- The balance for a CV is (Energy changes in the CV) = (Energy increases in the CV due to heat transfer) − (Energy out of CV via work done on the surrounding) + (Energy transported into the CV by fluid flow)
- Work can be classified into two categories
  - *Flow work* is work that is done by the pressure force in a flowing fluid
  - *Shaft work* is any work that is not flow work.

The Energy Equation

- The energy equation is the law of conservation of energy simplified so that it applies to common situations that occur in fluid mechanics. Some of the most important assumptions are steady state, one inflow and one outflow port to the CV, constant density, and all thermal energy terms (except for head loss) are neglected.
- The energy equation describes an energy balance for a control volume (CV).

$$\text{(energy into CV)} = \text{(energy out of CV)}$$
$$\text{(energy into CV by flow and pumps)} = \text{(energy out by flow, turbines, and head loss)}$$

- The energy equation, using math symbols, is

$$\left(\frac{p_1}{\gamma} + \alpha_1\frac{V_1^2}{2g} + z_1\right) + h_p = \left(\frac{p_2}{\gamma} + \alpha_2\frac{V_2^2}{2g} + z_2\right) + h_t + h_L$$

$$\begin{pmatrix}\text{pressure head}\\ \text{velocity head}\\ \text{elevation head}\end{pmatrix}_1 + \begin{pmatrix}\text{pump}\\ \text{head}\end{pmatrix} = \begin{pmatrix}\text{pressure head}\\ \text{velocity head}\\ \text{elevation head}\end{pmatrix}_2 + \begin{pmatrix}\text{turbine}\\ \text{head}\end{pmatrix} + \begin{pmatrix}\text{head}\\ \text{loss}\end{pmatrix}$$

- Regarding head
  - Head can be thought of as the ratio of energy to weight for a fluid particle.
  - Head can also describe the energy per time that is passing across a section because head and power are related by $P = \dot{m}gh$
- Regarding head loss (h_L)
  - Head loss represents an irreversible conversion of mechanical energy to thermal energy through the action of viscosity.
  - Head loss is always positive and is analogous to frictional heating.
  - Head loss for a sudden expansion is given by

$$h_L = \frac{(V_1 - V_2)^2}{2g}$$

- Regarding the kinetic energy correction factor α
  - This factor accounts for the distribution of kinetic energy in a flowing fluid. It is defined as the ratio of (actual KE/time that crosses a surface) to (KE/time that would cross if the velocity was uniform).
  - For most situations, engineers set $\alpha = 1$. If the flow is known to be fully developed and laminar, then engineers use $\alpha = 2$. In other cases, one can go back to the mathematical definition and calculate a value of α.

Power and Mechanical Efficiency

- Mechanical efficiency is the ratio of (power output) to (power input) for a machine or system.
- There are several equations that engineers use to calculate power.
  - For translational motion such as a car or an airplane $P = FV$
  - For rotational motion such as the shaft on a pump $P = T\omega$
  - For the pump, the power added to the flow is: $P = \gamma Q h_p$
  - For a turbine, the power extracted from the flow is $P = \gamma Q h_t$

The HGL and EGL

- The hydraulic grade line (HGL) is a profile of the piezometric head, $p/\gamma + z$, along a pipe.
- The energy grade line (EGL) is a profile of the total head, $V^2/2g + p/\gamma + z$, along a pipe.
- If the hydraulic grade line falls below the elevation of a pipe, subatmospheric pressure exists in the pipe at that location, giving rise to the possibility of cavitation.

REFERENCES

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2. "James Prescott Joule (1818–1889): A Manchester Son and the Father of the International Unit of Energy," Winhoven, S.H. & Gibbs, N.K., accessed on 1/23/11, http://www.bad.org.uk/Portals/_Bad/History/Historical%20poster%2006.pdf

3. Cengel, Y. A., and M. A. Boles. *Thermodynamics: An Engineering Approach*. New York: McGraw-Hill, 1998.

4. Moran, M. J., and H. N. Shapiro. *Fundamentals of Engineering Thermodynamics*. New York: John Wiley, 1992.

PROBLEMS

PLUS Problem available in *WileyPLUS* at instructor's discretion.

GO Guided Online (GO) Problem, available in *WileyPLUS* at instructor's discretion.

Energy Concepts (§7.1)

7.1 From the list below, select one topic that is interesting to you. Then, use references such as the Internet to research your topic and prepare one page of documentation that you could use to present your topic to your peers.

a. Explain how hydroelectric power is produced.

b. Explain how a Kaplan turbine works, how a Francis turbine works, and the differences between these two types of turbines.

c. Explain how a horizontal-axis wind turbine is used to produce electrical power.

d. Explain how a steam turbine is used to produce electrical power.

7.2 PLUS Using Section 7.1 and other resources, answer the following questions. Strive for depth, clarity, and accuracy. Also, strive for effective use of sketches, words, and equations.

a. What are the common forms of energy? Which of these forms are relevant to fluid mechanics?

b. What is work? Describe three example of work that are relevant to fluid mechanics.

c. List three significant differences between power and energy.

7.3 WILEY PLUS Apply the grid method to each situation.

a. Calculate the energy in joules used by a 746 W pump that is operating for 6 hours. Also, calculate the cost of electricity for this time period. Assume that electricity costs \$0.15 per kW-hr.

b. A motor is being to used to turn the shaft of a centrifugal pump. Apply Eq. (7.3b) on p. 255 of §7.2 to calculate the power in watts corresponding to a torque of 11 N • m and a rotation speed of 89.3 rad/s.

c. A turbine produces a power of 10.2 kW. Calculate the power in hp.

7.4 WILEY PLUS Energy (select all that are correct):

a. has same units as work

b. has same units as power

c. has same units work/time

d. can have units of Joule

e. can have units of Watt

7.5 WILEY PLUS Power (select all that are correct)

a. has same units as energy

b. has same units as energy/time

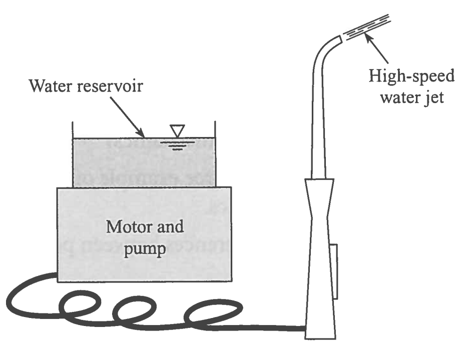
c. has same units as work/time

d. can have units of Joule

e. can have units of Watt

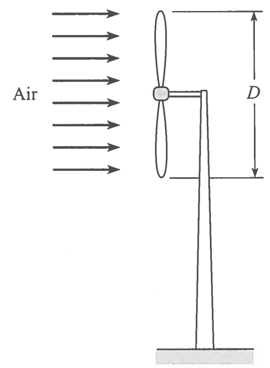
7.6 Estimate the power required to spray water out of the spray bottle that is pictured in Fig. 7.2a on p. 254 of §7.2. *Hint:* Make appropriate assumptions about the number of sprays per unit time and the force exerted by the finger.

7.7 WILEY PLUS The sketch shows a common consumer product called the Water Pik. This device uses a motor to drive a piston pump that produces a jet of water (d = 1 mm, T = 10°C) with a speed of 27 m/s. Estimate the minimum electrical power in watts that is required by the device. *Hints:* (a) Assume that the power is used only to produce the kinetic energy of the water in the jet; and (b) in a time interval Δt, the amount of mass that flows out the nozzle is Δm, and the corresponding amount of kinetic energy is $(\Delta m V^2/2)$.



