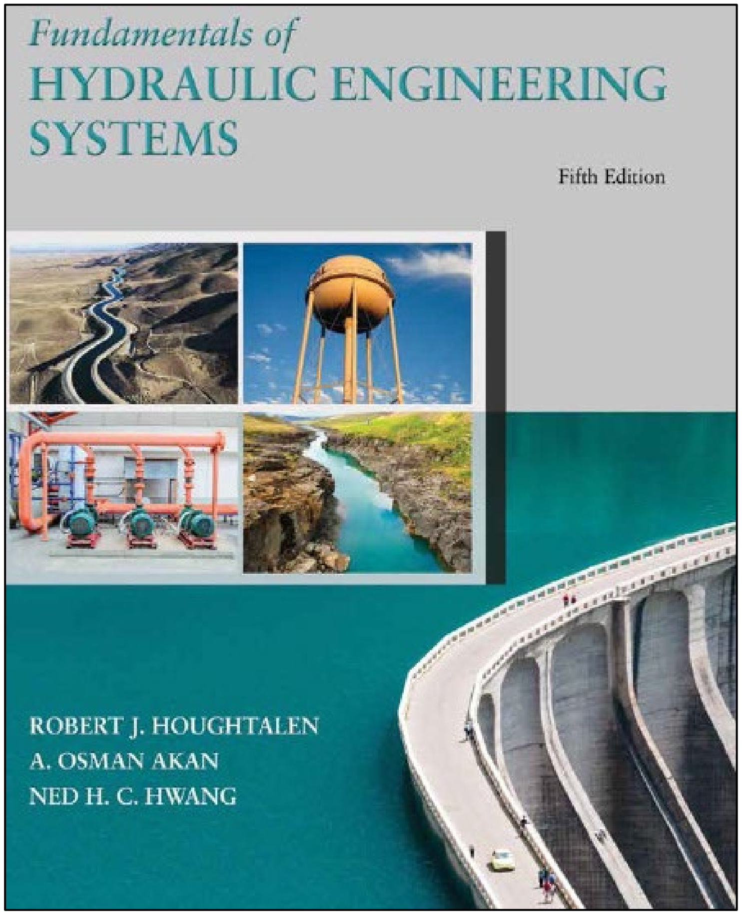
Fundamentals of Hydraulic Engineering Systems

Fifth Edition



Chapter 4a

Pipelines and Pipe Networks

Learning Objectives

4.1 Explain the hydraulic principles used to analyze and design **pipelines connecting two reservoirs**.

4.2 Describe the **negative pressure scenarios** that can occur in pipelines and pumps.

4.3 Understand **branching pipe system** analysis.

4.4 Define the hydraulic concepts used to evaluate the flow in complex **pipe networks**.

4.5 Describe **water hammer** phenomena in pipelines and the available solution methodologies.

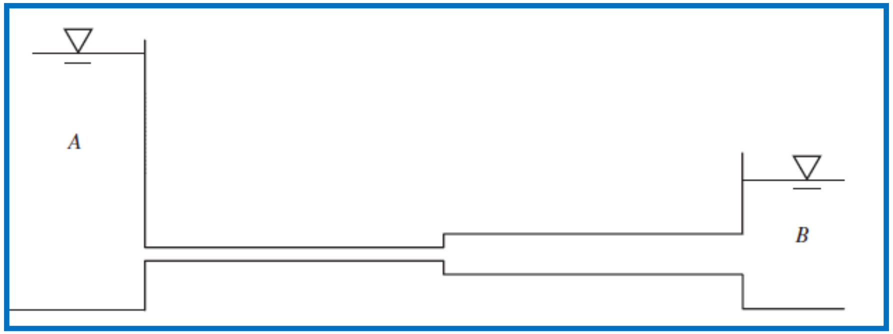
4.6 Calculate solutions to various pipeline and pipe network problems that involve these concepts.

