Page No	Current version	Corrected version
806	**14–27E** The performance data for a centrifugal water pump are shown in Table P14–27E for water at 77°F (gpm = gallons per minute). (*a*) For each row of data, calculate the pump efficiency (percent). *Show all units and unit conversions for full credit*. (*b*) Estimate the volume flow rate (gpm) and net head (ft) at the BEP of the pump.	14-27 The performance data for a centrifugal water pump are shown in Table P14-27 for water at 25°C. (a) For each row of data, calculate the pump efficiency (percent). Show all units and unit conversions for full credit. (b) Estimate the volume flow rate (Lpm) and net head (m) at BEP of the pump.
806	**TABLE P14–27E** $\dot{V}$, gpm — H, ft — bhp, hp 0.0 — 19.0 — 0.06 4.0 — 18.5 — 0.064 8.0 — 17.0 — 0.069 12.0 — 14.5 — 0.074 16.0 — 10.5 — 0.079 20.0 — 6.0 — 0.08 24.0 — 0.0 — 0.078	TABLE P14-27 V, Lpm — H, m — bhp, W 0.0 — 5.70 — 44.76 15.2 — 5.55 — 47.74 30.4 — 5.10 — 51.47 45.6 — 4.35 — 55.20 60.8 — 3.15 — 58.93 76.0 — 1.80 — 59.68 91.0 — 0.00 — 58.18
806	**14–29E** For the centrifugal water pump of Prob. 14–27E, plot the pump's performance data: H (ft), bhp (hp), and η_{pump} (percent) as functions of $\dot{V}$ (gpm), using symbols only (no lines). Perform linear least-squares polynomial curve fits for all three parameters, and plot the fitted curves as lines (no symbols) on the same plot. For consistency, use a first-order curve fit for H as a function of $\dot{V}^2$, use a second-order curve fit for bhp as a function of both $\dot{V}$ and $\dot{V}^2$, and use a third-order curve fit for η_{pump} as a function of $\dot{V}$, $\dot{V}^2$, and $\dot{V}^3$. List all curve-fitted equations and coefficients (with units) for full credit. Calculate the BEP of the pump based on the curve-fitted expressions.	14-29 For the centrifugal water pump of Prob. 14-27, plot the pump's performance data: H (m), bhp (hp), and η_{pump} (percent) as functions of V (Lpm), using symbols only (no lines). Perform linear least-squares polynomial curve fits for all three parameters, and plot the fitted curves as lines (no symbols) on the same plot. For consistency, use a first-order curve fit for H as a function of V^2 use a second-order curve fit for kW as a function of both V and V^2 and use a third-order curve fit for η_{pump} as a function of V, V^2, and V^3. List all curve-fitted equations and coefficients (with units) for full credit. Calculate the BEP of the pump based on the curve-fitted expressions.

807	**14–30E** Suppose the pump of Probs. 14–27E and 14–29E is used in a piping system that has the system requirement $H_{required} = (z_2 - z_1) + b\dot{V}^2$, where elevation difference $z_2 - z_1 = 15.5$ ft, and coefficient $b = 0.00986$ ft/(gpm)^2. Estimate the operating point of the system, namely, $\dot{V}_{operating}$ (gpm) and $H_{operating}$ (ft). *Answers: 9.14 gpm, 16.3 ft*	14-30 Suppose the pump of Probs. 14-27 and 14-29 is used in a piping system that has the system requirement $H_{required} = (z_2 - z_1) + bV^2$, where elevation difference $z_2 - z_1 = 4.65$m, and coefficient $b = .043$m/(Lpm)^2. Estimate the operating point of the system, namely, $V_{operating}$ (Lpm) and $H_{operating}$ (m).