PROBLEM 7.7

7.8 An engineer is considering the development of a small wind turbine (D = 1.25 m) for home applications. The design wind speed is 24 km/hr at T = 10°C and p = 90 kPa. The efficiency of the turbine is η = 20%, meaning that 20% of the kinetic energy in the wind can be extracted. Estimate the power in watts that can be produced by the turbine. *Hint:* In a time interval Δt, the amount of mass that flows through the rotor is $\Delta m = \dot{m}\Delta t$, and the corresponding amount of kinetic energy in this flow is $(\Delta m V^2/2)$.



PROBLEM 7.8

Conservation of Energy (§7.2)

7.9 WILEY PLUS The first law of thermodynamics for a closed system can be characterized in words as

a. (change in energy in a system) = (thermal energy in) − (work done on surroundings)

b. (change in energy in a system) = (thermal energy out) − (work done by surroundings)

c. either of the above

7.10 WILEY PLUS The application of Reynolds transport theorem to the first law of thermodynamics (select all that are correct)

a. refers to the increase of energy stored in a closed system

b. extends the applicability of the first law from a closed system to an open system (control volume)

c. refers only to heat transfer, and not to work

The Kinetic Energy Correction Factor (§7.3)

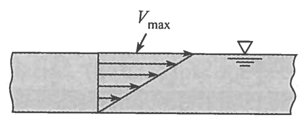
7.11 WILEY PLUS Using Section 7.3 and other resources, answer the questions below. Strive for depth, clarity, and accuracy while also combining sketches, words, and equations in ways that enhance the effectiveness of your communication.

a. What is the kinetic-energy correction factor? Why do engineers use this term?

b. What is the meaning of each variable (α, A, V, $\bar{V}$) that appears in Eq. (7.21) on p. 260 of §7.3?

c. What values of α are commonly used?

7.12 For this hypothetical velocity distribution in a wide rectangular channel, evaluate the kinetic-energy correction factor α.

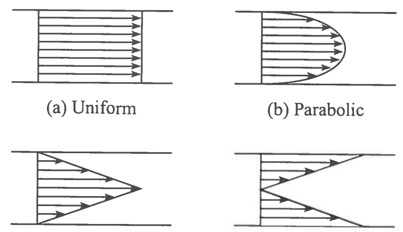


PROBLEM 7.12

7.13 WILEY PLUS For these velocity distributions in a round pipe, indicate whether the kinetic-energy correction factor α is greater than, equal to, or less than unity.

7.14 Calculate α for case (*c*).

7.15 Calculate α for case (*d*).



(a) Uniform (b) Parabolic

(c) Linear (d) Linear

PROBLEMS 7.13, 7.14, 7.15

7.16 An approximate equation for the velocity distribution in a pipe with turbulent flow is

$$\frac{V}{V_{max}} = \left(\frac{y}{r_0}\right)^n$$

where V_{max} is the centerline velocity, y is the distance from the wall of the pipe, r_0 is the radius of the pipe, and n is an exponent that depends on the Reynolds number and varies between 1/6 and 1/8 for most applications. Derive a formula for α as a function of n. What is α if n = 1/7?

7.17 An approximate equation for the velocity distribution in a rectangular channel with turbulent flow is

$$\frac{u}{u_{max}} = \left(\frac{y}{d}\right)^n$$

where u_{max} is the velocity at the surface, y is the distance from the floor of the channel, d is the depth of flow, and n is an exponent that varies from about 1/6 to 1/8 depending on the Reynolds number. Derive a formula for α as a function of n. What is the value of α for n = 1/7?

7.18 The following data were taken for turbulent flow in a circular pipe with a radius of 3.5 cm. Evaluate the kinetic energy correction factor. The velocity at the pipe wall is zero.

r (cm)	V (m/s)	r (cm)	V (m/s)
0.0	32.5	2.8	22.03
0.5	32.44	2.9	21.24
1.0	32.27	3.0	20.49
1.5	31.22	3.1	19.6
2.0	28.21	3.2	18.69
2.25	26.51	3.25	18.16
2.5	24.38	3.3	17.54
2.6	23.7	3.35	17.02
2.7	22.88	3.4	16.14

The Energy Equation (§7.3)

7.19 Using Section 7.3 and other resources, answer the questions below. Strive for depth, clarity, and accuracy. Also, strive for effective use of sketches, words, and equations.

a. What is conceptual meaning of the first law of thermodynamics for a system?

b. What is flow work? How is the equation for flow work (Eq. 7.16) on p. 259 of §7.3 derived?

c. What is shaft work? How is shaft work different than flow work?

7.20 Using Section 7.3 and other resources, answer the questions below. Strive for depth, clarity, and accuracy. Also, strive for effective use of sketches, words, and equations.

a. What is head? How is head related to energy? To power?

b. What is head of a turbine?

c. How is head of a pump related to power? To energy?

d. What is head loss?

7.21 WILEY PLUS **part (a) only** Using Sections 7.3 and 7.7 and using other resources, answer the following questions. Strive for depth, clarity, and accuracy. Also, strive for effective use of sketches, words and equations.

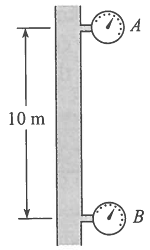
a. What are the five main terms in the energy equation (7.29) on p. 262 of §7.3? What does each term mean?

b. How are terms in the energy equation related to energy? To power?

c. What assumptions are required for using the energy equation (7.29) on p. 262 of §7.3?

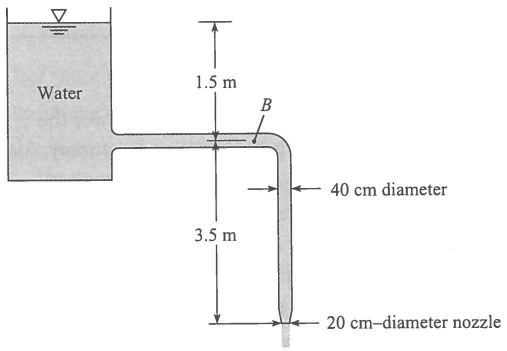
7.22 Using the energy equation (7.29 on p. 262 of §7.3), prove that fluid in a pipe will flow from a location with high piezometric head to a location with low piezometric head. Assume there are no pumps or turbines and that the pipe has a constant diameter.

7.23 WILEY PLUS Water flows at a steady rate in this vertical pipe. The pressure at A is 10 kPa, and at B it is 98.1 kPa. Then the flow in the pipe is (a) upward, (b) downward, or (c) no flow. (*Hint:* See problem 7.23.)



PROBLEM 7.23

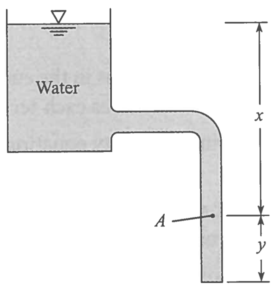
7.24 Determine the discharge in the pipe and the pressure at point B. Neglect head losses. Assume $\alpha = 1.0$ at all locations.



PROBLEM 7.24

7.25 A pipe drains a tank as shown. If $x = 4.25$ m, $y = 1.2$ m, and head losses are neglected, what is the pressure at point A and what is the velocity at the exit? Assume $\alpha = 1.0$ at all locations.

