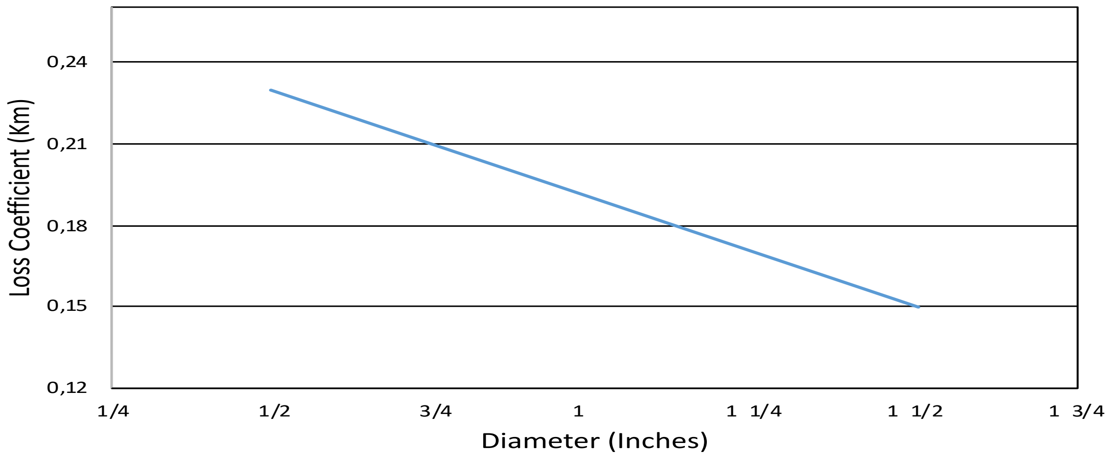

Figure 4. Reductions: general loss coefficient Km vs Diameter

The calculated Km of the reductions of diameters 2 to 1½ inches, 1 to 1½ inches, and ¾ to ½ inches, are 0.15; 0.19, and 0.23 respectively, values like those reported in the technical literature (0.135; 0.21, and 0.22) respectively (Mott, 2006). These results corroborate that the Km loss coefficients in reductions depend on the diameter of the fitting.

3.3 Ball valve - PVC fitting

To find the value of the loss coefficient for ball valve fittings, we worked with diameters of 2, 1 ½, and 1 inch. It was established that these increases consider the decrease in diameter, as shown in Table 7.

Table 7. Summary of calculations Ball Valve – PVC

Nominal ϕ (Inches)	**Flow (m^3/s)**	**hL (m.c.a)**	**Velocity (m/s)**	**Km**	**Mean Km**
2	0.00078	0.0027	0.33	0.47	0.48
	0.00083	0.0030	0.36	0.46	
	0.00084	0.0030	0.36	0.46	
	0.00086	0.0033	0.37	0.49	
	0.00089	0.0037	0.38	0.50	
	0.00091	0.0040	0.39	0.52	
1 1/2	0.00084	0.0080	0.56	0.50	0.52
	0.00086	0.0083	0.57	0.50	
	0.00089	0.0100	0.59	0.56	
	0.00091	0.0100	0.61	0.53	
1	0.00083	0.0330	1.16	0.48	0.52
	0.00084	0.0363	1.17	0.52	
	0.00086	0,0390	1.20	0.53	
	0.00091	0.0440	1.27	0.53	
Km= 0.51± 0.02*					

*Mean ± Standard deviation

Table 8 shows the ANOVA for the PVC ball valve, according to the experimental results obtained.

Table 8. ANOVA for K by Diameter (inches)

Source	Sum of Squares	DF	Mean Squares	F-Reason	P-Value
Between groups	0.00441310	2	0.002206550	3.41	0.0702
Intra groups	0.00710833	11	0.000646212		
Total (Corr.)	0.01152140	13			

It was observed that there is no statistically significant difference between the mean Km between one Diameter and another, with a 95.0% confidence level. The Multiple Range test was performed, and it was established that the means were significantly different from others with outliers present (See Table 9).

Table 9. Multiple Range Tests for K by Diameter (inches) for the ball valve.

