Chapter 3 (Cont.): Water Flow in Pipe Systems

Review - Key Hydraulic Equations (1 of 2)

Review from the last two classes.

Mean Velocity: $V = \frac{Q}{A}$

Continuity: $A_1(V_1) = A_2(V_2)$

Momentum: $\sum F = \rho Q(V_2 - V_1)$ (or Impulse-Momentum)

Bernoulli: $h_1 + \frac{p_1}{\gamma} + \frac{v_1^2}{2g} = h_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2g}$

Energy: $h_1 + \frac{p_1}{\gamma} + \frac{v_1^2}{2g} = h_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + h_L$

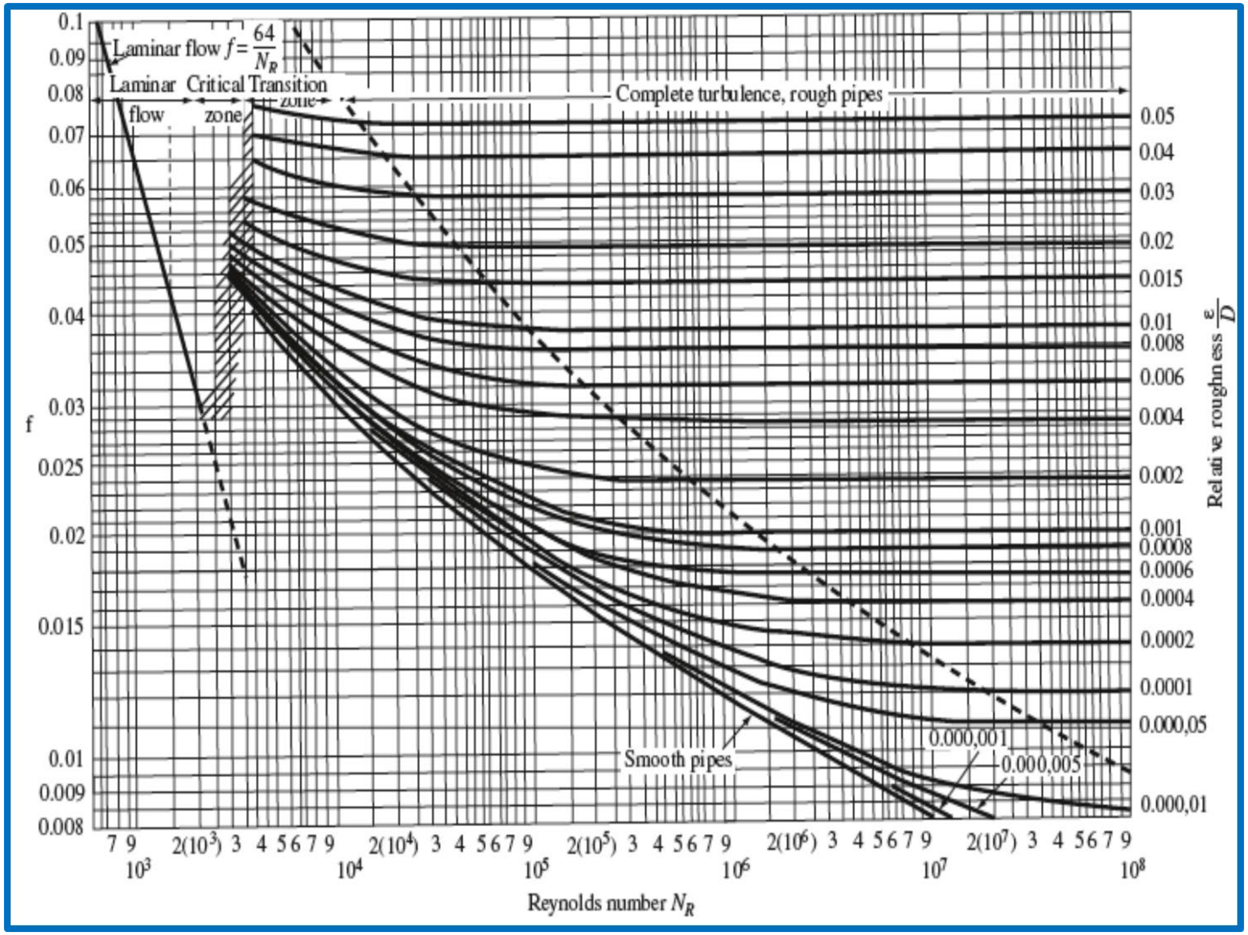
Review - Key Hydraulic Equations (2 of 2)

