Research on the Local Head Loss Coefficient in Short-Tube Hydraulic Testing

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Abstract. Fluid mechanics is one of the important disciplines in civil engineering. It studies the movement of fluids under static and dynamic conditions. Hydraulics, which is related to this, is an important branch in civil engineering. It mainly focuses on the movement of water, water pressure, water flow velocity, and related issues. Gas and liquid flow in pipe systems is a common occurrence in engineering. The extent and impact of pressure head loss along pipes and across different fittings can be investigated and measured by controlling the pipe friction apparatus. According to literature, altering the cross-section or introducing flow control devices can modify these losses. The objective is to conduct a series of experiments on fluid flow through pipes, valves, junctions, and expansions/contractions. These experiments are essential for quantifying pressure losses or friction losses that occur as incompressible flow traverses through the pipe systems. A crucial aspect involves comparing the experimental data with numerical predictions. By analyzing the differences and similarities between the two sets of data, conclusions can be drawn regarding the experimental results.

Keywords: Civil engineering; Hydraulics; Local head loss coefficient; Analysis and comparison

1 Introduction

The pressure losses or friction losses can be noticed when the incompressible flow goes through the pipe systems. [1] In engineering design and water resources management, accurately estimating and controlling head losses is crucial. This article will introduce the concept of head losses and local head loss coefficient, their classification, calculation methods, and influencing factors. By analyzing and comparing experimental and theoretical data, relevant conclusions will be further drawn.

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2 Resistance to Flow in a Pipe

If a real fluid goes through the pipes and fitting system, considering the internal roughness of the pipe wall, it will generate local eddy currents. As a consequence, it will add some resistance to flow of the fluid. [2-3] In small diameter pipes, the internal roughness is a major influence on the friction factor. Compared to small diameter pipes, the effect of the eddy currents created in larger pipes is less significant. As to how much effect will have on the friction resistance, it depends on the material of subject. The smooth walls, such as glass, copper, brass and polyethylene just add a slight resistance on the friction. If the pipes have concrete, cast iron and steel theses kind of rough walls, pipes will create larger eddy currents and have more frictional resistance.[4] According to the existent observation, a real fluid going through a pipe, the velocity of fluid is different at the center of the stream and the edge of the stream. Generally, the fluid in the center part moves more quickly than the fluid towards the edge of stream.

3 Hydraulic Head

Fluid pressure is often expressed in terms of a head of liquid. In fluid dynamics, this pressure is linked to the energy present in a viscous fluid, represented by the height of an equivalent static column of the fluid. In practical scenarios, the energy of a real fluid is partially dissipated due to friction losses as the flow traverses through pipe systems. [5-6]

There are two main categories of head loss encountered in fluid flow. The first category is "major losses”, called friction head loss, which are associated with the energy loss per unit length of pipe. Generally, turbulent flows with high Reynolds numbers tend to dissipate more energy due to their turbulent nature. The second category of head loss is "minor losses", called local head loss, which arise from factors such as bends, fittings, valves, and other obstructions in the flow path.[7]

3.1 Local Head Loss

The reason for this is due to the inertia effect, where the main flow separates from the wall surface, forming a vortex region or causing a sharp adjustment in the local flow structure. This intensifies the frictional effects within the fluid, leading to a significant dissipation of mechanical energy.Based on a large number of experimental results, the formula for calculating local head loss h_j is as follows:

$$h_j = \zeta \frac{v^2}{2g} \tag{1}$$

Where:

ζ is the local head loss coefficient

v is the corresponding average flow velocity at the section (m/s)

The locations where local losses occur are subject to strong disturbances from local obstacles, causing fluctuations to become turbulent even at relatively low levels. In general, the value of ζ is determined by the shape factor of the local obstruction, which, due to its highly complex nature, is mostly determined through experimentation.