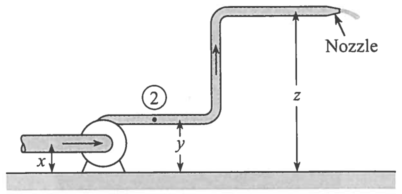
7.26 A pipe drains a tank as shown. If $x = 6$ m, $y = 4$ m, and head losses are neglected, what is the pressure at point A and what is the velocity at the exit? Assume $\alpha = 1.0$ at all locations.



PROBLEMS 7.25, 7.26

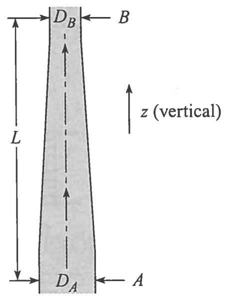
7.27 For this system, the discharge of water is 0.1 m³/s, $x = 1.0$ m, $y = 1.5$ m, $z = 6.0$ m, and the pipe diameter is 30 cm. Assuming a head loss of 0.5 m, what is the pressure head at point 2 if the jet from the nozzle is 10 cm in diameter? Assume $\alpha = 1.0$ at all locations.

7.28 For this diagram of an industrial pressure washer system, $x = 0.3$ m, $y = 0.9$ m, $z = 3$ m, $Q = 0.1$ m³/s, and the hose diameter is 10 cm. Assuming a head loss of 0.3 m is derived over the distance from point 2 to the jet, what is the pressure at point 2 if the jet from the nozzle is 2.5 cm in diameter? Assume $\alpha = 1.0$ throughout.



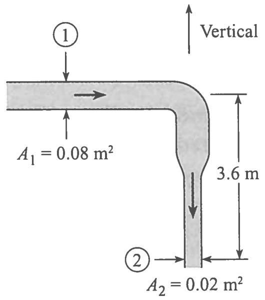
PROBLEMS 7.27, 7.28

7.29 For this refinery pipe, $D_A = 20$ cm, $D_B = 14$ cm, and $L = 1$ m. If crude oil ($S = 0.90$) is flowing at a rate of 0.05 m³/s, determine the difference in pressure between sections A and B. Neglect head losses.



PROBLEM 7.29

7.30 Gasoline having a specific gravity of 0.8 is flowing in the pipe shown at a rate of 0.15 m³/s. What is the pressure at section 2 when the pressure at section 1 is 124 kPa gage and the head loss is 1.8 m between the two sections? Assume $\alpha = 1.0$ at all locations.

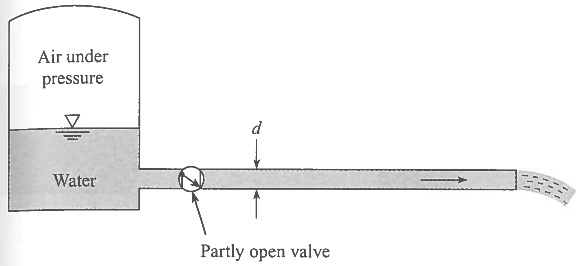


PROBLEM 7.30

7.31 Water flows from a pressurized tank as shown. The pressure in the tank above the water surface is 100 kPa gage, and the water surface level is 8 m above the outlet. The water exit velocity is 10 m/s. The head loss in the system varies as $h_L = K_L V^2/2g$, where K_L is the minor-loss coefficient. Find the value for K_L. Assume $\alpha = 1.0$ at all locations.

7.32 A reservoir with water is pressurized as shown. The pipe diameter is 2.5 cm. The head loss in the system is given by $h_L = 5V^2/2g$. The height between the water surface and the pipe outlet is 3 m. A discharge of 0.003 m³/s is needed. What must the pressure in the tank be to achieve such a flow rate? Assume $\alpha = 1.0$ at all locations.

7.33 In the figure shown, suppose that the reservoir is open to the atmosphere at the top. The valve is used to control the flow rate from the reservoir. The head loss across the valve is given as $h_L = 4V^2/2g$, where V is the velocity in the pipe. The cross-sectional area of the pipe is 8 cm². The head loss due to friction in the pipe is negligible. The elevation of the water level in the reservoir above the pipe outlet is 9 m. Find the discharge in the pipe. Assume $\alpha = 1.0$ at all locations.



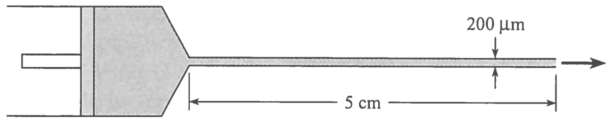
PROBLEMS 7.31, 7.32, 7.33

7.34 A minor artery in the human arm, diameter D = 3 mm, tapers gradually over a distance of 20 cm to a diameter of d = 1.6 mm. The blood pressure at D is 110 mm Hg, and at d is 85 mm Hg. What is the head loss (m) that occurs over this 20-cm distance if the blood ($S = 1.06$) is moving with a flowrate of 300 milliliters/min, and the arm is being held horizontally? Idealize the flow in the artery as steady, the fluid as Newtonian, and the walls of the artery as rigid.

7.35 As shown, a microchannel is being designed to transfer fluid in a MEMS (microelectrical mechanical system) application. The channel is 200 micrometers in diameter and is 5 cm long. Ethyl alcohol is driven through the system at the rate of 0.1 microliters/s (μL/s) with a syringe pump, which is essentially a moving piston. The pressure at the exit of the channel is atmospheric. The flow is laminar, so $\alpha = 2$. The head loss in the channel is given by

$$h_L = \frac{32\mu LV}{\gamma D^2}$$

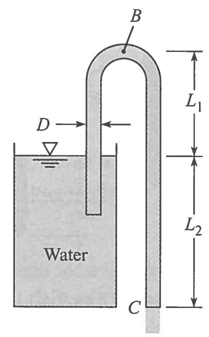
where L is the channel length, D the diameter, V the mean velocity, μ the viscosity of the fluid, and γ the specific weight of the fluid. Find the pressure in the syringe pump. The velocity head associated with the motion of the piston in the syringe pump is negligible.



PROBLEM 7.35

7.36 Firefighting equipment requires that the exit velocity of the firehose be 30 m/s at an elevation of 45 m above the hydrant. The nozzle at the end of the hose has a contraction ratio of 4:1 ($A_e/A_{hose} = 1/4$). The head loss in the hose is $8V^2/2g$, where V is the velocity in the hose. What must the pressure be at the hydrant to meet this requirement? The pipe supplying the hydrant is much larger than the firehose.

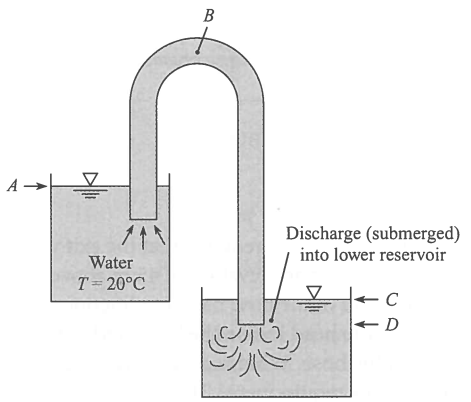
7.37 The discharge in the siphon is 0.08 m³/s, $D = 20$ cm, $L_1 = 0.9$ m, and $L_2 = 0.9$ m. Determine the head loss between the reservoir surface and point C. Determine the pressure at point B if three-quarters of the head loss (as found above) occurs between the reservoir surface and point B. Assume $\alpha = 1.0$ at all locations.