Definitions and Concepts (1 of 2)

Pipe Systems, Pipelines, and Pipe Networks

Pipe Systems: An arrangement of interconnecting pipes in series, parallel, or branches to transport fluids.
Pipelines: a pipe system in a series configuration.
Pipe Networks: a pipe system other than a pipeline

The Two Reservoir Problem: (See the figure below.)
Q: How do you determine the head loss? **Energy Equation**
Q: Between what 2 points? **The two water surfaces.**



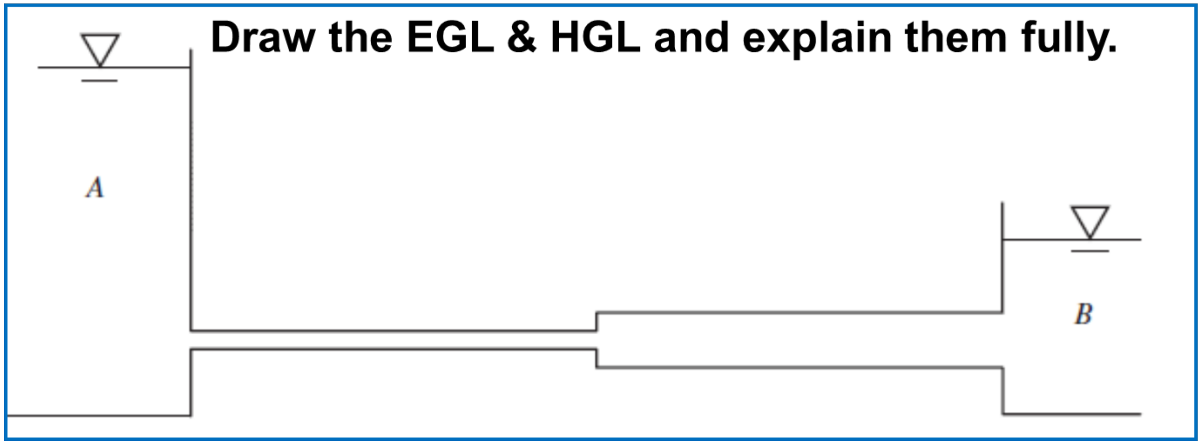
Definitions and Concepts (2 of 2)

Pipelines Connecting Two Reservoirs

The Two Reservoir Problem: (See the figure below.)

Q: Write out the equation that results from balancing energy between the two reservoir (water) surfaces.

$$h_A - h_B = h_L = \sum f\left(\frac{L}{D}\right)\frac{V^2}{2g} + \sum K\left(\frac{V^2}{2g}\right)$$

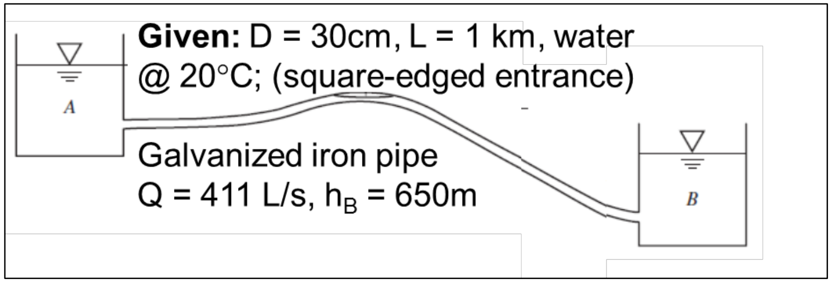


Two Reservoir Example Problem (1 of 4)

Find the head loss given pipe size, material, and flow rate.

Determine the water surface elevation in reservoir “A.”

