

Pressure Drop Analysis in Designed Piping Installation for Laboratory Flow Capacity Testing

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Abstract— This study analyzes pressure drop and energy losses in a laboratory-scale piping system with various fittings using experimental and theoretical approaches. The measured flow rate was $0.000533 \text{ m}^3/\text{s}$ with an average velocity of 1.09 m/s indicating turbulent flow conditions. Theoretical calculations show major head loss of 0.48 m and minor head loss of 1.195 m , resulting in a total head loss of 1.68 m . Experimental results indicate total head loss of 1.103 m with a difference of 0.577 m (34.3%) compared to theoretical values. Minor losses dominate the system with a contribution of 71%, while major losses contribute 29%. The required hydraulic pump power is 8.78 W and shaft power is 12.54 W with 70% efficiency. The results demonstrate that fitting configuration significantly affects pressure drop and pump power requirements in piping systems.

Keywords— head loss, pressure drop, piping system, fittings, pump power.

I. INTRODUCTION

Pressure drop in piping systems occurs due to energy losses caused by friction along the pipe wall and local disturbances generated by fittings such as elbows, tees, and valves [1], [2]. These energy losses are generally classified into major losses due to pipe friction and minor losses caused by fittings and flow disturbances, both of which significantly influence the overall hydraulic performance of the system [3], [4]. The energy balance of fluid flow in piping installations can be described using Bernoulli's equation, which relates pressure, velocity, elevation, and head losses along the flow path [1]. Flow passing through fittings experiences separation and turbulence, resulting in additional local energy losses that contribute considerably to pressure drop in practical piping networks [5], [6]. Furthermore, head losses directly affect pump power requirements, since higher losses increase the energy needed to maintain the desired flow rate within the system [7]. Therefore, an accurate analysis of pressure drop and head loss characteristics is essential for evaluating the performance and efficiency of piping installations used in laboratory-scale fluid flow testing.

II. MATERIALS AND METHODS

A. Design of piping System

The piping installation used in this study was designed to analyze pressure drop and head loss caused by various fittings. The design consists of a network of PVC pipes with a nominal diameter of 1 inch, equipped with elbows, tees, ball valves, and a venturi meter. Several pressure measurement points were also included along the piping system to observe pressure distribution. The design layout of the piping installation is presented in Fig. 1.

B. Experimental Setup

The designed piping system was assembled and installed in the laboratory to perform experimental testing. The installation includes various fittings such as elbows, tees, ball valves, and a venturi meter to evaluate pressure drop and energy losses along

the piping network. Pressure measurement points were installed at several locations to obtain pressure data before and after fittings. The actual experimental setup used in this study is shown in Fig. 2.

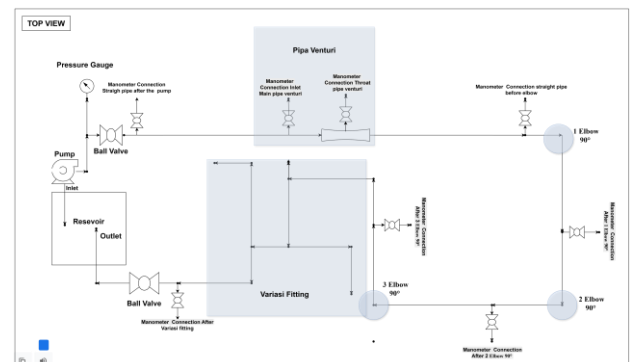


Fig. 1. Schematic of the laboratory piping installation.

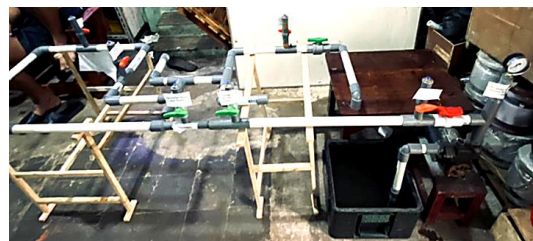


Fig. 2. Actual experimental setup of the designed piping installation with various fittings and pressure measurement points.

C. Research Procedure

The research procedure carried out in this study is illustrated in the flowchart shown in Fig. 3. The procedure begins with problem identification and literature review, followed by the design and preparation of the experimental piping system. Experimental testing is then conducted to obtain pressure and flow rate data at several measurement points.

The collected data are subsequently processed to determine flow characteristics and pressure drop across the piping system. Finally, the results are analyzed and discussed to evaluate the

effect of fitting variations on head loss and overall system performance.

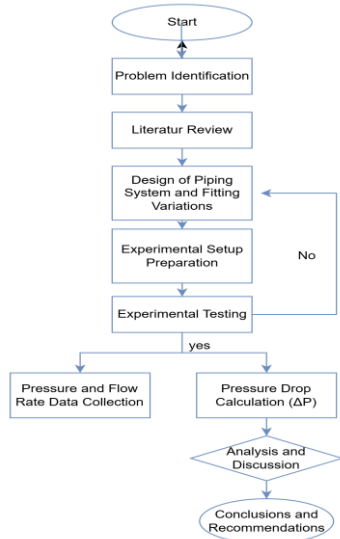


Fig. 3. Research flowchart for pressure drop and head loss analysis in the piping installation.

