Pipe Flow Analysis: Darcy-Weisbach and Friction Factors

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Abstract

This report presents computational analysis of pipe flow using the Darcy-Weisbach equation. We examine Reynolds number regimes, friction factor correlations including the Colebrook-White equation, the Moody diagram, minor losses, and pipe network analysis. Python-based computations provide quantitative analysis with dynamic visualization.

Contents

1 Introduction to Pipe Flow

Internal flow through pipes is fundamental to hydraulic system design. Key applications include:

- Water distribution networks
- Oil and gas pipelines
- HVAC systems
- Process piping in chemical plants

2 Fundamental Equations

2.1 Reynolds Number

The Reynolds number characterizes flow regime:

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

where ρ is density, V is velocity, D is diameter, and μ is dynamic viscosity.

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Figure 1: Flow regime classification based on Reynolds number.

2.2 Darcy-Weisbach Equation

Head loss in pipe flow:

$$h_f = f \frac{L}{D} \frac{V^2}{2g} \tag{2}$$

or in terms of pressure drop:

$$\Delta P = f \frac{L}{D} \frac{\rho V^2}{2} \tag{3}$$

3 Friction Factor Correlations

3.1 Laminar Flow

For laminar flow ($Re < 2300$):

$$f = \frac{64}{Re} \tag{4}$$

3.2 Turbulent Flow - Colebrook-White Equation

For turbulent flow:

$$\frac{1}{\sqrt{f}} = -2 \log_{10} \left(\frac{\epsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}} \right) \tag{5}$$

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Figure 2: Moody diagram showing friction factor vs Reynolds number for various relative roughness values.

4 Pipe Flow Analysis

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Figure 3: Pipe flow analysis showing velocity, Reynolds number, pressure drop, and system curve.

4.1 Design Point Results

For a design flow rate of $Q = 20$ L/s:

Table 1: Pipe Flow Design Calculations

Parameter	Value	Units
Velocity	**??**	m/s
Reynolds number	**??**	–
Friction factor	**??**	–
Pressure drop	**??**	kPa
Head loss	**??**	m

5 Minor Losses

Minor (local) losses from fittings and valves:

$$h_m = K\frac{V^2}{2g} \tag{6}$$

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Figure 4: Minor loss coefficients and system head loss breakdown.

Total minor losses: $h_m =$ **??** m

6 Pipe Diameter Effect

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Figure 5: Effect of pipe diameter on pressure drop and velocity for constant flow rate.

7 Pipe Network Analysis

7.1 Pipes in Series

For pipes in series, flow rate is constant and head losses add:

$$h_{f,total} = \sum_{i=1}^{n} h_{f,i} \tag{7}$$

7.2 Pipes in Parallel

For pipes in parallel, head loss is equal and flow rates add:

$$Q_{total} = \sum_{i=1}^{n} Q_i \quad \text{with} \quad h_{f,1} = h_{f,2} = \cdots \tag{8}$$

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Figure 6: Parallel pipe analysis showing system curves and flow distribution.

8 Pump Selection

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Figure 7: Pump selection showing operating point and performance characteristics.

Pump power required: $P =$ **??** kW (at $\eta =$ **??**%)

9 Conclusions

This analysis demonstrates key aspects of pipe flow:

1. The Darcy-Weisbach equation provides accurate head loss predictions
2. Friction factors depend on both Reynolds number and relative roughness
3. The Moody diagram visualizes friction factor correlations
4. Minor losses from fittings can be significant in short pipe runs
5. Pipe diameter has a strong effect on pressure drop (varies as D^{-5} for constant Q)
6. Parallel pipe analysis requires iterative solution for flow distribution
7. Pump operating point is determined by intersection of system and pump curves