807	**14–35E** A manufacturer of small water pumps lists the performance data for a family of its pumps as a parabolic curve fit, $H_{available} = H_0 - a\dot{V}^2$, where H_0 is the pump's shutoff head and a is a coefficient. Both H_0 and a are listed in a table for the pump family, along with the pump's free delivery. The pump head is given in units of feet of water column, and capacity is given in units of gallons per minute. (*a*) What are the units of coefficient a? (*b*) Generate an expression for the pump's free delivery $\dot{V}_{max}$ in terms of H_0 and a. (*c*) Suppose one of the manufacturer's pumps is used to pump water from one large reservoir to another at a higher elevation. The free surfaces of both reservoirs are exposed to atmospheric pressure. The system curve simplifies to $H_{required} = (z_2 - z_1) + b\dot{V}^2$. Calculate the operating point of the pump ($\dot{V}_{operating}$ and $H_{operating}$) in terms of H_0, a, b, and elevation difference $z_2 - z_1$.	14-35 A manufacturer of small water pumps lists the performance data for a family of its pumps as a parabolic curve fit, $H_{available} = H_0 - aV^2$, where H_0 is the pump's shutoff head and a is a coefficient. Both H_0 and a are listed in a table for the pump family, along with the pump's free delivery. The pump head is given in units of liters per minute. (a) What are the units of coefficient a (b) Generate an expression for the pump's free delivery V_{max} in terms of H_0 and a. (c) Suppose one of the manufacturer's pumps is used to pump water from one large reservoir to another at a higher elevation. The free surfaces of both reservoirs are exposed to atmospheric pressure. The system curves simplifies to $H_{required} = (z_2-z_1) + bV^2$. Calculate the operating point of the pump ($V_{operating}$ and $H_{operating}$) in terms of H_0, a, b, and elevation difference $z_2 - z_1$.
807	**14–37E** A water pump is used to pump water from one large reservoir to another large reservoir that is at a higher elevation. The free surfaces of both reservoirs are exposed to atmospheric pressure, as sketched in Fig. P14–37E. The dimensions and minor loss coefficients are provided in the figure. The pump's performance is approximated by the expression $H_{available} = H_0 - a\dot{V}^2$, where the shutoff head $H_0 = 125$ ft of water column, coefficient $a = 2.50$ ft/gpm^2, available pump head $H_{available}$ is in units of feet of water column, and capacity $\dot{V}$ is in units of gallons per minute (gpm). Estimate the capacity delivered by the pump. *Answer: 6.34 gpm*	14-37 A water pump is used to pump water from one large reservoir to another large reservoir that is at a higher elevation. The free surfaces of both reservoirs are exposed to atmospheric pressure, as sketched in Fig. P14-37. The dimensions and minor loss