Energy Equation: $h_A - h_B = h_L$



$$h_L = h_e + h_f + h_d$$

$$h_L = [f\left(\frac{L}{D}\right) + \sum K]\left(\frac{V^2}{2g}\right)$$

$$V = \frac{Q}{A} = 5.81 \text{ m/s};\ N_R = \frac{(5.81*0.3)}{0.000001} = 1.74 * 10^6$$

$$\frac{\varepsilon}{D} = \frac{0.15}{300} = 5.0 \times 10^{-4};\ f = 0.017;\ \text{now substituting}$$

$$h_L = \left[0.017\left(\frac{1000}{0.30}\right) + 0.5 + 1.0\right]\left(\frac{5.81^2}{2g}\right) = 100\text{m}$$

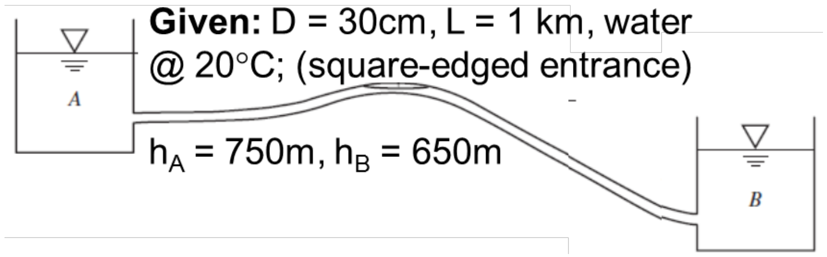
Therefore, $h_A = h_B + h_L = 650 + 100 = 750\text{m}$

Pearson

Two Reservoir Example Problem (2 of 4)

Find the flow rate given pipe size, material, and head loss.

Determine the flow rate in the galvanized iron pipe.



$$h_A - h_B = 100\text{m} = h_L$$

$$h_L = h_e + h_f + h_d$$

$$h_L = [f\left(\frac{L}{D}\right) + \sum K]\left(\frac{V^2}{2g}\right)$$

Assume complete turbulence; $\frac{\varepsilon}{D} = \frac{0.15}{300} = 5.0 \times 10^{-4}$;

$$f = 0.017;\ h_L = 100 = \left[0.017\left(\frac{1000}{0.30}\right) + 0.5 + 1.0\right]\left(\frac{V^2}{2g}\right)$$

$$V = 5.81\ \text{m/s; thus } N_R = \frac{(5.81*0.3)}{0.000001} = 1.74 * 10^6$$

Check f = 0.017; (ok); Therefore, Q = VA = 0.411 m^3/s

Two Reservoir Example Problem (3 of 4)

Find the pipe size given material, flow rate, and head loss.

Determine the galvanized iron pipe size required.

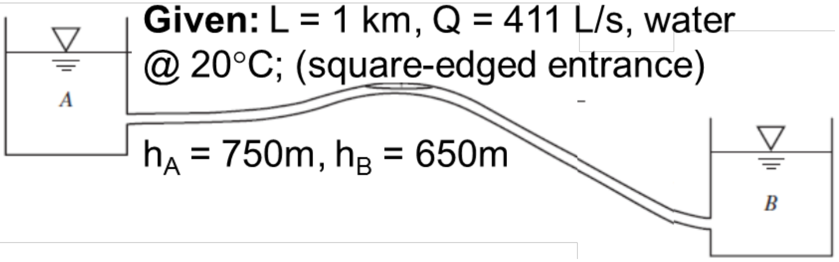
$$h_A - h_B = 100\text{m} = h_L$$

$$h_L = h_e + h_f + h_d$$

$$h_L = [f\left(\frac{L}{D}\right) + \sum K]\left(\frac{V^2}{2g}\right)$$

Given: L = 1 km, Q = 411 L/s, water @ 20°C; (square-edged entrance)

h_A = 750m, h_B = 650m



$$\text{But, } V = \frac{Q}{A} = \frac{0.523}{D^2}; \text{ and if } \frac{L}{D} \gg 1000, \text{ ignore} \sum K:$$

$$h_L = 100 = f\left(\frac{1000}{D}\right)\left[\frac{(0.523)^2}{2gD^4}\right]; \text{ or } 7.17 = \frac{f}{D^5};$$

$$\frac{\varepsilon}{D} = \frac{0.15\text{mm}}{D}; N_R = \frac{DV}{\nu} = \frac{D(0.523/D^2)}{0.000001} = \frac{5.23\times10^5}{D}$$

$$\text{Assume } D = 0.5\text{m}; \frac{\varepsilon}{D} = 3.00\times10^{-4}; N_R = 1.05\times10^6; f = 0.016$$

Two Reservoir Example Problem (4 of 4)

Substituting (energy equation): $7.17 = \frac{0.016}{D^5}$; $D = 0.295m$

Continue iterations with D = 0.3 as your next trial diameter.

