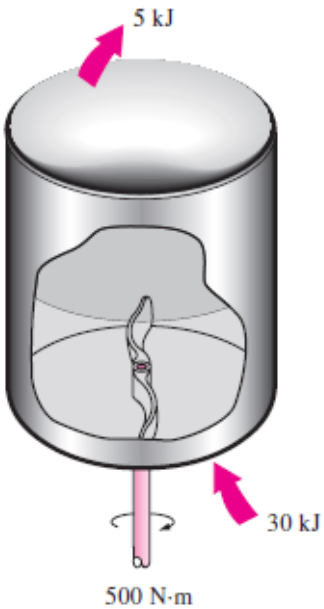
2–37 Water is being heated in a closed pan on top of a range while being stirred by a paddle wheel. During the process, 30 kJ of heat is transferred to the water, and 5 kJ of heat is lost to the surrounding air. The paddle-wheel work amounts to 500 N · m. Determine the final energy of the system if its initial energy is 10 kJ. *Answer:* 35.5 kJ



2-37 Water is heated in a pan on top of a range while being stirred. The energy of the water at the end of the process is to be determined.

Assumptions The pan is stationary and thus the changes in kinetic and potential energies are negligible.

Analysis We take the water in the pan as our system. This is a closed system since no mass enters or leaves. Applying the energy balance on this system gives

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$Q_{in} + W_{sh,in} - Q_{out} = \Delta U = U_2 - U_1$$

$$30\text{ kJ} + 0.5\text{ kJ} - 5\text{ kJ} = U_2 - 10\text{ kJ}$$

$$U_2 = \mathbf{35.5\ kJ}$$

Therefore, the final internal energy of the system is 35.5 kJ.

2–39 A classroom that normally contains 40 people is to be air-conditioned with window air-conditioning units of 5-kW cooling capacity. A person at rest may be assumed to dissipate heat at a rate of about 360 kJ/h. There are 10 light-bulbs in the room, each with a rating of 100 W. The rate of heat transfer to the classroom through the walls and the windows is estimated to be 15,000 kJ/h. If the room air is to be maintained at a constant temperature of 21°C, determine the number of window air-conditioning units required. *Answer:* 2 units

2-39 A classroom is to be air-conditioned using window air-conditioning units. The cooling load is due to people, lights, and heat transfer through the walls and the windows. The number of 5-kW window air conditioning units required is to be determined.

Assumptions There are no heat dissipating equipment (such as computers, TVs, or ranges) in the room.

Analysis The total cooling load of the room is determined from

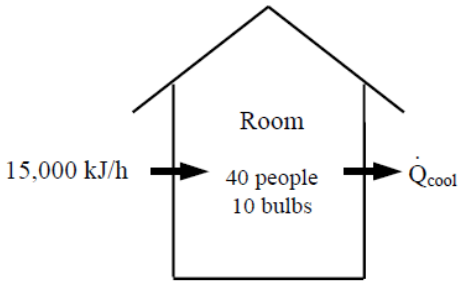
$$\dot{Q}_{\text{cooling}} = \dot{Q}_{\text{lights}} + \dot{Q}_{\text{people}} + \dot{Q}_{\text{heat gain}}$$

where

$$\dot{Q}_{\text{lights}} = 10 \times 100 \text{ W} = 1 \text{ kW}$$

$$\dot{Q}_{\text{people}} = 40 \times 360 \text{ kJ/h} = 4 \text{ kW}$$

$$\dot{Q}_{\text{heat gain}} = 15{,}000 \text{ kJ/h} = 4.17 \text{ kW}$$



Substituting,

$$\dot{Q}_{\text{cooling}} = 1 + 4 + 4.17 = 9.17 \text{ kW}$$

Thus the number of air-conditioning units required is

$$\frac{9.17 \text{ kW}}{5 \text{ kW/unit}} = 1.83 \longrightarrow \textbf{2 units}$$

2–41 The lighting needs of a storage room are being met by 6 fluorescent light fixtures, each fixture containing four lamps rated at 60 W each. All the lamps are on during operating hours of the facility, which are 6 AM to 6 PM 365 days a year. The storage room is actually used for an average of 3 h a day. If the price of electricity is $0.08/kWh, determine the amount of energy and money that will be saved as a result of installing motion sensors. Also, determine the simple payback period if the purchase price of the sensor is $32 and it takes 1 hour to install it at a cost of $40.

2-41 The lighting energy consumption of a storage room is to be reduced by installing motion sensors. The amount of energy and money that will be saved as well as the simple payback period are to be determined.

Assumptions The electrical energy consumed by the ballasts is negligible.