PROBLEM 7.37

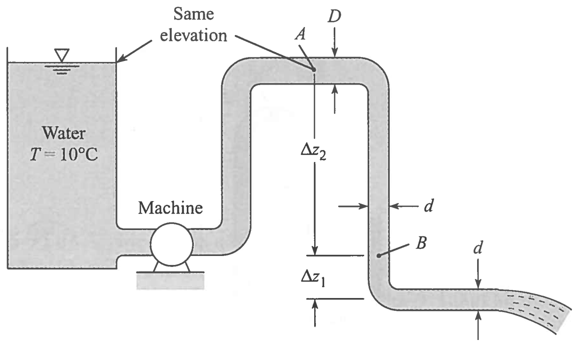
7.38 For this siphon the elevations at A, B, C, and D are 30 m, 32 m, 27 m, and 26 m, respectively. The head loss between the inlet and point B is three-quarters of the velocity head, and the head loss in the pipe itself between point B and the end of the pipe is one-quarter of the velocity head. For these conditions, what is the discharge and what is the pressure at point B? The pipe diameter = 25 cm. Assume $\alpha = 1.0$ at all locations.

7.39 For this system, point B is 10 m above the bottom of the upper reservoir. The head loss from A to B is $1.1V^2/2g$, and the pipe area is 8×10^{-4} m². Assume a constant discharge of 8×10^{-4} m³/s. For these conditions, what will be the depth of water in the upper reservoir for which cavitation will begin at point B? Vapor pressure = 1.23 kPa and atmospheric pressure = 100 kPa. Assume $\alpha = 1.0$ at all locations.



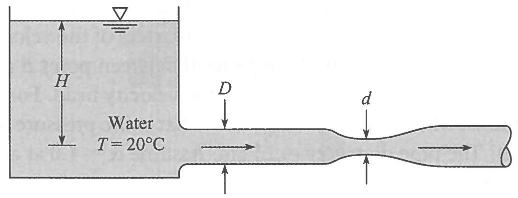
PROBLEMS 7.38, 7.39

7.40 In this system, d = 15 cm, D = 30 cm, Δz_1 = 1.8 m, and Δz_2 = 3.6 m. The discharge of water in the system is 0.3 m³/s. Is the machine a pump or a turbine? What are the pressures at points A and B? Neglect head losses. Assume α = 1.0 at all locations.



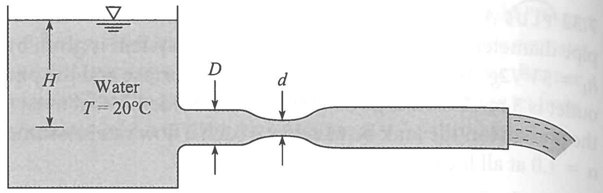
PROBLEM 7.40

7.41 The pipe diameter D is 30 cm, d is 15 cm, and the atmospheric pressure is 100 kPa. What is the maximum allowable discharge before cavitation occurs at the throat of the venturi meter if H = 5 m? Assume α = 1.0 at all locations.



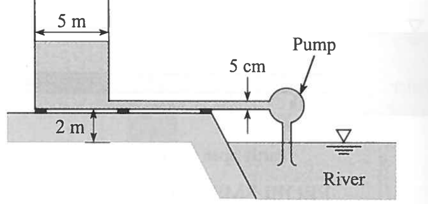
PROBLEM 7.41

7.42 In this system d = 15 cm, D = 35 cm, and the head loss from the venturi meter to the end of the pipe is given by $h_L = 1.5\,V^2/2g$, where V is the velocity in the pipe. Neglecting all other head losses, determine what head H will first initiate cavitation if the atmospheric pressure is 100 kPa absolute. What will be the discharge at incipient cavitation? Assume α = 1.0 at all locations.



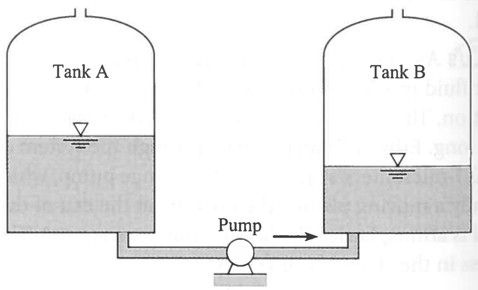
PROBLEM 7.42

7.43 A pump is used to fill a tank 5 m in diameter from a river as shown. The water surface in the river is 2 m below the bottom of the tank. The pipe diameter is 5 cm, and the head loss in the pipe is given by $h_L = 10\,V^2/2g$, where V is the mean velocity in the pipe. The flow in the pipe is turbulent, so α = 1. The head provided by the pump varies with discharge through the pump as $h_p = 20 - 4 \times 10^4\,Q^2$, where the discharge is given in cubic meters per second (m³/s) and h_p is in meters. How long will it take to fill the tank to a depth of 10 m?



PROBLEM 7.43

7.44 A pump is used to transfer SAE-30 oil from tank A to tank B as shown. The tanks have a diameter of 12 m. The initial depth of the oil in tank A is 20 m, and in tank B the depth is 1 m. The pump delivers a constant head of 60 m. The connecting pipe has a diameter of 20 cm, and the head loss due to friction in the pipe is $20\,V^2/2g$. Find the time required to transfer the oil from tank A to B; that is, the time required to fill tank B to 20 m depth.



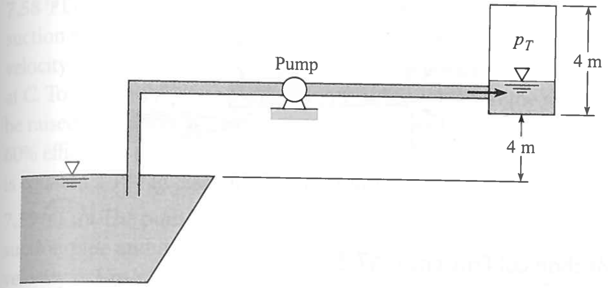
PROBLEM 7.44

7.45 A pump is used to pressurize a tank to 300 kPa abs. The tank has a diameter of 2 m and a height of 4 m. The initial level of water in the tank is 1 m, and the pressure at the water surface is 0 kPa gage. The atmospheric pressure is 100 kPa. The pump operates with a constant head of 50 m. The water is drawn from a source that is 4 m below the tank bottom. The pipe connecting the source and the tank is 4 cm in diameter and the head loss, including the expansion loss at the tank, is $10\,V^2/2g$. The flow is turbulent.

Assume the compression of the air in the tank takes place isothermally, so the tank pressure is given by

$$p_T = \frac{3}{4 - z_t}\,p_0$$

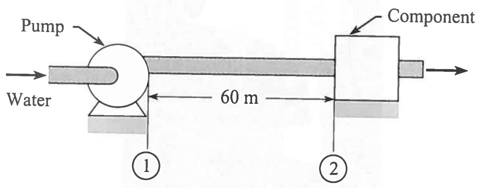
where z_t is the depth of fluid in the tank in meters. Write a computer program that will show how the pressure varies in the tank with time, and find the time to pressurize the tank to 300 kPa abs.