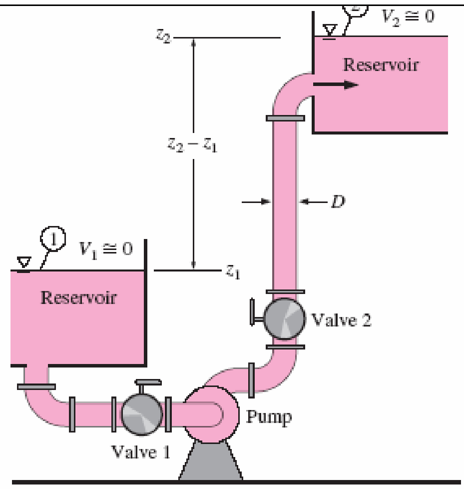
<table>
<tr><td></td><td></td><td>coefficients are provided in the figure. The pump's performance is approximated by the expression $H_{available} = H_0 - aV^2$, where the shutoff head H_0 = 37.5m of water column, coefficient a = 10.83m/Lpm^2, available pump head $H_{available}$ is in units of meter of water column, and capacity V is in units liters per minute (Lpm). Estimate the capacity delivered by the pump.</td></tr>
<tr><td>808</td><td>$z_2 - z_1$ = 22.0 ft (elevation difference)
D = 1.20 in (pipe diameter)
$K_{L,\text{ entrance}}$ = 0.50 (pipe entrance)
$K_{L,\text{ valve 1}}$ = 2.0 (valve 1)
$K_{L,\text{ valve 2}}$ = 6.8 (valve 2)
$K_{L,\text{ elbow}}$ = 0.34 (each elbow—there are 3)
$K_{L,\text{ exit}}$ = 1.05 (pipe exit)
L = 124 ft (total pipe length)
ε = 0.0011 in (pipe roughness)</td><td>$z_2 - z_1$ = 6.6m ft (elevation difference)
D = 3cm (pipe diameter)
$K_{L,\text{ entrance}}$ = 0.50 (pipe entrance)
$K_{L,\text{ valve 1}}$ = 2.0 (valve 1)
$K_{L,\text{ valve 2}}$ = 6.8 (valve 2)
$K_{L,\text{ elbow}}$ = 0.34 (each elbow—there are 3)
$K_{L,\text{ exit}}$ = 1.05 (pipe exit)
L =37m (total pipe length)
ε =0.0028cm (pipe roughness)</td></tr>
<tr><td>808</td><td>

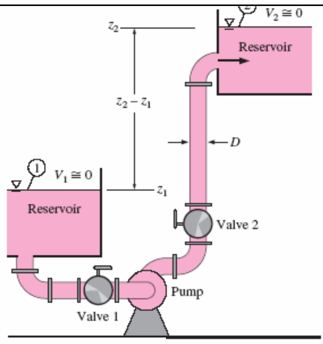
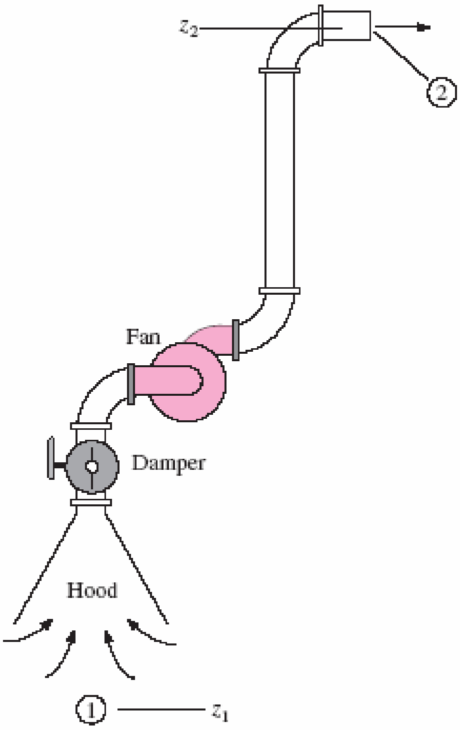
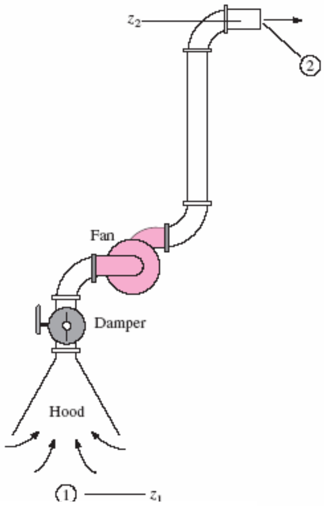
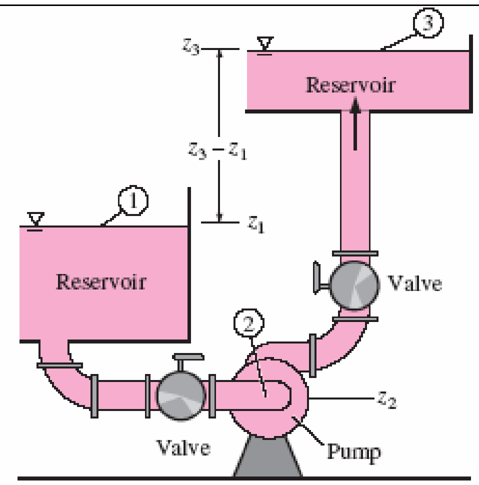
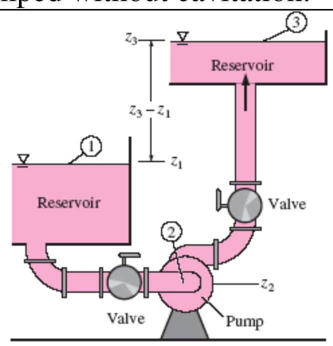
FIGURE P14–37E</td><td>

FIGURE P14-37</td></tr>
<tr><td>808</td><td>14–38E For the pump and piping system of Prob. 14–37E, plot the required pump head $H_{required}$ (ft of water column) as a function of volume flow rate $\dot{V}$ (gpm). On the same plot, compare the available pump head $H_{available}$ versus $\dot{V}$, and mark the operating point. Discuss.</td><td>14-38 For the pump and piping system of Prob. 14-37, plot the required pump head $H_{required}$ (ft of water column) as a function of volume flow rate V (Lpm). On the same plot, compare the available pump head $H_{available}$ versus V, and mark the operating point. Discuss.</td></tr>
<tr><td>808</td><td>14–39E Suppose that the two reservoirs in Prob. 14–37E are 1000 ft further apart horizontally, but at the same elevations. All the constants and parameters are identical to those of Prob. 14–37E except that the total pipe length is 1124 ft instead of 124 ft. Calculate the volume flow rate for this case and compare with the result of Prob. 14–37E. Discuss.</td><td>14-39 Suppose that the two reservoirs in Prob. 14-37 are 300m further apart horizontally, but at the same</td></tr>
</table>

		elevations. Al the constants and parameters are identical to those of Prob. 14-37 except that the total pipe length is 337m instead of 37m. Calculate the volume flow rate for this case and compare with the result of Prob. 14-37. Discuss.