Analysis The plant operates 12 hours a day, and thus currently the lights are on for the entire 12 hour period. The motion sensors installed will keep the lights on for 3 hours, and off for the remaining 9 hours every day. This corresponds to a total of 9×365 = 3285 off hours per year. Disregarding the ballast factor, the annual energy and cost savings become

$$\begin{aligned}\text{Energy Savings} &= (\text{Number of lamps})(\text{Lamp wattage})(\text{Reduction of annual operating hours})\\ &= (24 \text{ lamps})(60 \text{ W/lamp})(3285 \text{ hours/year})\\ &= \textbf{4730 kWh/year}\end{aligned}$$

$$\begin{aligned}\text{Cost Savings} &= (\text{Energy Savings})(\text{Unit cost of energy})\\ &= (4730 \text{ kWh/year})(\$0.08/\text{kWh})\\ &= \textbf{\$378/year}\end{aligned}$$

The implementation cost of this measure is the sum of the purchase price of the sensor plus the labor,

$$\text{Implementation Cost} = \text{Material} + \text{Labor} = \$32 + \$40 = \$72$$

This gives a simple payback period of

$$\text{Simple payback period} = \frac{\text{Implementation cost}}{\text{Annual cost savings}} = \frac{\$72}{\$378/\text{year}} = \textbf{0.19 year} \quad (2.3 \text{ months})$$

Therefore, the motion sensor will pay for itself in about 2 months.

2–42 A university campus has 200 classrooms and 400 faculty offices. The classrooms are equipped with 12 fluorescent tubes, each consuming 110 W, including the electricity used by the ballasts. The faculty offices, on average, have half as many tubes. The campus is open 240 days a year. The classrooms and faculty offices are not occupied an average of 4 h a day, but the lights are kept on. If the unit cost of electricity is \$0.082/kWh, determine how much the campus will save a year if the lights in the classrooms and faculty offices are turned off during unoccupied periods.

2-42 The classrooms and faculty offices of a university campus are not occupied an average of 4 hours a day, but the lights are kept on. The amounts of electricity and money the campus will save per year if the lights are turned off during unoccupied periods are to be determined.

Analysis The total electric power consumed by the lights in the classrooms and faculty offices is

$$\dot{E}_{\text{lighting, classroom}} = (\text{Power consumed per lamp}) \times (\text{No. of lamps}) = (200 \times 12 \times 110\ \text{W}) = 264{,}000 = 264\ \text{kW}$$

$$\dot{E}_{\text{lighting, offices}} = (\text{Power consumed per lamp}) \times (\text{No. of lamps}) = (400 \times 6 \times 110\ \text{W}) = 264{,}000 = 264\ \text{kW}$$

$$\dot{E}_{\text{lighting, total}} = \dot{E}_{\text{lighting, classroom}} + \dot{E}_{\text{lighting, offices}} = 264 + 264 = 528\ \text{kW}$$

Noting that the campus is open 240 days a year, the total number of unoccupied work hours per year is

$$\text{Unoccupied hours} = (4\ \text{hours/day})(240\ \text{days/year}) = 960\ \text{h/yr}$$

Then the amount of electrical energy consumed per year during unoccupied work period and its cost are

$$\text{Energy savings} = (\dot{E}_{\text{lighting, total}})(\text{Unoccupied hours}) = (528\ \text{kW})(960\ \text{h/yr}) = 506{,}880\ \text{kWh}$$

$$\text{Cost savings} = (\text{Energy savings})(\text{Unit cost of energy}) = (506{,}880\ \text{kWh/yr})(\$0.082/\text{kWh}) = \mathbf{\$41{,}564/yr}$$

Discussion Note that simple conservation measures can result in significant energy and cost savings.

2–44 A fan is to accelerate quiescent air to a velocity of 10 m/s at a rate of 4 m^3/s. Determine the minimum power that must be supplied to the fan. Take the density of air to be 1.18 kg/m^3. *Answer:* 236 W

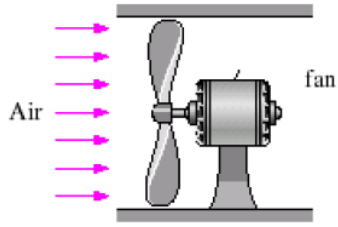
2-44 A fan is to accelerate quiescent air to a specified velocity at a specified flow rate. The minimum power that must be supplied to the fan is to be determined.

Assumptions The fan operates steadily.

Properties The density of air is given to be $\rho = 1.18$ kg/m^3.