PROBLEM 7.45

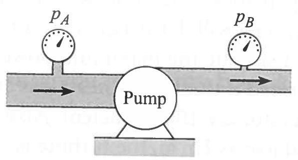
The Power Equation (§7.4)

7.46 As shown, water at 15°C is flowing in a 15-cm-diameter by 60-m-long run of pipe that is situated horizontally. The mean velocity is 2 m/s, and the head loss is 2 m. Determine the pressure drop and the required pumping power to overcome head loss in the pipe.



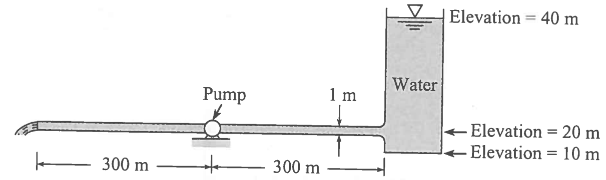
PROBLEM 7.46

7.47 The pump shown in the figure supplies energy to the flow such that the upstream pressure (30 cm pipe) is 35 kPa and the downstream pressure (15 cm pipe) is 380 kPa when the flow of water is 0.085 m³/s. What kilowatt power is delivered by the pump to the flow? Assume α = 1.0 at all locations.



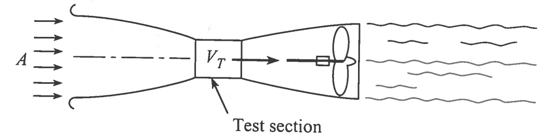
PROBLEM 7.47

7.48 A water discharge of 8 m³/s is to flow through this horizontal pipe, which is 1 m in diameter. If the head loss is given as $7\,V^2/2g$ (V is velocity in the pipe), how much power will have to be supplied to the flow by the pump to produce this discharge? Assume α = 1.0 at all locations.



PROBLEM 7.48

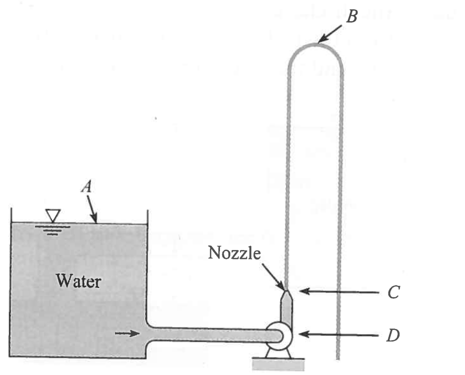
7.49 An engineer is designing a subsonic wind tunnel. The test section is to have a cross-sectional area of 4 m² and an airspeed of 60 m/s. The air density is 1.2 kg/m³. The area of the tunnel exit is 10 m². The head loss through the tunnel is given by $h_L = (0.025)(V_T^2/2g)$, where V_T is the airspeed in the test section. Calculate the power needed to operate the wind tunnel. *Hint:* Assume negligible energy loss for the flow approaching the tunnel in region A, and assume atmospheric pressure at the outlet section of the tunnel. Assume α = 1.0 at all locations.



PROBLEM 7.49

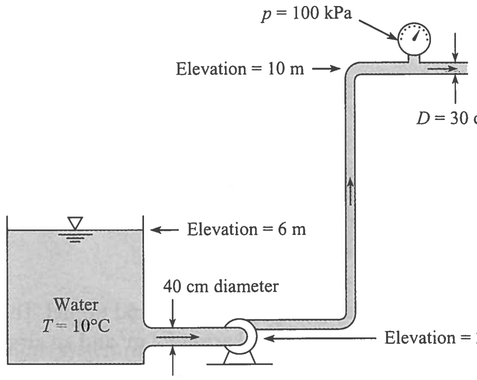
7.50 Neglecting head losses, determine how many kilowatts of power the pump must deliver to produce the flow as shown. Here the elevations at points A, B, C, and D are 35 m, 47 m, 33 m, and 27 m, respectively. The nozzle area is 0.01 m².

7.51 Neglecting head losses, determine what power the pump must deliver to produce the flow as shown. Here the elevations at points A, B, C, and D are 40 m, 65 m, 35 m, and 30 m, respectively. The nozzle area is 25 cm².



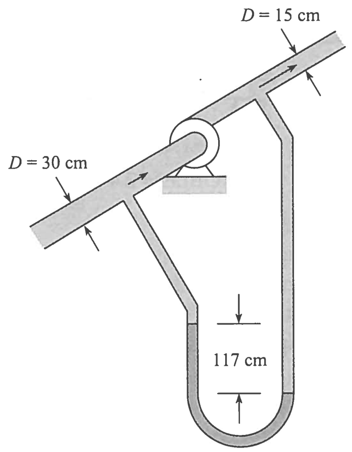
PROBLEMS 7.50, 7.51

7.52 Water (10°C) is flowing at a rate of 0.35 m^3/s, and it is assumed that $h_L = 2\,V^2/2g$ from the reservoir to the gage, where V is the velocity in the 30-cm pipe. What power must the pump supply? Assume $\alpha = 1.0$ at all locations.



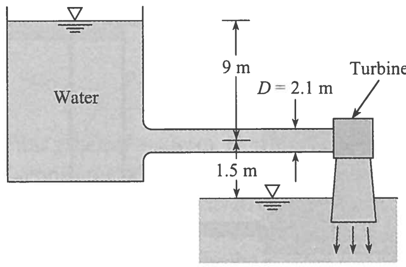
PROBLEM 7.52

7.53 In the pump test shown, the rate of flow is 0.17 m^3/s of oil (S = 0.88). Calculate the kilowatt power that the pump supplies to the oil if there is a differential reading of 117 cm of mercury in the U-tube manometer. Assume $\alpha = 1.0$ at all locations.



PROBLEM 7.53

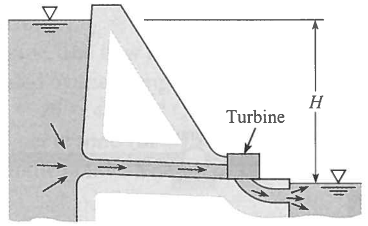
7.54 If the discharge is 14.2 m^3/s, what power output may be expected from the turbine? Assume that the turbine efficiency is 90% and that the overall head loss is 1.5 $V^2/2g$,



PROBLEM 7.54

where V is the velocity in the 2.1 m penstock Assume $\alpha = 1.0$ at all locations.

7.55 A small-scale hydraulic power system is shown. The elevation difference between the reservoir water surface and the pond water surface downstream of the reservoir, H, is 24 m. The velocity of the water exhausting into the pond is 7 m/s, and the discharge through the system is 4 m^3/s. The head loss due to friction in the penstock (inlet pipe to turbine, under very high pressure) is negligible. Find the power produced by the turbine in kilowatts.



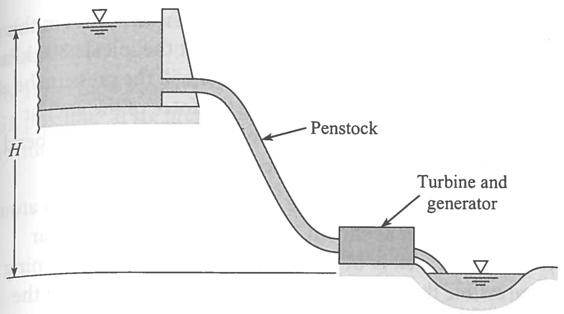
PROBLEM 7.55

Mechanical Efficiency (§7.5)

7.56 A fan produces a pressure rise of 6 mm of water to move air through a hair dryer. The mean velocity of the air at the exit is 10 m/s, and the exit diameter is 44 mm. Estimate the electrical power in watts that needs to be supplied to operate the fan. Assume that the fan/motor combination has an efficiency of 60%.