Darcy-Weisbach: $h_f = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right) \rightarrow \text{f: Moody Diagram}^*$

You can solve most pipe flow problems with these equation's!

*Note: $\frac{e}{D} = \text{relative roughness;} \qquad N_R = \frac{(DV\rho)}{\mu} = \frac{(VD)}{\nu}$

Friction Factors for Flow in Pipes: The Moody Diagram



Friction Factors for Various Types of Flows (Review)

The Darcy-Weisbach Equation

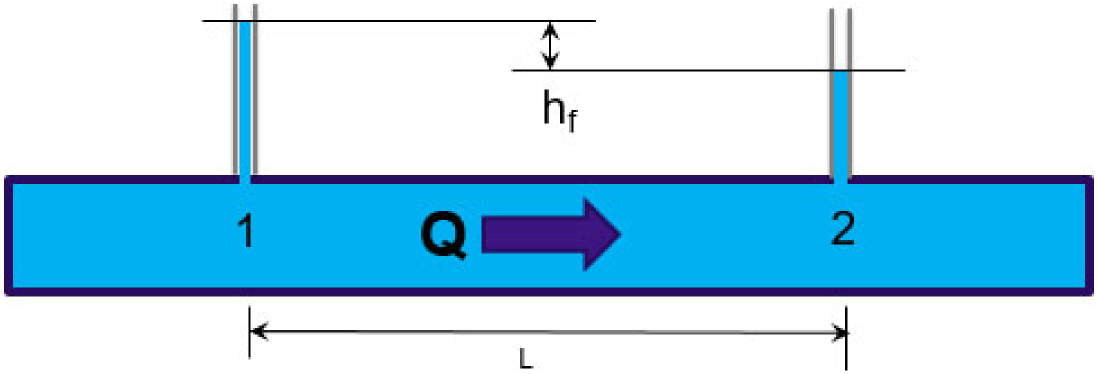
$$h_f = f\left(L/D\right)\left(V^2/2g\right)$$

Determination of the Friction Factor

- Laminar Flow: $"f"$ requires N_R
- Turbulent Flow: $"f"$ requires N_R and $\left(e/D\right)$
- Complete Turbulence: $"f"$ requires $\left(e/D\right)$
- Turb. (smooth pipe): $"f"$ requires N_R

Other Friction Loss Formulas

- Background: Popular formulas based on experiments.
- Empirical formulas - not dimensionally consistent (must use units established for formulas in experiments).
- Applicable only to conditions and ranges of experiments.



What are the vertical tubes? What do they measure? Sketch the HGL.