Analysis A fan transmits the mechanical energy of the shaft (shaft power) to mechanical energy of air (kinetic energy). For a control volume that encloses the fan, the energy balance can be written as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{\text{system}} / dt^{\nearrow 0\ \text{(steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0 \quad \rightarrow \quad \dot{E}_{in} = \dot{E}_{out}$$



$$\dot{W}_{\text{sh, in}} = \dot{m}_{\text{air}}\,\text{ke}_{\text{out}} = \dot{m}_{\text{air}}\frac{V_{\text{out}}^2}{2}$$

where

$$\dot{m}_{\text{air}} = \rho\dot{V} = (1.18\ \text{kg/m}^3)(4\ \text{m}^3/\text{s}) = 4.72\ \text{kg/s}$$

Substituting, the minimum power input required is determined to be

$$\dot{W}_{\text{sh, in}} = \dot{m}_{\text{air}}\frac{V_{\text{out}}^2}{2} = (4.72\ \text{kg/s})\frac{(10\ \text{m/s})^2}{2}\left(\frac{1\ \text{J/kg}}{1\ \text{m}^2/\text{s}^2}\right) = 236\ \text{J/s} = \mathbf{236\ W}$$

Discussion The conservation of energy principle requires the energy to be conserved as it is converted from one form to another, and it does not allow any energy to be created or destroyed during a process. In reality, the power required will be considerably higher because of the losses associated with the conversion of mechanical shaft energy to kinetic energy of air.

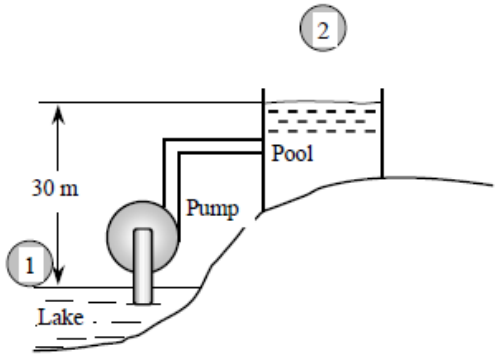
2–46 A water pump that consumes 2 kW of electric power when operating is claimed to take in water from a lake and pump it to a pool whose free surface is 30 m above the free surface of the lake at a rate of 50 L/s. Determine if this claim is reasonable.

2-46 A water pump is claimed to raise water to a specified elevation at a specified rate while consuming electric power at a specified rate. The validity of this claim is to be investigated.

Assumptions **1** The water pump operates steadily. **2** Both the lake and the pool are open to the atmosphere, and the flow velocities in them are negligible.

Properties We take the density of water to be $\rho = 1000$ kg/m^3 = 1 kg/L.

Analysis For a control volume that encloses the pump-motor unit, the energy balance can be written as



$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt^{\nearrow 0\ (steady)}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{in} + \dot{m}pe_1 = \dot{m}pe_2 \qquad \rightarrow \qquad \dot{W}_{in} = \dot{m}\Delta pe = \dot{m}g(z_2 - z_1)$$

since the changes in kinetic and flow energies of water are negligible. Also,

$$\dot{m} = \rho\dot{V} = (1\,\text{kg/L})(50\,\text{L/s}) = 50\,\text{kg/s}$$

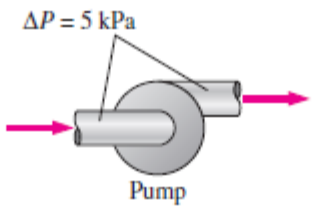
Substituting, the minimum power input required is determined to be

$$\dot{W}_{in} = \dot{m}g(z_2 - z_1) = (50\,\text{kg/s})(9.81\,\text{m/s}^2)(30\,\text{m})\left(\frac{1\,\text{kJ/kg}}{1000\,\text{m}^2/\text{s}^2}\right) = 14.7\,\text{kJ/s} = \mathbf{14.7\ kW}$$

which is much greater than 2 kW. Therefore, the claim is **false.**

Discussion The conservation of energy principle requires the energy to be conserved as it is converted from one form to another, and it does not allow any energy to be created or destroyed during a process. In reality, the power required will be considerably higher than 14.7 kW because of the losses associated with the conversion of electrical-to-mechanical shaft and mechanical shaft-to-potential energy of water.

2–47 The driving force for fluid flow is the pressure difference, and a pump operates by raising the pressure of a fluid (by converting the mechanical shaft work to flow energy). A gasoline pump is measured to consume 5.2 kW of electric power when operating. If the pressure differential between the outlet and inlet of the pump is measured to be 5 kPa and the changes in velocity and elevation are negligible, determine the maximum possible volume flow rate of gasoline.

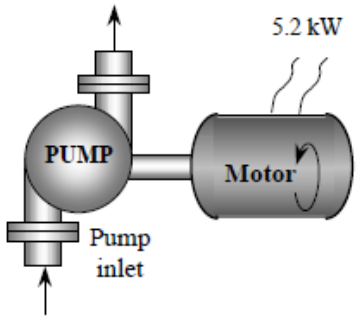


2-47 A gasoline pump raises the pressure to a specified value while consuming electric power at a specified rate. The maximum volume flow rate of gasoline is to be determined.

Assumptions **1** The gasoline pump operates steadily. **2** The changes in kinetic and potential energies across the pump are negligible.