PROBLEM 7.56 (Photo by Donald Elger)

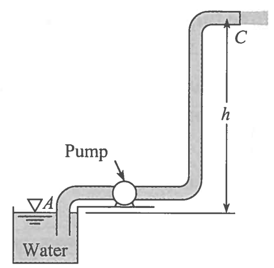
7.57 An engineer is making an estimate for a home owner. This owner has a small stream ($Q = 0.04$ m^3/s, $T = 5°C$) that is located at an elevation $H = 10$ m above the owner's residence. The owner is proposing to dam the stream, diverting the flow through a pipe (penstock). This flow will spin a hydraulic turbine, which in turn will drive a generator to produce electrical power. Estimate the maximum power in kilowatts that can be generated if there is no head loss and both the turbine and generator are 100% efficient. Also, estimate the power if the head loss is 1.7 m, the turbine is 70% efficient, and the generator is 90% efficient.



PROBLEM 7.57

7.58 The pump shown draws water through an 20 cm suction pipe and discharges it through a 15 cm pipe in which the velocity is 3.6 m/s. The 15 cm pipe discharges horizontally into air at C. To what height h above the water surface at A can the water be raised if 12.7 kW is used by the pump? The pump operates at 60% efficiency and that the head loss in the pipe between A and C is equal to $2\,V_C^2/2g$. Assume $\alpha = 1.0$ throughout.

7.59 The pump shown draws water (20°C) through a 20 cm suction pipe and discharges it through a 10 cm pipe in which the velocity is 3 m/s. The 10 cm pipe discharges horizontally into air at point C. To what height h above the water surface at A can the water be raised if 26 kW is delivered to the pump? Assume that the pump operates at 60% efficiency and that the head loss in the pipe between A and C is equal to $2\,V_C^2/2g$. Assume $\alpha = 1.0$ throughout.



PROBLEMS 7.58, 7.59

7.60 A pumping system is to be designed to pump crude oil a distance of 1.6 km in a 0.3 m foot-diameter pipe at a rate of 13.25 kL/min. The pressures at the entrance and exit of the pipe are atmospheric, and the exit of the pipe is 60 m higher than the entrance. The pressure loss in the system due to pipe friction is 415 kPa. The specific weight of the oil is 8330 N/m^3. Find the power, in kilowatts, required for the pump.

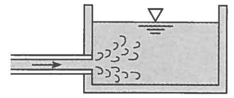
Contrasting Bernoulli Eqn. to Energy Eqn. (§7.6)

7.61 How is the energy equation (7.29) on p. 262 of §7.3 similar to the Bernoulli equation? How is it different? Give three important similarities and three important differences.

Transitions (§7.7)

7.62 What is the head loss at the outlet of the pipe that discharges water into the reservoir at a rate of 0.3 m^3/s if the diameter of the pipe is 30 cm?

7.63 What is the head loss at the outlet of the pipe that discharges water into the reservoir at a rate of 0.5 m^3/s if the diameter of the pipe is 50 cm?

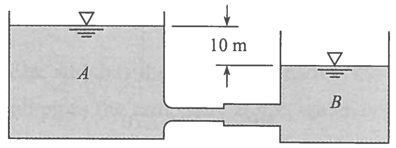


PROBLEMS 7.62, 7.63

7.64 A 7 cm pipe carries water with a mean velocity of 2 m/s. If this pipe abruptly expands to a 15 cm pipe, what will be the head loss due to the abrupt expansion?

7.65 A 15 cm pipe abruptly expands to a 30 cm size. If the discharge of water in the pipes is 0.15 m^3/s, what is the head loss due to abrupt expansion?

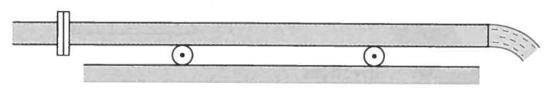
7.66 Water is draining from tank A to tank B. The elevation difference between the two tanks is 10 m. The pipe connecting the two tanks has a sudden-expansion section as shown. The cross-sectional area of the pipe from A is 8 cm^2, and the area of the pipe into B is 25 cm^2. Assume the head loss in the system consists only of that due to the sudden-expansion section and the loss due to flow into tank B. Find the discharge between the two tanks.



PROBLEM 7.66

7.67 A 40 cm pipe abruptly expands to a 60 cm size. These pipes are horizontal, and the discharge of water from the smaller size to the larger is 1.0 m^3/s. What horizontal force is required to hold the transition in place if the pressure in the 40 cm pipe is 70 kPa gage? Also, what is the head loss? Assume $\alpha = 1.0$ at all locations.

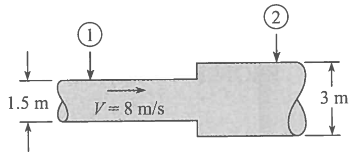
7.68 Water ($\gamma = 9810$ N/m^3) flows through a horizontal constant diameter pipe with a cross-sectional area of 58 cm^2. The velocity in the pipe is 4.5 m/s, and the water discharges to the atmosphere. The head loss between the pipe joint and the end of the pipe is 0.9 m. Find the force on the joint to hold the pipe. The pipe is mounted on frictionless rollers. Assume $\alpha = 1.0$ at all locations.



PROBLEM 7.68

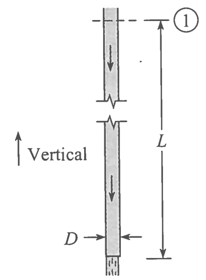
7.69 This abrupt expansion is to be used to dissipate the high-energy flow of water in the 1.5 m–diameter penstock. Assume $\alpha = 1.0$ at all locations.

a. What power (in kW) is lost through the expansion?
b. If the pressure at section 1 is 35 kPa gage, what is the pressure at section 2?
c. What force is needed to hold the expansion in place?



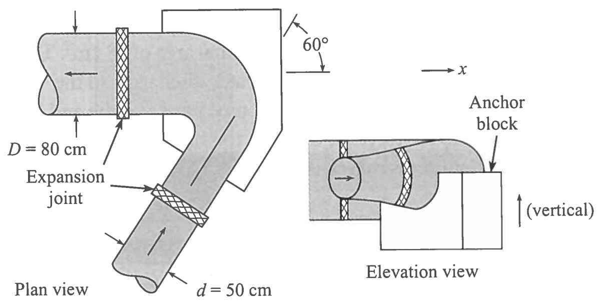
PROBLEM 7.69

7.70 This rough aluminum pipe is 15 cm in diameter. It weighs 22 N per meter of length, and the length L is 15 m. If the discharge of water is 0.17 m^3/s and the head loss due to friction from section 1 to the end of the pipe is 3 m, what is the longitudinal force transmitted across section 1 through the pipe wall?



PROBLEM 7.70

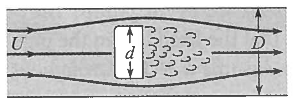
7.71 Water flows in this bend at a rate of 5 m^3/s, and the pressure at the inlet is 650 kPa. If the head loss in the bend is 10 m, what will the pressure be at the outlet of the bend? Also estimate the force of the anchor block on the bend in the x direction required to hold the bend in place. Assume $\alpha = 1.0$ at all locations.