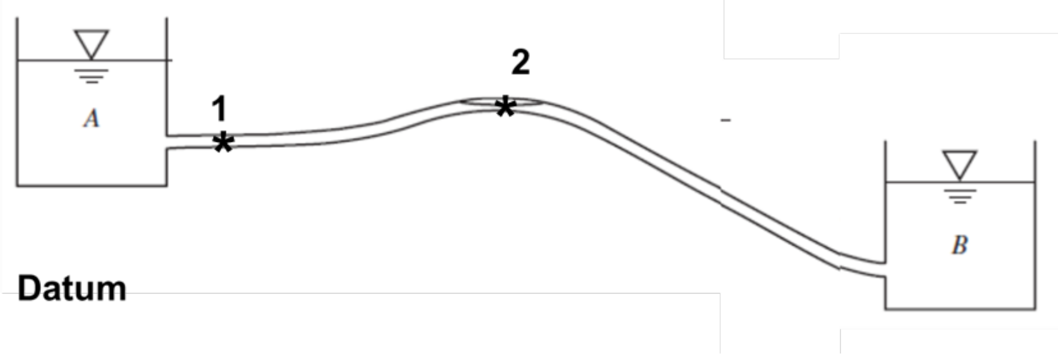
Pipelines with Negative Pressure

When does pressure becomes sub-atmospheric?

Exercise 1: Draw the EGL and HGL for the pipeline below.
Exercise 2: Given the datum, draw and identify the three forms of energy at point 1. Repeat for point 2.

$$H_1 = h_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} \qquad H_2 = h_2 - \frac{P_2}{\gamma} + \frac{V_2^2}{2g}$$

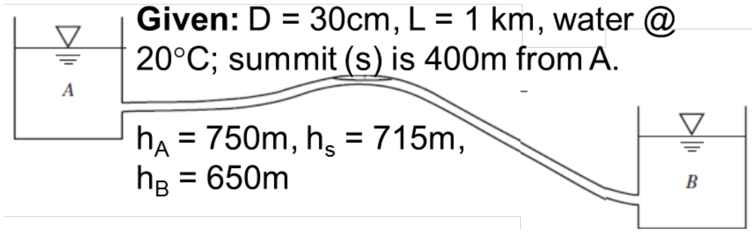
Q: What can you say about the pressure head at point 2?
Q: When is this scenario likely to happen?
Pipelines going over hills and the suction side of pumps.



Negative Pressure Example (1 of 2)

Determine the pressure head at the summit of the pipeline.

Balance energy: A to B Found $Q=411$ L/s. **Next?**



$$h_A = h_s + \frac{P_s}{\gamma} + \frac{V^2}{2g} + h_L$$

$$750 = 715 + \frac{P_s}{\gamma} + \frac{V^2}{2g} + \left[f\left(\frac{400}{0.3}\right) + 0.5 \right]\left(\frac{V^2}{2g}\right)$$

$$\text{But, } V = 5.81 \text{ m/s; } \frac{\varepsilon}{D} = 5.0 \times 10^{-4}\text{; } N_R = \frac{DV}{\nu} = 1.74 \times 10^6\text{; } f = 0.017$$

$$750 = 715 + \frac{P_s}{\gamma} + \left[1 + 0.017\left(\frac{400}{0.3}\right) + 0.5 \right]\frac{(5.81)^2}{2g}$$

Negative Pressure Example (2 of 2)

$\frac{P_s}{\gamma} = -6.6\text{m};$ Note: When the pressure falls below vapor pressure, vapor pockets form and implode downstream (higher pressure) causing vibration and pitting. A typical design limit is about -7m (two thirds vapor pressure, ≈ -10.1 m).

Homework Problems:

Pipeline Construction - Central Arizona Project

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