Analysis For a control volume that encloses the pump-motor unit, the energy balance can be written as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt^{\nearrow 0\ (steady)}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0 \quad \rightarrow \quad \dot{E}_{in} = \dot{E}_{out}$$



$$\dot{W}_{in} + \dot{m}(Pv)_1 = \dot{m}(Pv)_2 \quad \rightarrow \quad \dot{W}_{in} = \dot{m}(P_2 - P_1)v = \dot{V}\,\Delta P$$

since $\dot{m} = \dot{V}/v$ and the changes in kinetic and potential energies of gasoline are negligible, Solving for volume flow rate and substituting, the maximum flow rate is determined to be

$$\dot{V}_{max} = \frac{\dot{W}_{in}}{\Delta P} = \frac{5.2\ \text{kJ/s}}{5\ \text{kPa}}\left(\frac{1\ \text{kPa}\cdot\text{m}^3}{1\ \text{kJ}}\right) = \mathbf{1.04\ m^3/s}$$

Discussion The conservation of energy principle requires the energy to be conserved as it is converted from one form to another, and it does not allow any energy to be created or destroyed during a process. In reality, the volume flow rate will be less because of the losses associated with the conversion of electrical-to-mechanical shaft and mechanical shaft-to-flow energy.

2–48 The 60-W fan of a central heating system is to circulate air through the ducts. The analysis of the flow shows that the fan needs to raise the pressure of air by 50 Pa to maintain flow. The fan is located in a horizontal flow section whose diameter is 30 cm at both the inlet and the outlet. Determine the highest possible average flow velocity in the duct.

2-48 The fan of a central heating system circulates air through the ducts. For a specified pressure rise, the highest possible average flow velocity is to be determined.

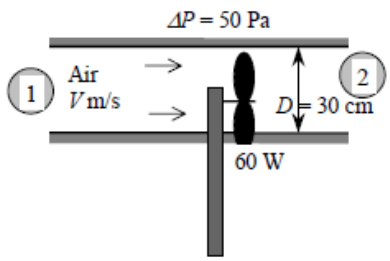
Assumptions **1** The fan operates steadily. **2** The changes in kinetic and potential energies across the fan are negligible.

Analysis For a control volume that encloses the fan unit, the energy balance can be written as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt^{\nearrow 0\ (steady)}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0 \quad \rightarrow \quad \dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{in} + \dot{m}(Pv)_1 = \dot{m}(Pv)_2 \quad \rightarrow \quad \dot{W}_{in} = \dot{m}(P_2 - P_1)v = \dot{V}\,\Delta P$$

since $\dot{m} = \dot{V}/v$ and the changes in kinetic and potential energies of gasoline are negligible, Solving for volume flow rate and substituting, the maximum flow rate and velocity are determined to be



$$\dot{V}_{max} = \frac{\dot{W}_{in}}{\Delta P} = \frac{60\ \text{J/s}}{50\ \text{Pa}}\left(\frac{1\ \text{Pa}\cdot\text{m}^3}{1\ \text{J}}\right) = 1.2\ \text{m}^3/\text{s}$$

$$V_{max} = \frac{\dot{V}_{max}}{A_c} = \frac{\dot{V}_{max}}{\pi D^2/4} = \frac{1.2\ \text{m}^3/\text{s}}{\pi(0.30\ \text{m})^2/4} = \mathbf{17.0\ m/s}$$

Discussion The conservation of energy principle requires the energy to be conserved as it is converted from one form to another, and it does not allow any energy to be created or destroyed during a process. In reality, the velocity will be less because of the losses associated with the conversion of electrical-to-mechanical shaft and mechanical shaft-to-flow energy.

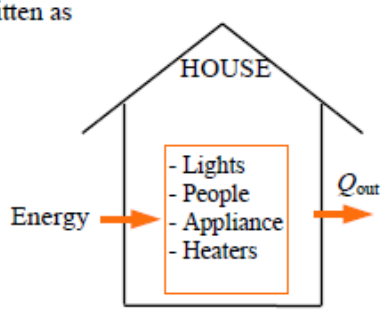
2–49E At winter design conditions, a house is projected to lose heat at a rate of 60,000 Btu/h. The internal heat gain from people, lights, and appliances is estimated to be 6000 Btu/h. If this house is to be heated by electric resistance heaters, determine the required rated power of these heaters in kW to maintain the house at constant temperature.

2-49E The heat loss from a house is to be made up by heat gain from people, lights, appliances, and resistance heaters. For a specified rate of heat loss, the required rated power of resistance heaters is to be determined.

Assumptions **1** The house is well-sealed, so no air enters or heaves the house. **2** All the lights and appliances are kept on. **3** The house temperature remains constant.