808	**14–40E** Paul realizes that the pump being used in Prob. 14–37E is not well-matched for this application, since its shutoff head (125 ft) is much larger than its required net head (less than 30 ft), and its capacity is fairly low. In other words, this pump is designed for high-head, low-capacity applications, whereas the application at hand is fairly low-head, and a higher capacity is desired. Paul tries to convince his supervisor that a less expensive pump, with lower shutoff head but higher free delivery, would result in a significantly increased flow rate between the two reservoirs. Paul looks through some online brochures, and finds a pump with the performance data shown in Table P14–40E. His supervisor asks him to predict the volume flow rate between the two reservoirs if the existing pump were	14-40 Paul realizes that the pump being used in Prob. 14–37 is not well-matched for this application, since its shutoff head (37.5m) is much larger than its required net head (less than 10m), and its capacity is fairly low. In other words, this pump is designed for highhead, low-capacity applications, whereas the application at hand is fairly low-head, and a higher capacity is desired. Paul tries to convince his supervisor that a less expensive pump, with lower shutoff head but higher free delivery, would result in a significantly increased flow rate between the two reservoirs. Paul looks through some online brochures, and finds a pump with the performance data shown in Table P14–40. His supervisor asks him to predict the volume flow rate between the two reservoirs if the existing pump were
808	replaced with the new pump. (*a*) Perform a least-squares curve fit (regression analysis) of $H_{available}$ versus $\dot{V}^2$, and calculate the best-fit values of coefficients H_0 and a that translate the tabulated data of Table P14–40E into the parabolic expression $H_{available} = H_0 - a\dot{V}^2$. Plot the data points as symbols and the curve fit as a line for comparison. (*b*) Estimate the operating volume flow rate of the new pump if it were to replace the existing pump, all else being equal. Compare to the result of Prob. 14–37E and discuss. Is Paul correct? (*c*) Generate a plot of required net head and available net head as functions of volume flow rate and indicate the operating point on the plot.	replaced with the new pump. (*a*) Perform a least-squares curve fit (regression analysis) of $H_{available}$ versus V^2, and calculate the best-fit values of coefficients H_0 and a that translate the tabulated data of Table P14–40 into the parabolic expression $H_{available} = H_0 - aV^2$. Plot the data points as symbols and the

		curve fit as a line for comparison. (*b*) Estimate the operating volume flow rate of the new pump if it were to replace the existing pump, all else being equal. Compare to the result of Prob. 14–37 and discuss. Is Paul correct? (*c*) Generate a plot of required net head and available net head as functions of volume flow rate and indicate the operating point on the plot.
808	**TABLE P14–40E** $\dot{V}$, gpm *H*, ft 0 38 4 37 8 34 12 29 16 21 20 12 24 0	TABLE P14-40 V, Lpm H, m 0 11.40 15.20 11.10 30.40 10.20 45.60 8.70 60.80 6.30 76.00 3.60 91.20 0
809	**14–49E** A local ventilation system (a hood and duct system) is used to remove air and contaminants produced by a welding operation (Fig. P14–49E). The inner diameter (ID) of the duct is D = 9.06 in, its average roughness is 0.0059 in, and its total length is L = 34.0 ft. There are three elbows along the duct, each with a minor loss coefficient of 0.21. Literature from the hood manufacturer lists the hood entry loss coefficient as 4.6 based on duct velocity. When the damper is fully open, its loss coefficient is 1.8. A squirrel	14-49 A local ventilation system (a hood and duct system) is used to remove air and contaminants produced by a welding operation (Fig. P14-49). The inner diameter (ID) of the duct is D = 23cm, its average roughness is 0.015cm, and its total length is L = 10.2m. There are three elbows along the duct, each with a minor loss coefficient of 0.21. Literature from the hood manufacturer lists the hood entry loss coefficient as 4.6 based on duct velocity. When the damper fully open, its loss coefficient is 1.8. A squirrel

809	 **FIGURE P14–49E**	 FIGURE P14-49
810	cage centrifugal fan with a 9.0-in inlet is available. Its performance data fit a parabolic curve of the form $H_{available} = H_0 - a\dot{V}^2$, where shutoff head H_0 = 2.30 inches of water column, coefficient $a = 8.50 \times 10^{-6}$ inches of water column per $(SCFM)^2$, available head $H_{available}$ is in units of inches of water column, and capacity $\dot{V}$ is in units of standard cubic feet per minute (SCFM, at 77°F). Estimate the volume flow rate in SCFM through this ventilation system. *Answer: 452 SCFM*	cage centrifugal fan with a 23cm inlet is available. Its performance data fits a parabolic curve of the form Havailable = $H_0 - aV^2$, where shutoff head H_0 = 6cm of water column, coefficient a = 2.16 x 10^{-5} cm of water column per $(SCMM)^2$, available head Havailable is in units of centimeters of water column, and capacity V is in units of standard cubic meter per minute (SCMM, at 25°C). Estimate the volume flow rate in SCMM through this ventilation system.