Manning's Equation

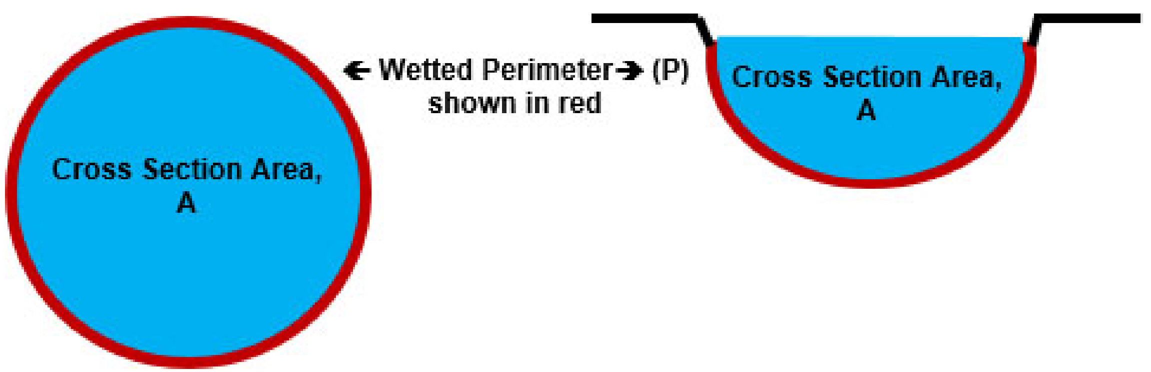
$$V = \left(\frac{1.49}{n}\right) R_h^{2/3} S^{1/2}$$

Define the variables? $R_h = \dfrac{A}{P}$ Where is h_f ?

Is the equation dimensionally consistent?

n → Table 3.3 see Slide 13 based on pipe material.

("n" is between 0.01 and 0.025 for most pipes)



Note: This equation is often used for open channel flow.

Table 3.3 Manning's Roughness Coefficient, *n*, for Pipe Flows

Type of Pipe	Manning's *n* Min.	Manning's *n* Max.
Brass	0.009	0.013
Cast iron	0.011	0.015
Cement mortar surfaces	0.011	0.015
Cement rubble surfaces	0.017	0.030
Concrete, precast	0.011	0.015
Copper	0.009	0.013
Corrugated metal (CMP)	0.020	0.024
Ductile iron (cement mortar lined)	0.011	0.013
Glass	0.009	0.013
High-density polyethylene (HDPE)	0.009	0.011
Polyvinyl chloride (PVC)	0.009	0.011
Steel, commercial	0.010	0.012
Steel, riveted	0.017	0.020
Vitrified sewer pipe	0.010	0.017
Wrought iron	0.012	0.017

The Hazen-Williams Formula

$$V = 1.318\, C_{HW} R_h^{0.63} S^{0.54}$$

Define the variables. Where is h_f ? Units?
$C_{HW} \rightarrow$ Table 3.2 see Slide 15 based on pipe material (usually between 100 and 150 except very old pipes !)

Pipe cleaning and lining projects will increase pipe flow and pressure.

Homework Problems:

Pipe Tuberculation and Lining

http://www.ci.wilmington.de.us

Table 3.2 Hazen–Williams Coefficient, CH_W, for Different Types of Pipes

Pipe Materials	CH_W
Brass	130–140
Cast iron (common in older water lines)	
New, unlined	130
10-year-old	107–113
20-year-old	89–100
30-year-old	75–90
40-year-old	64–83
Concrete or concrete lined	
Smooth	140
Average	120
Rough	100
Copper	130–140
Ductile iron (cement mortar lined)	140

Pipe Materials	CH_W
Glass	140
High-density polyethylene (HDPE)	150
Plastic	130–150
Polyvinyl chloride (P V C)	150
Steel	
Commercial	140–150
Riveted	90–110
Welded (seamless)	100
Vitrified clay	110