Analysis Taking the house as the system, the energy balance can be written as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt^{\nearrow 0\ (steady)}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0 \quad \rightarrow \quad \dot{E}_{in} = \dot{E}_{out}$$



where $\dot{E}_{out} = \dot{Q}_{out} = 60{,}000$ Btu/h and

$$\dot{E}_{in} = \dot{E}_{people} + \dot{E}_{lights} + \dot{E}_{appliance} + \dot{E}_{heater} = 6000 \text{ Btu/h} + \dot{E}_{heater}$$

Substituting, the required power rating of the heaters becomes

$$\dot{E}_{heater} = 60{,}000 - 6000 = 54{,}000 \text{ Btu/h}\left(\frac{1 \text{ kW}}{3412 \text{ Btu/h}}\right) = \mathbf{15.8\ kW}$$

Discussion When the energy gain of the house equals the energy loss, the temperature of the house remains constant. But when the energy supplied drops below the heat loss, the house temperature starts dropping.

2–51 Consider a 1400-kg car cruising at constant speed of 70 km/h. Now the car starts to pass another car, by accelerating to 110 km/h in 5 s. Determine the additional power needed to achieve this acceleration. What would your answer be if the total mass of the car were only 700 kg? *Answers:* 77.8 kW, 38.9 kW

2-51 A car cruising at a constant speed to accelerate to a specified speed within a specified time. The additional power needed to achieve this acceleration is to be determined.

Assumptions **1** The additional air drag, friction, and rolling resistance are not considered. **2** The road is a level road.

Analysis We consider the entire car as the system, except that let's assume the power is supplied to the engine externally for simplicity (rather that internally by the combustion of a fuel and the associated energy conversion processes). The energy balance for the entire mass of the car can be written in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0 \quad \rightarrow \quad \dot{E}_{in} = dE_{sys}/dt \cong \frac{\Delta E_{sys}}{\Delta t}$$

$$\dot{W}_{in} = \frac{\Delta KE}{\Delta t} = \frac{m(V_2^2 - V_1^2)/2}{\Delta t}$$

since we are considering the change in the energy content of the car due to a change in its kinetic energy (acceleration). Substituting, the required additional power input to achieve the indicated acceleration becomes

$$\dot{W}_{in} = m\frac{V_2^2 - V_1^2}{2\Delta t} = (1400\text{ kg})\frac{(110/3.6\text{ m/s})^2 - (70/3.6\text{ m/s})^2}{2(5\text{ s})}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = 77.8\text{ kJ/s} = \mathbf{77.8\ kW}$$

since 1 m/s = 3.6 km/h. If the total mass of the car were 700 kg only, the power needed would be

$$\dot{W}_{in} = m\frac{V_2^2 - V_1^2}{2\Delta t} = (700\text{ kg})\frac{(110/3.6\text{ m/s})^2 - (70/3.6\text{ m/s})^2}{2(5\text{ s})}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = \mathbf{38.9\ kW}$$

Discussion Note that the power needed to accelerate a car is inversely proportional to the acceleration time. Therefore, the short acceleration times are indicative of powerful engines.

2–56 Consider a 3-kW hooded electric open burner in an area where the unit costs of electricity and natural gas are \$0.07/kWh and \$1.20/therm, respectively. The efficiency of open burners can be taken to be 73 percent for electric burners and 38 percent for gas burners. Determine the rate of energy consumption and the unit cost of utilized energy for both electric and gas burners.

2-56 A hooded electric open burner and a gas burner are considered. The amount of the electrical energy used directly for cooking and the cost of energy per "utilized" kWh are to be determined.

Analysis The efficiency of the electric heater is given to be 73 percent. Therefore, a burner that consumes 3-kW of electrical energy will supply

$$\eta_{gas} = 38\%$$

$$\eta_{electric} = 73\%$$

$$\dot{Q}_{utilized} = (\text{Energy input}) \times (\text{Efficiency}) = (3\,\text{kW})(0.73) = \mathbf{2.19\ kW}$$

of useful energy. The unit cost of utilized energy is inversely proportional to the efficiency, and is determined from

$$\text{Cost of utilized energy} = \frac{\text{Cost of energy input}}{\text{Efficiency}} = \frac{\$0.07/\text{kWh}}{0.73} = \mathbf{\$0.096/kWh}$$

Noting that the efficiency of a gas burner is 38 percent, the energy input to a gas burner that supplies utilized energy at the same rate (2.19 kW) is

$$\dot{Q}_{input,\,gas} = \frac{\dot{Q}_{utilized}}{\text{Efficiency}} = \frac{2.19\,\text{kW}}{0.38} = \mathbf{5.76\ kW}\ \ (= 19{,}660\ \text{Btu/h})$$

since 1 kW = 3412 Btu/h. Therefore, a gas burner should have a rating of at least 19,660 Btu/h to perform as well as the electric unit.

Noting that 1 therm = 29.3 kWh, the unit cost of utilized energy in the case of gas burner is determined the same way to be

$$\text{Cost of utilized energy} = \frac{\text{Cost of energy input}}{\text{Efficiency}} = \frac{\$1.20/(29.3\,\text{kWh})}{0.38} = \mathbf{\$0.108/kWh}$$

2–59 A 75-hp (shaft output) motor that has an efficiency of 91.0 percent is worn out and is to be replaced by a high-efficiency motor that has an efficiency of 95.4 percent. The motor operates 4368 hours a year at a load factor of 0.75. Taking the cost of electricity to be \$0.08/kWh, determine the amount of energy and money saved as a result of installing the high-efficiency motor instead of the standard motor. Also, determine the simple payback period if the purchase prices of the standard and high-efficiency motors are \$5449 and \$5520, respectively.