4 Methodology

Experimental research was conducted on the local head loss coefficient in short pipes. Local head loss experimental apparatus is shown in Figure 1. Master the measures for determining the local resistance coefficient of pipelines and compare them with the calculated values from theoretical formulas or empirical formulas. Observe the changes in the water surface line of the pressure measuring tube in the vortex zone under various boundary abrupt changes, such as sudden enlargement of pipe diameter, and compare the magnitude of local head losses between sudden enlargement and sudden contraction situations.

4.1 Experimental Study

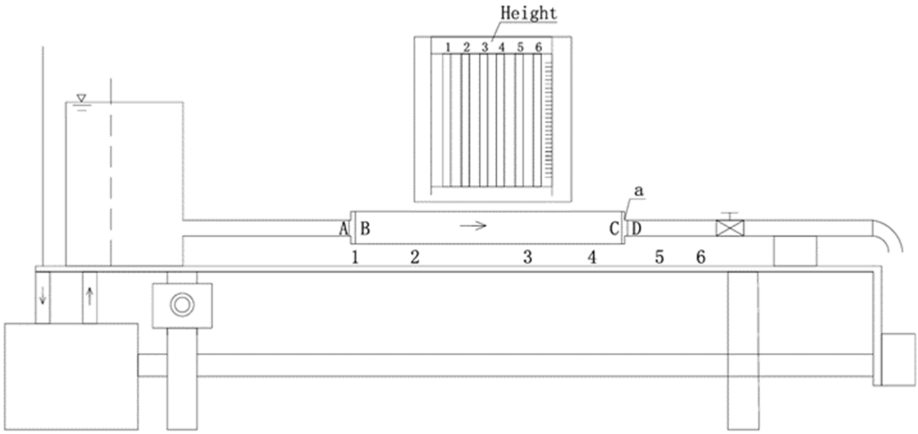

Fig. 1. Local head loss experimental apparatus

Sudden Expansion Section:
Considering the change, the measured local head loss coefficient can be determined as follows:

$$\zeta_e = \frac{h_j}{\frac{v_1{}^2}{2g}} \tag{2}$$

The theoretical local head loss coefficient can be determined as follows:

$$\zeta_e{}' = \left(1 - \frac{A_1}{A_2}\right)^2 \tag{3}$$

Sudden Contraction Section:

Considering the change, the measured local head loss coefficient can be determined as follows:

$$\zeta_c = \frac{h_j}{\frac{v_5{}^2}{2g}} \tag{4}$$

The theoretical local head loss coefficient can be determined as follows:

$$\zeta_c{}' = 0.5\left(1 - \frac{A_5}{A_4}\right) \tag{5}$$

4.2 Constants of the Experiments.

Circular pipe diameter: d1=0.97cm, d2=d3=d4=2.01cm, d5=d6=1.02cm,
The distance between two points: L1=12.02cm, L2-3=23.98cm, L3-4=11.99cm.
The point that suddenly shrinks is point a，
L4-a=5.99cm, La-5=6.0cm, L5-6=5.99cm

4.3 Experimental Data Record and Calculation.

Table 1. Experimental Data Record

Number of observations	Height(cm)					
	h1	h2	h3	h4	h5	h6
1	16.60	21.00	19.05	18.10	5.05	3.10
2	17.60	20.85	20.35	19.65	8.35	6.55
3	18.85	21.80	21.10	20.30	10.25	8.65
4	20.20	22.95	22.15	21.50	12.15	10.50
5	21.00	23.75	23.20	22.80	13.65	12.30

	Volume (cm^3)	Time (s)	Flow rate (cm^3/s)	Velocity (cm/s)			
	V	T	Q	V1	V2	V4	V5
1	1082	10	108.2	146.5	34.1	34.1	137.6
2	1509	15	100.6	136.2	31.7	32.3	128.2
3	1453.5	15	96.9	131.2	30.6	30.9	123.4
4	1838	20	91.9	124.4	29.0	29	117.1
5	1804	20	90.2	122.1	28.4	28.4	114.9