Contrast	Sig.	Difference	+/- Boundaries
1 - 1½		-0.0075000	0.0395631
1 - 2		0.0316667	0.036116
1½ - 2	*	0.0391667	0.036116

Table 9 shows that there is no significant difference between the means, and homogeneity is found in the results, in the contrast range of diameters 1 to 1 ½ inches, the difference is not significant, which represents similarity in the results of these levels. In the ranges of the 1 to 2 inches and 1½ to 2 inches diameter levels, there are statistically significant differences with a 95.0% confidence level. According to these results, Figure 5 shows the behavior of the loss coefficient as a function of the ball valve diameter.

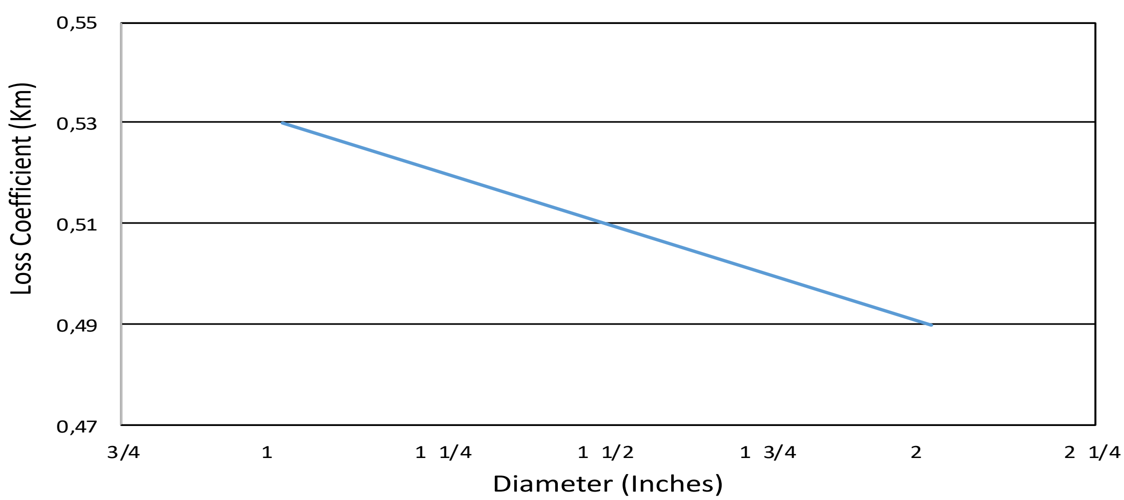

Figure 5. Ball valve: overall loss coefficient Km vs Diameter

The experimental Km values achieved were compared with those in the literature by Monterroso (2012), where the author reported a single Km value for the ball valve of 0.5. The Km calculated in this work for diameters of 1, 1½, and 2 inches, vary from 0.49; to 0.51, and 0.53, respectively. By calculating the experimental Km for different diameters of the ball valve, it was found that each diameter has a different Km.

3.4 Universal joint - PVC

In calculating the Km for the universal joint, diameters of 2, 1½, and 1 inch were taken in the experimental tests. Table 10 shows a summary of the results achieved.

Table 10. Summary of Universal Joint Calculations – PVC

Nominal ϕ (Inches)	**Flow (m^3/s)**	**hL (m.c.a)**	**Velocity (m/s)**	**Km**	**Mean Km**
2	0.00083	0.0013	0.36	0.21	0.24
	0.00084	0.0017	0.36	0.25	
	0.00086	0.0017	0.37	0.24	
	0.00091	0.0020	0.39	0.26	
1 1/2	0.00083	0.0040	0.56	0.25	0.26
	0.00084	0.0043	0.56	0.27	
	0.00091	0.0050	0.61	0.27	
1	0.00083	0.0170	1.16	0.25	0.28
	0.00084	0.0190	1.17	0.27	
	0.00086	0.0213	1.20	0.29	
	0.00089	0.0230	1.24	0.30	
	0.00091	0.0243	1.27	0.30	
Km= 0.26 ±0.02*					

*Mean ± Standard deviation

Table 11 shows the ANOVA found for the universal joint in PVC, according to the experimental results obtained.

Table 11. ANOVA for Km per Diameter (inch).

Source	**Sum of Squares**	**DF**	**Mean Squares**	**F-Reason**	**P-Value**
Between groups	0.00392000	2	0.001960000	4.97	0.0351
Intra groups	0.00354667	9	0.000394074		
Total (Corr.)	0.00746667	11			

Based on the values reported in Table 11, it could be established that there is a statistically significant difference between the mean Km between one diameter and another, with a 95.0% confidence level. Table 12 shows the results of Fisher's Multiple Range Test analysis for Km of the Universal Union.