2-59 A worn out standard motor is to be replaced by a high efficiency one. The amount of electrical energy and money savings as a result of installing the high efficiency motor instead of the standard one as well as the simple payback period are to be determined.

Assumptions The load factor of the motor remains constant at 0.75.

Analysis The electric power drawn by each motor and their difference can be expressed as

$$\dot{W}_{\text{electric in, standard}} = \dot{W}_{\text{shaft}} / \eta_{\text{standard}} = (\text{Power rating})(\text{Load factor}) / \eta_{\text{standard}}$$

$$\dot{W}_{\text{electric in, efficient}} = \dot{W}_{\text{shaft}} / \eta_{\text{efficient}} = (\text{Power rating})(\text{Load factor}) / \eta_{\text{efficient}}$$

$$\text{Power savings} = \dot{W}_{\text{electric in, standard}} - \dot{W}_{\text{electric in, efficient}}$$

$$= (\text{Power rating})(\text{Load factor})[1/\eta_{\text{standard}} - 1/\eta_{\text{efficient}}]$$

where η_{standard} is the efficiency of the standard motor, and $\eta_{\text{efficient}}$ is the efficiency of the comparable high efficiency motor. Then the annual energy and cost savings associated with the installation of the high efficiency motor are determined to be

Energy Savings = (Power savings)(Operating Hours)

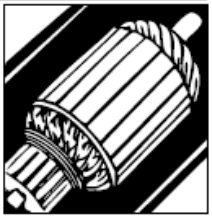
= (Power Rating)(Operating Hours)(Load Factor)($1/\eta_{\text{standard}}$- $1/\eta_{\text{efficient}}$)

= (75 hp)(0.746 kW/hp)(4,368 hours/year)(0.75)(1/0.91 - 1/0.954)

= **9,290 kWh/year**

$\eta_{\text{old}} = 91.0\%$

$\eta_{\text{new}} = 95.4\%$



Cost Savings = (Energy savings)(Unit cost of energy)

= (9,290 kWh/year)($0.08/kWh)

= **$743/year**

The implementation cost of this measure consists of the excess cost the high efficiency motor over the standard one. That is,

Implementation Cost = Cost differential = $5,520 - $5,449 = $71

This gives a simple payback period of

$$\text{Simple payback period} = \frac{\text{Implementation cost}}{\text{Annual cost savings}} = \frac{\$71}{\$743/\text{year}} = \textbf{0.096 year} \text{ (or 1.1 months)}$$

Therefore, the high-efficiency motor will pay for its cost differential in about one month.

2–63 Consider a classroom for 55 students and one instructor, each generating heat at a rate of 100 W. Lighting is provided by 18 fluorescent lightbulbs, 40 W each, and the ballasts consume an additional 10 percent. Determine the rate of internal heat generation in this classroom when it is fully occupied.

2-63 A classroom has a specified number of students, instructors, and fluorescent light bulbs. The rate of internal heat generation in this classroom is to be determined.

Assumptions **1** There is a mix of men, women, and children in the classroom. **2** The amount of light (and thus energy) leaving the room through the windows is negligible.

Properties The average rate of heat generation from people seated in a room/office is given to be 100 W.

Analysis The amount of heat dissipated by the lamps is equal to the amount of electrical energy consumed by the lamps, including the 10% additional electricity consumed by the ballasts. Therefore,

$$\dot{Q}_{\text{lighting}} = (\text{Energy consumed per lamp}) \times (\text{No. of lamps})$$
$$= (40\ \text{W})(1.1)(18) = 792\ \text{W}$$
$$\dot{Q}_{\text{people}} = (\text{No. of people}) \times \dot{Q}_{\text{person}} = 56 \times (100\ \text{W}) = 5600\ \text{W}$$

Then the total rate of heat gain (or the internal heat load) of the classroom from the lights and people become

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{lighting}} + \dot{Q}_{\text{people}} = 792 + 5600 = \mathbf{6392\ W}$$

2–65 Electric power is to be generated by installing a hydraulic turbine–generator at a site 70 m below the free surface of a large water reservoir that can supply water at a rate of 1500 kg/s steadily. If the mechanical power output of the turbine is 800 kW and the electric power generation is 750 kW, determine the turbine efficiency and the combined turbine–generator efficiency of this plant. Neglect losses in the pipes.

2-65 A hydraulic turbine-generator is generating electricity from the water of a large reservoir. The combined turbine-generator efficiency and the turbine efficiency are to be determined.