Table 2. Experimental Data Calculation

Experimental data of sudden expansion section			A-A	B-B					
Number of observations	$\frac{v1^2}{2g}$ (cm)	$\frac{v2^2}{2g}$ (cm)	Total Height H1 (cm)	Total Height H2 (cm)	h_f (cm)	h_j (cm)	ζ	ζ'	$\bar{\zeta}$
1	7.7	0.6	24.3	21.00	0.05	3.3	0.42	0.59	0.45
2	6.7	0.5	24.3	21.40	0.06	2.8	0.42	0.59	0.45
3	6.2	0.5	25.1	22.30	0.07	2.7	0.43	0.59	0.45
4	5.6	0.5	26.6	23.40	0.06	3.1	0.56	0.59	0.45
5	5.4	0.4	26.4	24.20	0.05	2.1	0.40	0.59	0.45
Experimental data of contraction section			C-C	D-D					
Number of observations	$\frac{v4^2}{2g}$ (cm)	$\frac{v5^2}{2g}$ (cm)	Total Height H4 (cm)	Total Height H5 (cm)	h_f (cm)	h_j (cm)	ζ	ζ'	$\bar{\zeta}$
1	0.63	8.17	18.73	13.22	1.94	3.57	0.44	0.38	0.37
2	0.57	7.09	20.22	15.44	1.85	2.93	0.41	0.38	0.37
3	0.52	6.58	20.82	16.83	1.93	2.06	0.31	0.38	0.37
4	0.46	5.92	21.96	18.07	1.82	2.07	0.35	0.38	0.37
5	0.44	5.70	23.24	19.35	1.85	2.04	0.36	0.38	0.37

Where:

ζ is the measured local head loss coefficient

ζ' is the theoretical local head loss coefficient

$\bar{\zeta}$ is the Average value of measured local head loss coefficient

V is the corresponding average flow velocity at the section (cm/s)

h_f is the measured friction head loss

h_j is the measured local head loss

All experimental data are described in Table 1 and Table 2 above.

4.4 Graphical Results

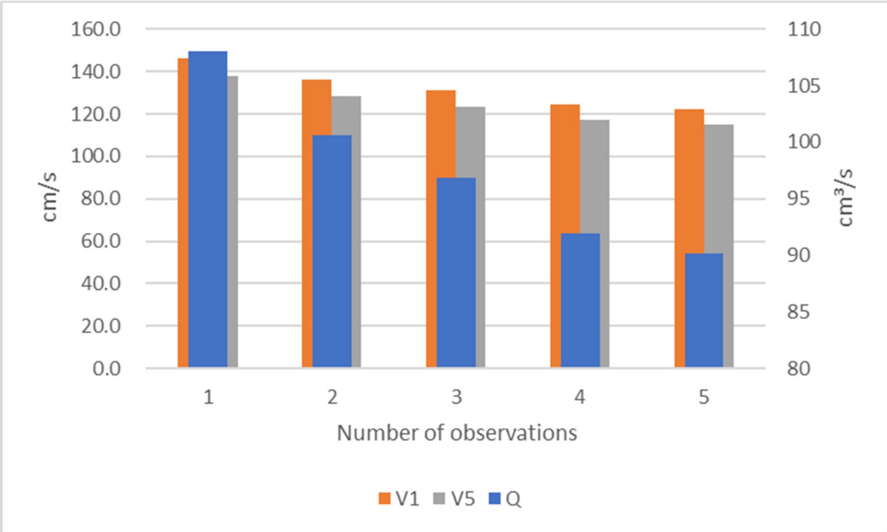

Fig. 2. The relationship between flow rate and flow velocity

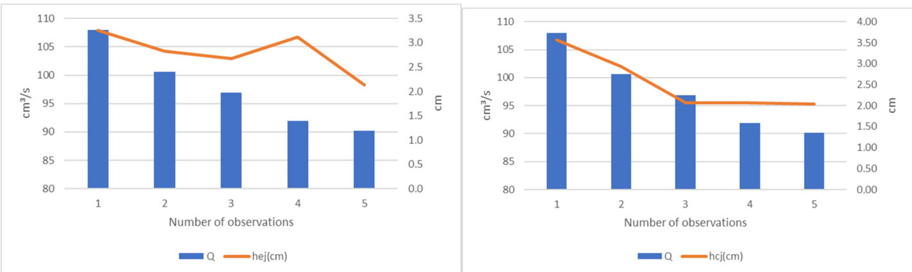

Fig. 3. The relationship between flow rate and local head losses due to sudden expansion or contraction