810	**14–50E** For the duct system and fan of Prob. 14–49E, partially closing the damper would decrease the flow rate. All else being unchanged, estimate the minor loss coefficient of the damper required to decrease the volume flow rate by a factor of 2.	14-50 For the duct system and fan of Pob. 14-49, partially closing the damper would decrease the flow rate. All else being unchanged, estimate the minor loss coefficient of the damper required to decrease the volume flow rate by a factor of 2.
810	**14–51E** Repeat Prob. 14–49E, ignoring all minor losses. How important are the minor losses in this problem? Discuss.	14-51 Repeat Prob. 14-49,

		ignoring all minor losses. How important are the minor losses in this problem. Discuss.
810	**14–56E** A centrifugal pump is used to pump water at 77°F from a reservoir whose surface is 20.0 ft above the centerline of the pump inlet (Fig. P14–56E). The piping system consists of 67.5 ft of PVC pipe with an ID of 1.2 in and negligible average inner roughness height. The length of pipe from the bottom of the lower reservoir to the pump inlet is 12.0 ft. There are several minor losses in the piping system: a sharp-edged inlet (K_L = 0.5), two flanged smooth 90° regular elbows (K_L = 0.3 each), two fully open flanged globe valves (K_L = 6.0 each), and an exit loss into the upper reservoir (K_L = 1.05). The pump's required net positive suction head is provided by the manufacturer as a curve fit: $NPSH_{required}$ = 1.0 ft + (0.0054 ft/gpm^2)$\dot{V}^2$, where volume flow rate is in gpm. Estimate the maximum volume flow rate (in units of gpm) that can be pumped without cavitation.	14-56 A centrifugal pump is used to pump water at 25°C from a reservoir whose surface is 6m above the centerline of the pump inlet (Fig. P14-56). The piping system consists of 20m of PVC pipe with an ID of 3cm and negligible average inner roughness height. The length of pipe from the bottom of the lower reservoir to the pump inlet is 4m. There are several minor losses in the piping system: a sharpedged inlet (K_L = 0.5), two flanged smooth 90° regular elbows (K_L = 0.3 each), two fully open flanged globe valves (K_L = 6.0 each), and an exit loss into the upper reservoir (K_L = 1.05). The pump's required net positive suction head is provided by the manufacturer as a curve fit: NPSHrequired = 0.3m + (0.023m/Lpm^2)V^2, where volume flow rate is in Lpm. Estimate the maximum volume flow rate that could be pumped without cavitation.
810	 **FIGURE P14–56E**	 FIGURE P14-56
811	**14–57E** Repeat Prob. 14–56E, but at a water temperature of 150°F. Discuss.	14-57 Repeat Prob. 14-56, but at a water temperature of 65.5°C. Discuss.

811	**14–63E** The two-lobe rotary pump of Fig. P14–63E moves 0.145 gal of a coal slurry in each lobe volume $\dot{V}_{lobe}$. Calculate the volume flow rate of the slurry (in gpm) for the case where $\dot{n}$ = 300 rpm. *Answer: 174 gpm*	**14–63** The two-lobe rotary pump of Fig. P14–63 moves 0.55L of a coal slurry in each lobe volume V_{lobe}. Calculate the volume flow rate of the slurry (in Lpm) for the case where n = 300 rpm.
811	**14–64E** Repeat Prob. 14–63E for the case in which the pump has *three* lobes on each rotor instead of two, and $\dot{V}_{lobe}$ = 0.087 gal.	14–64 Repeat Prob. 14–63 for the case in which the pump has three lobes on each rotor instead of two, and V_{lobe} = 0.33L.