D. Flow Measurement

Flow measurement in this study was conducted using the volumetric method. The water flowing through the piping system was collected in a measuring container, and the time required to reach a certain volume was recorded. This method allows the direct determination of flow rate based on measured volume and time under steady flow conditions. The measured flow rate was then used as the basis for calculating other flow parameters required in the analysis.

E. Flow Parameters Calculation

The main flow parameters include flow rate, flow velocity, and Reynolds number, which are calculated to determine the flow characteristics and regime within the piping system.

The flow rate is calculated as:

$$Q = \frac{V}{t} \quad (1)$$

where Q is the volumetric flow rate (m^3/s), V is the collected fluid volume (m^3), and t is the measured filling time (s).

The flow velocity is obtained using the continuity equation:

$$V = \frac{Q}{A} \quad (2)$$

where V is the flow velocity (m/s) and A is the pipe cross-sectional area (m^2).

The Reynolds number is calculated to identify the flow regime:

$$Re = \frac{\rho V D}{\mu} \quad (3)$$

where Re is the Reynolds number, ρ is the fluid density (kg/m^3), V is the flow velocity (m/s), D is the pipe diameter (m), and μ is the dynamic viscosity (Pa·s).

F. Head Loss Calculation

The energy balance in the piping system is analyzed using Bernoulli's equation considering head loss due to friction and fittings:

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + h_{loss} \quad (4)$$

where P is pressure (Pa), ρ is fluid density (kg/m^3), V is velocity (m/s), g is gravitational acceleration (9.81 m/s^2), z is elevation head (m), and h_{loss} is the total head loss (m).

The major head loss due to pipe friction is calculated using the Darcy–Weisbach equation:

$$h_f = f \frac{L V^2}{D 2g} \quad (5)$$

where h_f is the major head loss (m), f is the Darcy friction factor, L is the pipe length (m), and D is the pipe diameter (m).

The friction factor f is determined using the Moody diagram based on the calculated Reynolds number and the relative roughness of the pipe material obtained from the pipe specifications. The Moody diagram used in this study is presented in Fig. 4

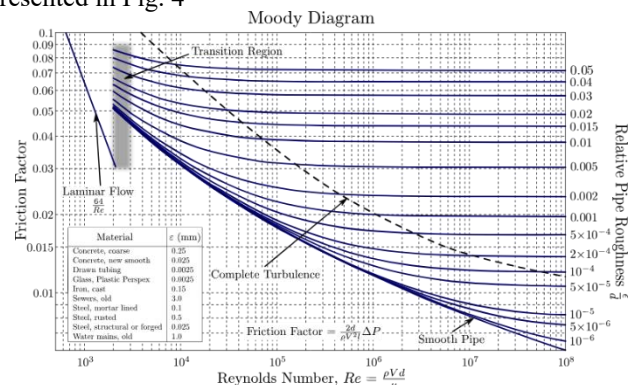


Fig. 4. Moody diagram used to determine the Darcy friction factor based on Reynolds number and relative roughness.

The use of the Moody diagram allows accurate estimation of friction losses for turbulent flow conditions in the piping system.

The minor head loss caused by fittings is calculated using:

$$h_m = K \frac{V^2}{2g} \quad (6)$$

where h_m is the minor head loss (m) and K is the loss coefficient for each fitting component.

G. Pump Power Calculation

The hydraulic power of the pump is calculated using:

$$P_h = \rho g Q H \quad (7)$$

where P_h is the hydraulic power (W), Q is the flow rate (m^3/s), and H is the total head of the system (m).

The shaft power of the pump is then determined by considering the pump efficiency:

$$P_{shaft} = \frac{P_h}{\eta} \quad (8)$$

where P_{shaft} is the pump shaft power (W) and η is the pump efficiency.

III. RESULTS AND DISCUSSION

A. Pressure Drop Analysis

Experimental measurements indicate that pressure decreases at each fitting component due to energy losses caused by flow disturbances. The pressure drop trend for each fitting is presented in Fig. 5.

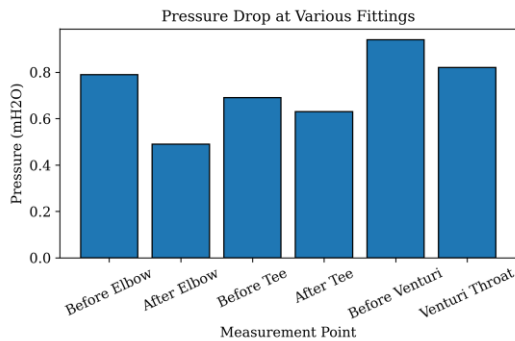


Fig. 5. Pressure drop at different fittings (elbow, tee, and venturi).