PROBLEMS 7.71, 7.72

7.72 WILEY PLUS In a local water treatment plant, water flows in this bend at a rate of 7 m^3/s, and the pressure at the inlet is 800 kPa. If the head loss in the bend is 13 m, what will the pressure be at the outlet of the bend? Also estimate the force of the anchor block on the bend in the x direction required to hold the bend in place. Assume $\alpha = 1.0$ at all locations.

7.73 Fluid flowing along a pipe of diameter D accelerates around a disk of diameter d as shown in the figure. The velocity far upstream of the disk is U, and the fluid density is ρ. Assuming incompressible flow and that the pressure downstream of the disk is the same as that at the plane of separation, develop an expression for the force required to hold the disk in place in terms of U, D, d, and ρ. Using the expression you developed, determine the force when $U = 10$ m/s, $D = 5$ cm, $d = 4$ cm, and $\rho = 1.2$ kg/m^3. Assume $\alpha = 1.0$ at all locations.



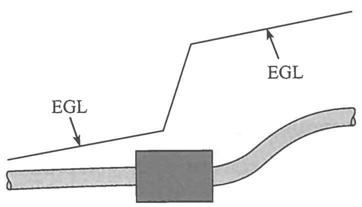
PROBLEM 7.73

EGL and HGL (§7.8)

7.74 WILEY PLUS **part (b) only** Using Section 7.8 and other resources, answer the following questions. Strive for depth, clarity, and accuracy while also combining sketches, words, and equations in ways that enhance the effectiveness of your communication.

a. What are three important reasons that engineers use the HGL and the EGL?
b. What factors influence the magnitude of the HGL? What factors influence the magnitude of the EGL?
c. How are the EGL and HGL related to the piezometer? To the stagnation tube?
d. How is the EGL related to the energy equation?
e. How can you use an HGL or an EGL to determine the direction of flow?

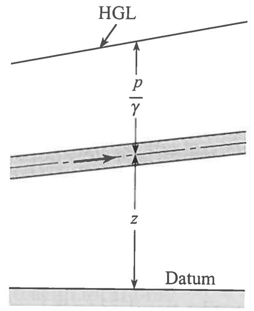
7.75 WILEY PLUS The energy grade line for steady flow in a uniform-diameter pipe is shown. Which of the following could be in the "black box"? (a) a pump, (b) a partially closed valve, (c) an abrupt



PROBLEM 7.75

expansion, or (d) a turbine. Choose all valid answer(s) and state your rationale.

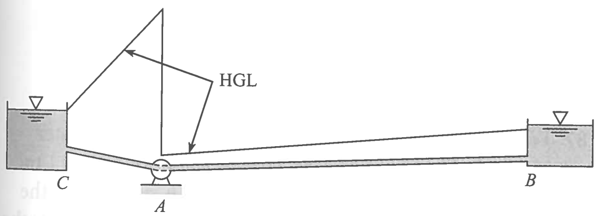
7.76 If the pipe shown has constant diameter, is this type of HGL possible? If so, under what additional conditions? If not, why not?



PROBLEM 7.76

7.77 WILEY PLUS For the system shown,

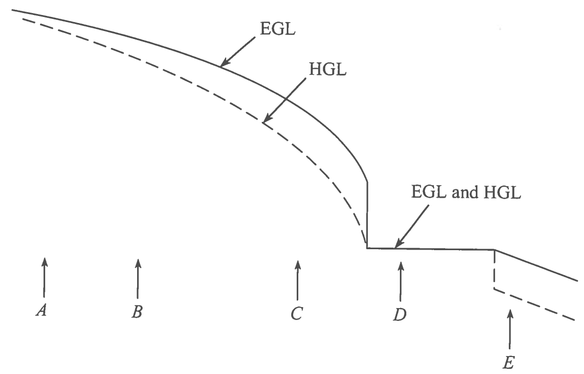
a. What is the flow direction?
b. What kind of machine is at A?
c. Do you think both pipes, AB and CA, are the same diameter?
d. Sketch in the EGL for the system.
e. Is there a vacuum at any point or region of the pipes? If so, identify the location.



PROBLEM 7.77

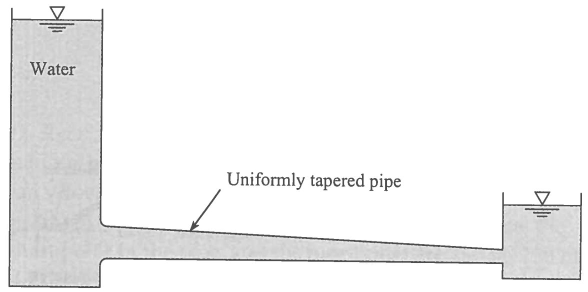
7.78 The HGL and the EGL are as shown for a certain flow system.

a. Is flow from A to E or from E to A?
b. Does it appear that a reservoir exists in the system?
c. Does the pipe at E have a uniform or a variable diameter?
d. Is there a pump in the system?
e. Sketch the physical setup that could yield the conditions shown between C and D.
f. Is anything else revealed by the sketch?



PROBLEM 7.78

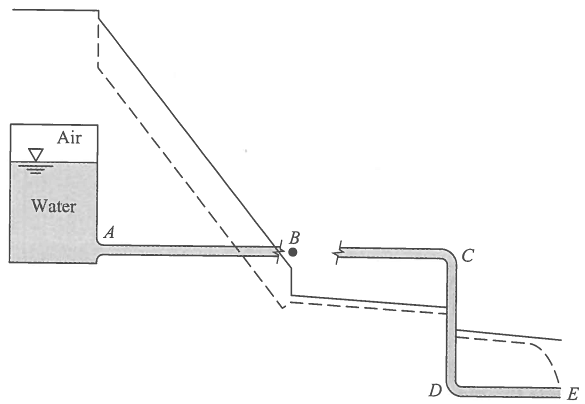
7.79 Sketch the HGL and the EGL for this conduit, which tapers uniformly from the left end to the right end.



PROBLEM 7.79

7.80 WILEY PLUS The HGL and the EGL for a pipeline are shown in the figure.

a. Indicate which is the HGL and which is the EGL.
b. Are all pipes the same size? If not, which is the smallest?
c. Is there any region in the pipes where the pressure is below atmospheric pressure? If so, where?
d. Where is the point of maximum pressure in the system?
e. Where is the point of minimum pressure in the system?



PROBLEM 7.80

f. What do you think is located at the end of the pipe at point E?

g. Is the pressure in the air in the tank above or below atmospheric pressure?

h. What do you think is located at point B?

7.81 WILEY GO Assume that the head loss in the pipe is given by $h_L = 0.014(L/D)(V^2/2g)$, where L is the length of pipe and D is the pipe diameter. Assume $\alpha = 1.0$ at all locations.

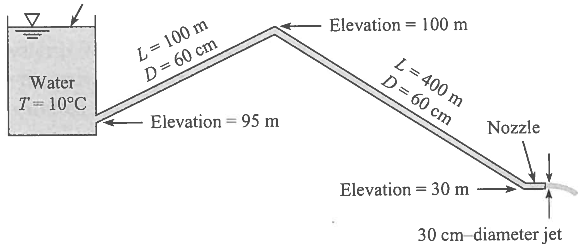
a. Determine the discharge of water through this system.

b. Draw the HGL and the EGL for the system.

c. Locate the point of maximum pressure.

d. Locate the point of minimum pressure.