Pipe Flow: Circular Culvert

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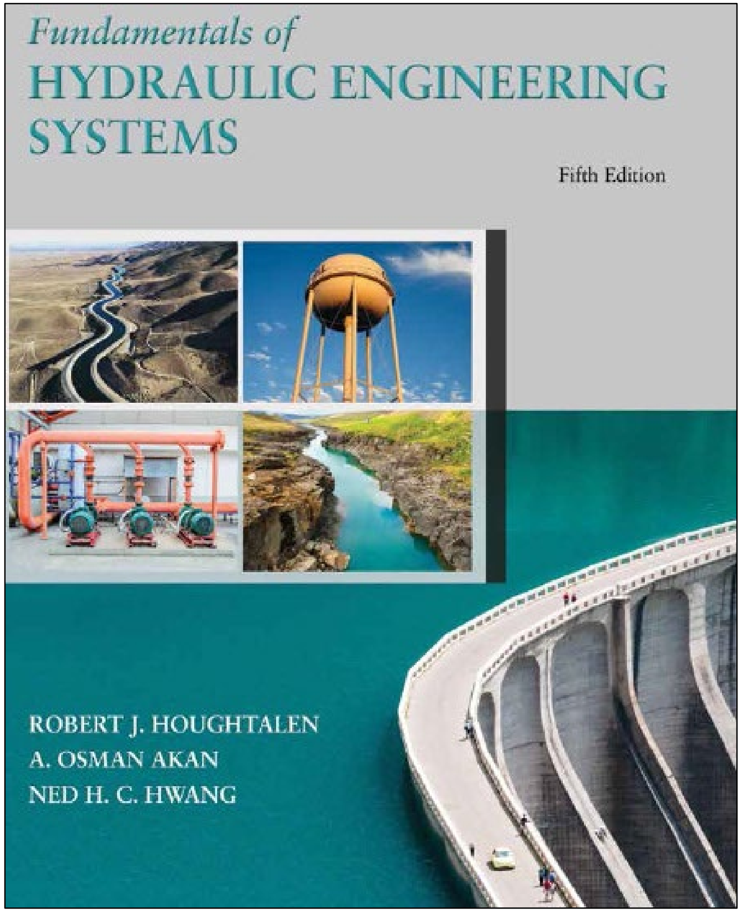
Fundamentals of Hydraulic Engineering Systems

Fifth Edition



Chapter 3d

Water Flow in Pipes

Pearson

In-Class Siphon Experiment (1 of 4)

Bernoulli's Equation

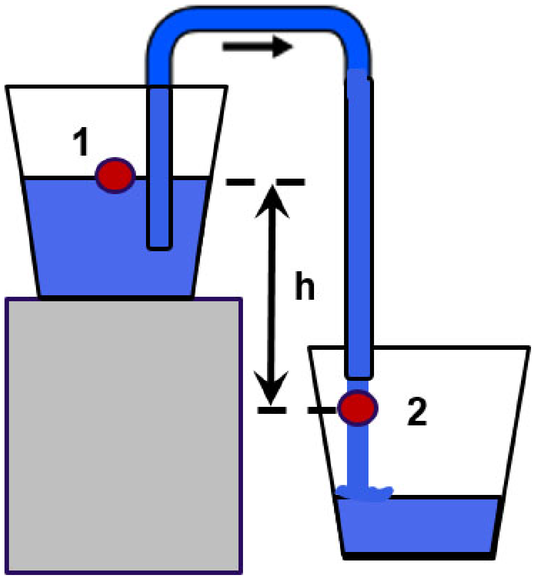
Let's test the validity of the Bernoulli Equation.

Does $\mathbf{Q_B\,(Bernoulli) = Q_m\,(measured)}$?

Questions:

1. How would we obtain the experimental flow rate?

$$\mathbf{Q = \frac{Volume}{time}}$$



In-Class Siphon Experiment

Bernoulli's Equation

2. How would we obtain the Bernoulli flow rate?

   Energy balance between 2 points

3. What 2 points to find Q? Resulting eq'n? Data needed?

$$h_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} = h_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g} \rightarrow h_1 - h_2 = h = \frac{V_2^2}{2g}$$

Pearson

In-Class Siphon Experiment (3 of 4)

Perform the experiment and compare results.