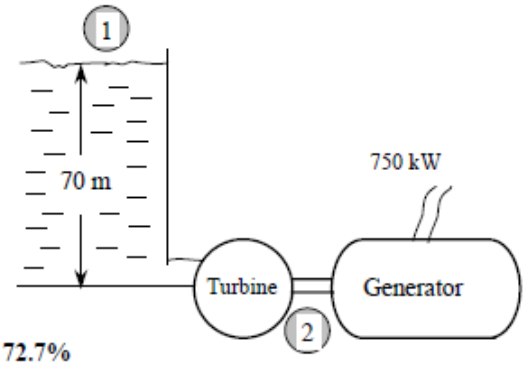
Assumptions **1** The elevation of the reservoir remains constant. **2** The mechanical energy of water at the turbine exit is negligible.

Analysis We take the free surface of the reservoir to be point 1 and the turbine exit to be point 2. We also take the turbine exit as the reference level ($z_2 = 0$), and thus the potential energy at points 1 and 2 are $pe_1 = gz_1$ and $pe_2 = 0$. The flow energy P/ρ at both points is zero since both 1 and 2 are open to the atmosphere ($P_1 = P_2 = P_{atm}$). Further, the kinetic energy at both points is zero ($ke_1 = ke_2 = 0$) since the water at point 1 is essentially motionless, and the kinetic energy of water at turbine exit is assumed to be negligible. The potential energy of water at point 1 is

$$pe_1 = gz_1 = (9.81\,\text{m/s}^2)(70\,\text{m})\left(\frac{1\,\text{kJ/kg}}{1000\,\text{m}^2/\text{s}^2}\right) = 0.687\,\text{kJ/kg}$$

Then the rate at which the mechanical energy of the fluid is supplied to the turbine become

$$\begin{aligned}\left|\Delta\dot{E}_{\text{mech,fluid}}\right| &= \dot{m}(e_{\text{mech,in}} - e_{\text{mech,out}}) = \dot{m}(pe_1 - 0)\\ &= \dot{m}pe_1\\ &= (1500\,\text{kg/s})(0.687\,\text{kJ/kg})\\ &= 1031\,\text{kW}\end{aligned}$$



The combined turbine-generator and the turbine efficiency are determined from their definitions,

$$\eta_{\text{turbine-gen}} = \frac{\dot{W}_{\text{elect,out}}}{|\Delta\dot{E}_{\text{mech,fluid}}|} = \frac{750\,\text{kW}}{1031\,\text{kW}} = 0.727 \quad \text{or} \quad \mathbf{72.7\%}$$

$$\eta_{\text{turbine}} = \frac{\dot{W}_{\text{shaft,out}}}{|\Delta\dot{E}_{\text{mech,fluid}}|} = \frac{800\,\text{kW}}{1031\,\text{kW}} = 0.776 \quad \text{or} \quad \mathbf{77.6\%}$$

Therefore, the reservoir supplies 1031 kW of mechanical energy to the turbine, which converts 800 kW of it to shaft work that drives the generator, which generates 750 kW of electric power.

Discussion This problem can also be solved by taking point 1 to be at the turbine inlet, and using flow energy instead of potential energy. It would give the same result since the flow energy at the turbine inlet is equal to the potential energy at the free surface of the reservoir.

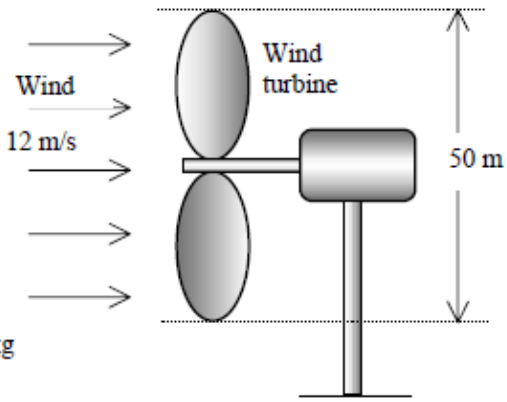
2–66 At a certain location, wind is blowing steadily at 12 m/s. Determine the mechanical energy of air per unit mass and the power generation potential of a wind turbine with 50-m-diameter blades at that location. Also determine the actual electric power generation assuming an overall efficiency of 30 percent. Take the air density to be 1.25 kg/m^3.

2-66 Wind is blowing steadily at a certain velocity. The mechanical energy of air per unit mass, the power generation potential, and the actual electric power generation are to be determined.

Assumptions **1** The wind is blowing steadily at a constant uniform velocity. **2** The efficiency of the wind turbine is independent of the wind speed.

Properties The density of air is given to be $\rho = 1.25$ kg/m^3.