812	**14–77E** A hydroelectric power plant is being designed. The gross head from the reservoir to the tailrace is 1065 ft, and the volume flow rate of water through each turbine is 203,000 gpm at 70°F. There are 12 identical parallel turbines, each with an efficiency of 95.2 percent, and all other mechanical energy losses (through the penstock, etc.) are estimated to reduce the output by 3.5 percent. The generator	**14–77** A hydroelectric power plant is being designed. The gross head from the reservoir to the tailrace is 320m, and the volume flow rate of water through each turbine is 771400Lpm at 21°C. There are 12 identical parallel turbines, each with an efficiency of 95.2 percent, and all other mechanical energy losses (through the penstock, etc.) are estimated to reduce the output by 3.5 percent. The generator
812	itself has an efficiency of 94.5 percent. Estimate the electric power production from the plant in MW.	itself has an efficiency of 94.5 percent. Estimate the electric power production from the plant in MW.
813	**14–81E** A Francis radial-flow hydroturbine has the following dimensions, where location 2 is the inlet and location 1 is the outlet: r_2 = 6.60 ft, r_1 = 4.40 ft, b_2 = 2.60 ft, and b_1 = 7.20 ft. The runner blade angles are β_2 = 82° and β_1 = 46° at the turbine inlet and outlet, respectively. The runner rotates at $\dot{n}$ = 120 rpm. The volume flow rate at design conditions is 4.70×10^6 gpm. Irreversible losses are neglected in this preliminary analysis. Calculate the angle α_2 through which the wicket gates should turn the flow, where α_2 is measured from the radial direction at the runner inlet (Fig. P14–78). Calculate the swirl angle α_1, where α_1 is measured from the radial direction at the runner outlet (Fig. P14–78). Does this turbine have forward or reverse swirl? Predict the power output (hp) and required net head (ft).	**14–81** A Francis radial-flow hydroturbine has the following dimensions, where location 2 is the inlet and location 1 is the outlet: r_2 = 2.0m, r_1 = 1.32m, b_2 = 0.78m, and b_1 = 2.16m. The runner blade angles are β_2 = 82° and β_1 = 46° at the turbine inlet and outlet, respectively. The runner rotates at n = 120 rpm. The volume flow rate at design conditions is 1.79 x 10^5 Lpm. Irreversible losses are neglected in this preliminary analysis. Calculate the angle α_2 through which the wicket gates should turn the flow,

		where α_2 is measured from the radial direction at the runner inlet (Fig. P14–78). Calculate the swirl angle α_1, where α_1 is measured from the radial direction at the runner outlet (Fig. P14–78). Does this turbine have forward or reverse swirl? Predict the power output (kW) and required net head (m).
813	**14–82E** Using EES or other software, adjust the runner blade trailing edge angle β_1 of Prob. 14–81E, keeping all other parameters the same, such that there is no swirl at the turbine outlet. Report β_1 and the corresponding shaft power.	14–82 Using EES or other software, adjust the runner blade trailing edge angle β_1 of Prob. 14–81, keeping all other parameters the same, such that there is no swirl at the turbine outlet. Report β_1 and the corresponding shaft power.
813	**14–92E** A large water pump is being designed for a nuclear reactor. The pump should deliver 2500 gpm of water at a net head of 45 ft at its best efficiency point. A motor that spins at 300 rpm is available. What kind of pump (centrifugal, mixed, or axial) should be designed? Show all your calculations and justify your choice. Estimate the maximum pump efficiency that can be hoped for with this pump. Estimate the power (brake horsepower) required to run the pump.	**14–92** A large water pump is being designed for a nuclear reactor. The pump should deliver 9500 Lpm of water at a net head of 13.5 m at its best efficiency point. A motor that spins at 300 rpm is available. What kind of pump (centrifugal, mixed, or axial) should be designed? Show all your calculations and justify your choice. Estimate the maximum pump efficiency that can be hoped for with this pump. Estimate the power (brake horsepower) required to run the pump.
814	**14–102E** Calculate the turbine specific speed of the turbine in Prob. 14–81E using customary U.S. units. Is it in the normal range for a Francis turbine? If not, what type of turbine would be more appropriate?	**14–102** Calculate the turbine specific speed of the turbine in Prob. 14–81. Is it in the normal range for a Francis turbine? If not, what type of turbine would be more appropriate?