As shown in Fig. 5, significant pressure reduction occurs after elbow and tee components, indicating that flow direction changes and branching strongly influence energy losses in the piping system.

B. Major and Minor Head Loss

The theoretical calculation shows that the major head loss is 0.48 m, while the minor head loss is 1.195 m, resulting in a total head loss of 1.68 m.

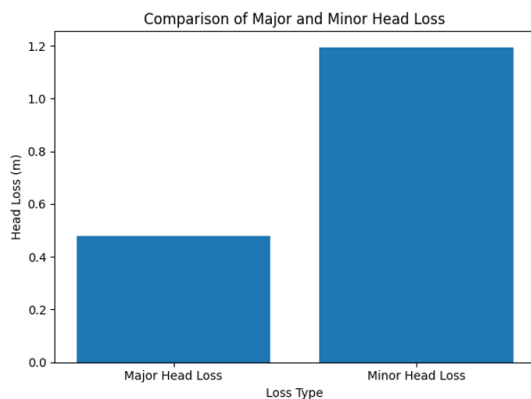


Fig. 6. Comparison of major and minor head losses in the piping system.

Fig. 6 clearly shows that minor losses contribute about 71% of the total head loss, while major losses contribute only 29%. This confirms that the number and type of fittings significantly affect pressure drop.

C. Bernoulli Equation Analysis

The comparison between theoretical and experimental head losses is illustrated in Fig. 7. The theoretical head loss is 1.68 m, while the experimental value is 1.103 m, resulting in a difference of 0.577 m or 34.3%.

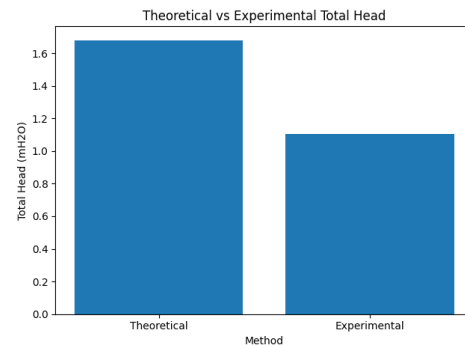


Fig. 7. Comparison between theoretical and experimental total head loss based on Bernoulli analysis.

As shown in Fig. 7, the discrepancy between theoretical and experimental results is caused by turbulence effects, measurement uncertainties, and assumptions in loss coefficient values obtained from literature references.

D. Pump Power Requirement

The required hydraulic power of the pump is calculated based on the total head and flow rate. The hydraulic power obtained from theoretical analysis is 8.78 W. Considering a pump efficiency of 70%, the shaft power required to operate the system is calculated to be 12.54 W.

These results indicate that the total head loss in the piping system directly affects the pump power requirement. Higher head losses caused by multiple fittings lead to increased energy demand, emphasizing the importance of optimizing piping design to reduce energy consumption.

E. Discussion on Dominance of Minor Losses

The experimental and theoretical analyses consistently show that minor head losses dominate the total energy loss in the piping system. This is primarily due to the presence of numerous fittings, including elbows, tees, and valves, which introduce flow separation and turbulence.

The findings demonstrate that, in laboratory-scale piping installations with complex fitting configurations, minor losses cannot be neglected and may significantly exceed friction losses in straight pipes. Therefore, accurate estimation of fitting loss coefficients and proper layout design are essential to improve system performance and reduce overall pressure drop.

IV. CONCLUSION

The study concludes that fitting variations significantly influence pressure drop in laboratory piping installations. Minor head loss dominates total energy loss with a contribution of 71%, while major head loss contributes 29%. The theoretical total head loss of 1.68 m differs from the experimental value of 1.103 m due to real flow conditions and turbulence effects. The required hydraulic pump power is 8.78 W and shaft power is 12.54 W, showing that higher head losses increase pump energy requirements. These results highlight the importance of optimizing fitting configuration to improve piping system efficiency.

REFERENCES

- [1] Y. A. Çengel and J. M. Cimbala, Fluid Mechanics: Fundamentals and

- Applications, 3rd ed. New York: McGraw-Hill, 2014.
- [2] R. W. Fox, A. T. McDonald, and P. J. Pritchard, Introduction to Fluid Mechanics, 8th ed. Hoboken, NJ: Wiley, 2015.
- [3] F. M. White, Fluid Mechanics, 7th ed. New York: McGraw-Hill, 2011.
- [4] B. R. Munson, D. F. Young, T. H. Okiishi, and W. W. Huebsch, Fundamentals of Fluid Mechanics, 7th ed. Hoboken, NJ: Wiley, 2013.
- [5] Crane Co., Flow of Fluids Through Valves, Fittings, and Pipe, Technical Paper No. 410, New York: Crane Co., 2018.
- [6] I. E. Idelchik, Handbook of Hydraulic Resistance, 3rd ed. Boca Raton: CRC Press, 1994.
- [7] A. J. Stepanoff, Centrifugal and Axial Flow Pumps: Theory, Design, and Application. New York: Wiley, 1993.