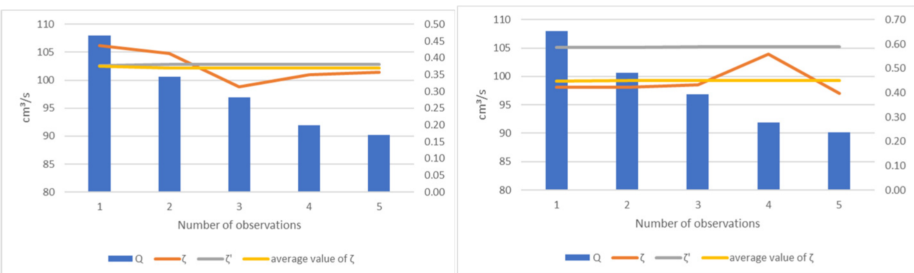

Fig. 4. The relationship between flow rate and the empirical and theoretical local loss coefficients

The correspondences between the flow rate and the interrelated parameters are shown in Figure 2, Figure3 and Figure 4.

5 Conclusions

1. Through the charts, it can be observed that the magnitude of the flow rate has a significant impact on the determination of the flow coefficient. As the flow rate decreases, the measured local resistance coefficient also decreases accordingly, but the difference between the measured value and the theoretical value increases. Therefore, the conclusion can be drawn that the smaller the flow rate, the greater the error between the measured local resistance coefficient and the theoretical value. Based on the above conclusion, in practical experimental operations, the flow rate should be appropriately increased according to the experimental conditions to reduce experimental errors.
2. Combining experimental results, under the same conditions, compare the head loss coefficients for sudden expansion and sudden contraction as shown in the following formula:

$$K = \frac{\zeta_c}{\zeta_e} = \frac{0.5\times\left(1-\frac{A1}{A2}\right)}{(1-\frac{A1}{A2})^2} \tag{6}$$

For a pipeline with only one obstruction, water flowing in different directions can be used to study both sudden expansions and sudden contractions of local head losses. As below formula, when A1/A2 < 0.5 or d1/d2 < 0.707, the head loss in sudden expansion is greater than the corresponding contraction.

3. The local head loss coefficient is related to the velocity and abrupt changes in solid boundaries. Its coefficient should correspond to the selected flow condition. In practical applications, smooth streamline or rounded pipe interfaces should be chosen whenever possible. Secondly, when the boundary conditions of the pipeline need to be altered, gradual transition pipes should be used instead of abrupt ones to prevent boundary layer separation, reduce the formation of eddy zones, and consequently decrease the loss of local head.
4. The measured local head loss coefficients, under the same pipe diameter change conditions, correspond to the same flow rate. The value for sudden expansion is greater than that for sudden contraction. This is because the resistance effect of vortices is more significant than the wall effect, leading to more pronounced head losses.

The main sources of error come from errors generated during flow rate measurement and reading errors. Additionally, starting the reading without waiting for a stable flow rate when changing the flow rate can also lead to significant errors.

6 Further work

In the future, MATLAB SimHydraulics software can be used to simulate key flow components, allowing for a clearer and more precise analysis of head losses. This will effectively guide practical applications and design more efficient devices to reduce unnecessary losses.

Fluid mechanics has evolved over time through the ongoing struggle between humanity and nature, as well as in practical production. The aforementioned stages represent significant milestones in the development of fluid mechanics. [8-9] With the continuous advancement of science and technology, along with the growing focus on fluid mechanics research, the field is poised to continue evolving and achieving breakthroughs.[10]

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