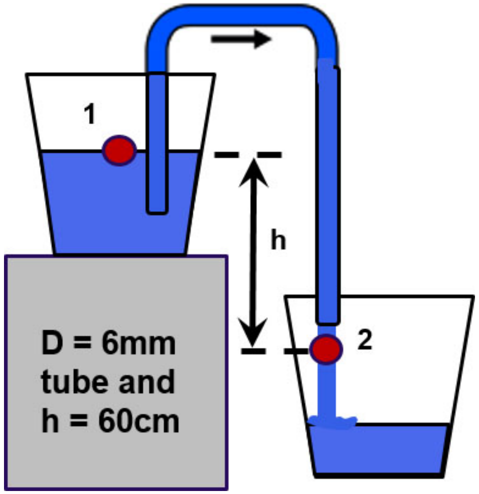
Does $Q_B\left(\text{Bernoulli}\right) = Q_m\left(\text{measured}\right)$?

$$Q_m = \frac{2 \text{ litres}}{\left(75 \sec\right)} = 0.0267 \text{ L/s}$$

Bernoulli Calculations:

$$h = 0.6 \text{ m} = \frac{V^2}{2g}; V = 3.43 \text{ m/sec};$$

$$Q_B = V.A = \mathbf{0.0970 \text{ L/sec}}$$



Why don't the flow rates compare closely? Perform the calculations a second time with the modifications* you think are necessary.

*Include friction loss in the analysis.

In-Class Siphon Experiment (4 of 4)

Energy Equation Calculations:

$$h = \frac{V^2}{2g} + \frac{f(L/D)V^2}{2g} = \frac{V^2}{2g}\left[1 + f\left(L/D\right)\right]$$

Moody Diagram for f (next slide):

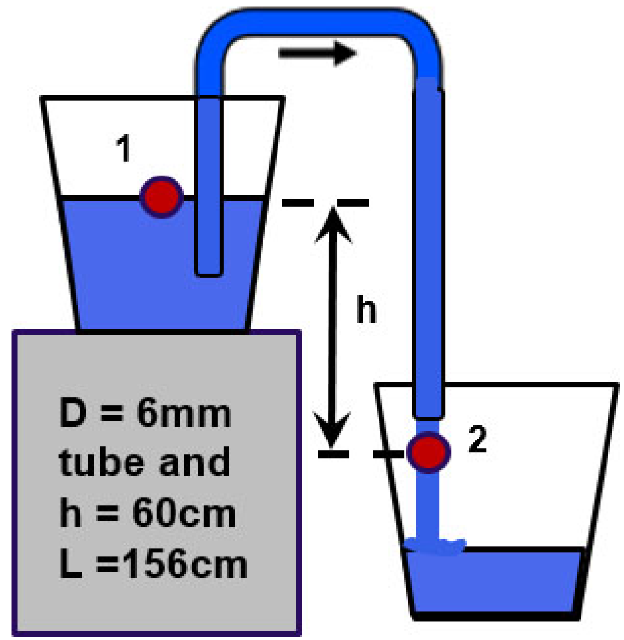
$$\frac{e}{D} = \frac{0.0015}{6} = 0.00025; \text{ w/measured}$$

$$V \rightarrow N_R = \frac{0.863(0.006)}{1 \times 10^{-6}} = 5,200$$

$$h = 0.6 = \frac{V^2}{2g[1 + \underline{0.038}(1.56/0.006)]}$$

$$V = 1.05\ m/s; \ Q_m = AV = 0.0297\ L/s$$

* Include entrance loss: Q = 0.0281.



Better!! Can we improve the results?

Pipe Flow Problems (Iterative Solution)

Example Problems – Solve on White Board

Determine the flow rate (L/sec) in a 4-cm-diameter copper pipe. The pressure at point A is 210 kPa, and the pressure at point B is 180 kPa. The elevation at A is 90 cm higher than point B and the two points are separated by 91.9 meters of pipeline. Assume no minor losses and water @ 10° C.

Solution:

$\gamma = 9800\ \text{N/m}^3;\ \nu = 1.306 \times 10^{-6}\ \text{m}^2/\text{sec};\ e = 0.0015\ \text{mm};\ h_L = h_f = 3.96\ \text{m};$

$\text{Final } f = 0.022;\ V = 1.24\ \text{m/sec};\ Q = 1.56\ \text{L/sec}$