Table 12. Fisher's Multiple Range Tests for Km by Diameter (inches) for Universal Union

Contrast	Sig.	Difference	+/- Boundaries
1 - 1½		0.0186667	0.0327953
1 - 2	*	0.0420000	0.0301244
1½ - 2		0.0233333	0.0342982

In Table 12, a greater significant difference was observed in the range of 1 to 2 inches.

Based on the results obtained, Figure 6 was projected, showing the Km behavior as a function of diameter for the universal joint.

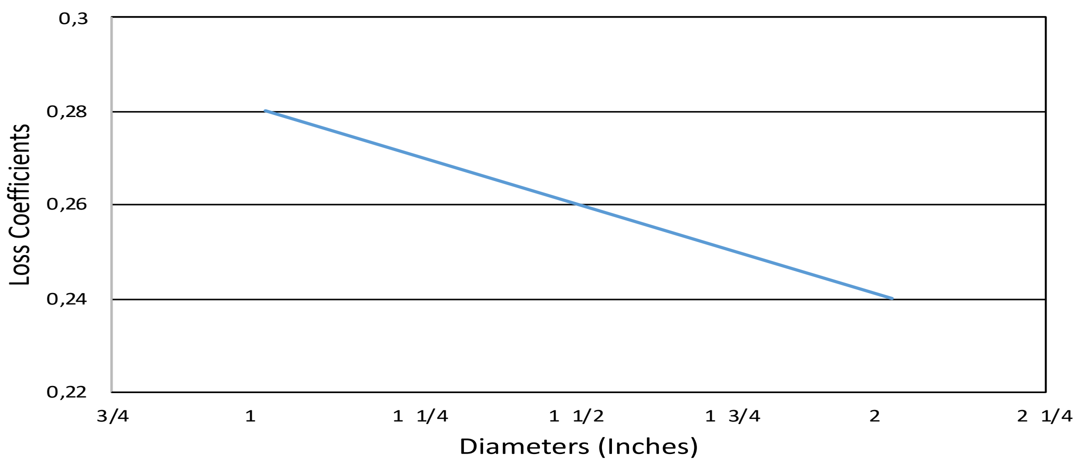

Figure 6. Universal Joint: General Km vs Diameter loss coefficient.

When comparing the values achieved experimentally and those reported by Silveiro et al. (2020), we found that they are like those reported in this work. The Km calculated for diameters of 1; 1½ and 2 inches are 0.24; 0.26 and 0.28, respectively, while the one reported by the author is 0.24. Therefore, it was observed that the Km varies according to the diameter.

Table 13, presents a comparison between the values obtained experimentally and the theoretical values from the technical literature.

Table 13. Summary of theoretical and experimental values for Km.

Accessory	Diameter (Inches)	Km (Experimental)	Km (literature)	Author
Regular PVC 90º Ell	1½	0.63	0.63	Cameron Hidraulic Data, 2017
	3/4	0.77	0.75	
	1/2	0.81	0.81	

Reductions	2 to 1½	0.15	0.13	Mott, 2006
	1½ to 1	0.19	0.21	
	3/4 to 1/2	0.23	0.22	
Ball valve PVC fitting	2	0.49	0.50	Monterroso, 2012
	1½	0.51	0.50	
	1	0.53	0.50	
Universal Joint	2	0.24	0.24	Silveiro et al, 2020
	1½	0.26	0.24	
	1	0.28	0.24	

When analyzing the results of Table 13, there is a high similarity between the Km obtained experimentally and the Km reported in the technical literature.

4. Conclusions

When performing a comparative analysis of the Km found experimentally and the theoretical ones, that is, those reported in the technical literature, great similarity and resemblance were found between them, which allowed establishing a significant correlation to select the best Km, according to their hydraulic behavior. According to the statistical model applied, the Km depends to a great extent on the diameter of the fittings, which allows using it with greater precision for the design and calculation of residential hydraulic networks in PVC material. In general, the fittings chosen with their respective diameters showed good behavior in obtaining the local loss coefficients Km, evidencing that as the diameter decreases, the losses by hL fittings increase, as well as the velocity and the value of Km calculated experimentally, in accordance with the studies, research and existing technical literature.

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