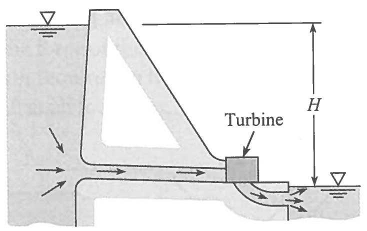
e. Calculate the maximum and minimum pressures in the system.



PROBLEM 7.81

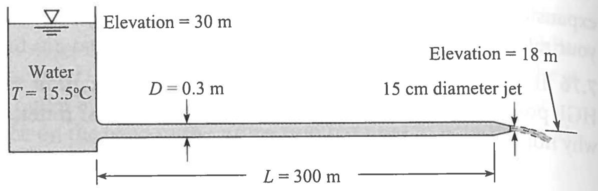
7.82 Sketch the HGL and the EGL for the reservoir and pipe of Example 7.2.

7.83 The discharge of water through this turbine is 28.3 m^3/s. What power is generated if the turbine efficiency is 85% and the total head loss is 1.2 m? $H = 30$ m. Also, carefully sketch the EGL and the HGL.



PROBLEM 7.83

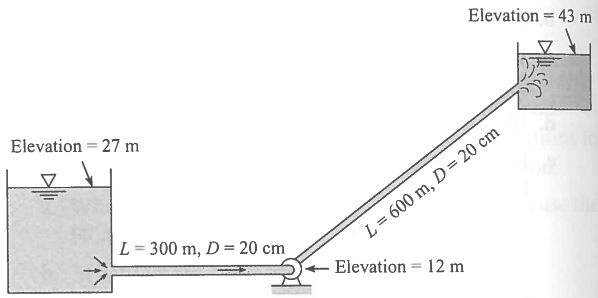
7.84 Water flows from the reservoir through a pipe and then discharges from a nozzle as shown. The head loss in the pipe itself is given as $h_L = 0.025(L/D)(V^2/2g)$, where L and D are the length and diameter of the pipe and V is the velocity in the pipe. What is the discharge of water? Also draw the HGL and EGL for the system. Assume $\alpha = 1.0$ at all locations.



PROBLEM 7.84

7.85 WILEY PLUS Refer to Fig. 7.15 on p. 275 of §7.8. Assume that the head loss in the pipes is given by $h_L = 0.02(L/D)(V^2/2g)$, where V is the mean velocity in the pipe, D is the pipe diameter, and L is the pipe length. The water surface elevations of the upper and lower reservoirs are 100 m and 70 m, respectively. The respective dimensions for upstream and downstream pipes are $D_u = 30$ cm, and $L_u = 200$ m, and $D_d = 15$ cm, and $L_d = 100$ m. Determine the discharge of water in the system.

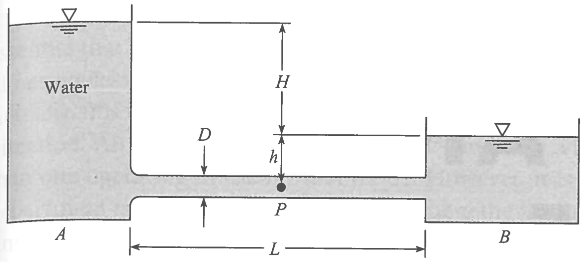
7.86 What power must be supplied to the water to pump 0.1 m^3/s at 20°C from the lower to the upper reservoir? Assume that the head loss in the pipes is given by $h_L = 0.018(L/D)(V^2/2g)$, where L is the length of the pipe in meters and D is the pipe diameter in meters. Sketch the HGL and the EGL.



PROBLEM 7.86

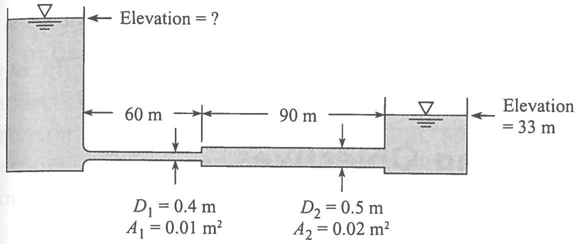
7.87 Water flows from reservoir A to reservoir B. The water temperature in the system is 10°C, the pipe diameter D is 1 m, and the pipe length L is 300 m. If $H = 16$ m, $h = 2$ m, and the pipe head loss is given by $h_L = 0.01(L/D)(V^2/2g)$, where V is the velocity in the pipe, what will be the discharge in the pipe? In your solution, include the head loss at the pipe outlet, and sketch the HGL and the EGL. What will be the pressure at point P halfway between the two reservoirs? Assume $\alpha = 1.0$ at all locations.

7.88 WILEY GO Water flows from reservoir A to reservoir B in a desert retirement community. The water temperature in the system is 37.8°C, the pipe diameter D is 1.2 m, and the pipe length L is 60 m. If $H = 10$ m, $h = 3$ m, and the pipe head loss is given by $h_L = 0.01(L/D)(V^2/2g)$, where V is the velocity in the pipe, what will be the discharge in the pipe? In your solution, include the head loss at the pipe outlet. What will be the pressure at point P halfway between the two reservoirs? Assume $\alpha = 1.0$ at all locations.



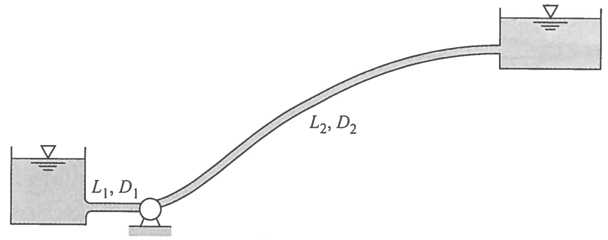
PROBLEMS 7.87, 7.88

7.89 Water flows from the reservoir on the left to the reservoir on the right at a rate of 0.45 m^3/s. The formula for the head losses in the pipes is $h_L = 0.02(L/D)(V^2/2g)$. What elevation in the left reservoir is required to produce this flow? Also carefully sketch the HGL and the EGL for the system. *Note:* Assume the head-loss formula can be used for the smaller pipe as well as for the larger pipe. Assume $\alpha = 1.0$ at all locations.



PROBLEM 7.89

7.90 What power is required to pump water at a rate of 3 m^3/s from the lower to the upper reservoir? Assume the pipe head loss is given by $h_L = 0.018(L/D)(V^2/2g)$, where L is the length of pipe, D is the pipe diameter, and V is the velocity in the pipe. The water temperature is 10°C, the water surface elevation in the lower reservoir is 150 m, and the surface elevation in the upper reservoir is 250 m. The pump elevation is 100 m, $L_1 = 100$ m, $L_2 = 1000$ m, $D_1 = 1$ m, and $D_2 = 50$ cm. Assume the pump and motor efficiency is 74%. In your solution, include the head loss at the pipe outlet and sketch the HGL and the EGL. Assume $\alpha = 1.0$ at all locations.



PROBLEM 7.90

7.91 Refer to Fig. 7.16 on p. 276 of §7.8. Assume that the head loss in the pipe is given by $h_L = 0.02(L/D)(V^2/2g)$, where V is the mean velocity in the pipe, D is the pipe diameter, and L is the pipe length. The elevations of the reservoir water surface, the highest point in the pipe, and the pipe outlet are 250 m, 250 m, and 210 m, respectively. The pipe diameter is 30 cm, and the pipe length is 200 m. Determine the water discharge in the pipe, and, assuming that the highest point in the pipe is halfway along the pipe, determine the pressure in the pipe at that point. Assume $\alpha = 1.0$ at all locations.