Analysis Kinetic energy is the only form of mechanical energy the wind possesses, and it can be converted to work entirely. Therefore, the power potential of the wind is its kinetic energy, which is $V^2/2$ per unit mass, and $\dot{m}V^2/2$ for a given mass flow rate:



$$e_{\text{mech}} = ke = \frac{V^2}{2} = \frac{(12\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = 0.072\text{ kJ/kg}$$

$$\dot{m} = \rho VA = \rho V\frac{\pi D^2}{4} = (1.25\text{ kg/m}^3)(12\text{ m/s})\frac{\pi(50\text{ m})^2}{4} = 29{,}450\text{ kg/s}$$

$$\dot{W}_{\max} = \dot{E}_{\text{mech}} = \dot{m}e_{\text{mech}} = (29{,}450\text{ kg/s})(0.072\text{ kJ/kg}) = \mathbf{2121\ kW}$$

The actual electric power generation is determined by multiplying the power generation potential by the efficiency,

$$\dot{W}_{\text{elect}} = \eta_{\text{wind turbine}}\dot{W}_{\max} = (0.30)(2121\text{ kW}) = \mathbf{636\ kW}$$

Therefore, 636 kW of actual power can be generated by this wind turbine at the stated conditions.

Discussion The power generation of a wind turbine is proportional to the cube of the wind velocity, and thus the power generation will change strongly with the wind conditions.

2–68 A wind turbine is rotating at 15 rpm under steady winds flowing through the turbine at a rate of 42,000 kg/s. The tip velocity of the turbine blade is measured to be 250 km/h. If 180 kW power is produced by the turbine, determine (*a*) the average velocity of the air and (*b*) the conversion efficiency of the turbine. Take the density of air to be 1.31 kg/m^3.

2-68 A wind turbine produces 180 kW of power. The average velocity of the air and the conversion efficiency of the turbine are to be determined.

Assumptions The wind turbine operates steadily.

Properties The density of air is given to be 1.31 kg/m^3.

Analysis (*a*) The blade diameter and the blade span area are

$$D = \frac{V_{tip}}{\pi \dot{n}} = \frac{(250\,\text{km/h})\left(\dfrac{1\,\text{m/s}}{3.6\,\text{km/h}}\right)}{\pi(15\,\text{L/min})\left(\dfrac{1\,\text{min}}{60\,\text{s}}\right)} = 88.42\,\text{m}$$

$$A = \frac{\pi D^2}{4} = \frac{\pi(88.42\,\text{m})^2}{4} = 6140\,\text{m}^2$$

Then the average velocity of air through the wind turbine becomes

$$V = \frac{\dot{m}}{\rho A} = \frac{42{,}000\,\text{kg/s}}{(1.31\,\text{kg/m}^3)(6140\,\text{m}^2)} = \mathbf{5.23\ m/s}$$

(*b*) The kinetic energy of the air flowing through the turbine is

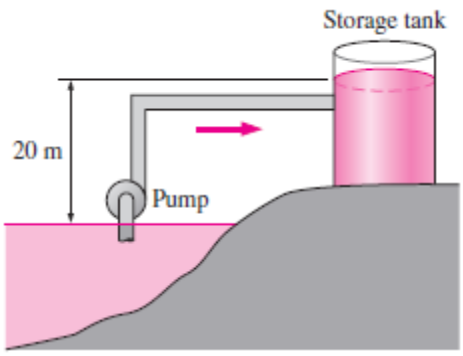
$$\dot{KE} = \frac{1}{2}\dot{m}V^2 = \frac{1}{2}(42{,}000\,\text{kg/s})(5.23\,\text{m/s})^2 = 574.3\,\text{kW}$$

Then the conversion efficiency of the turbine becomes

$$\eta = \frac{\dot{W}}{\dot{KE}} = \frac{180\,\text{kW}}{574.3\,\text{kW}} = \mathbf{0.313 = 31.3\%}$$

Discussion Note that about one-third of the kinetic energy of the wind is converted to power by the wind turbine, which is typical of actual turbines.

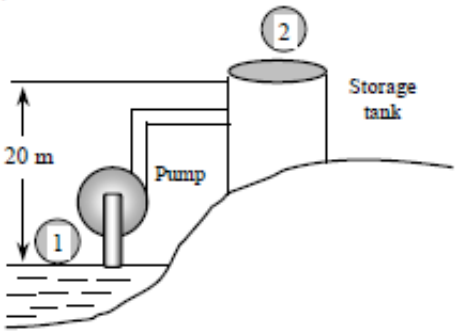
2–69 Water is pumped from a lake to a storage tank 20 m above at a rate of 70 L/s while consuming 20.4 kW of electric power. Disregarding any frictional losses in the pipes and any changes in kinetic energy, determine (*a*) the overall efficiency of the pump–motor unit and (*b*) the pressure difference between the inlet and the exit of the pump.



2-69 Water is pumped from a lake to a storage tank at a specified rate. The overall efficiency of the pump-motor unit and the pressure difference between the inlet and the exit of the pump are to be determined. √

Assumptions **1** The elevations of the tank and the lake remain constant. **2** Frictional losses in the pipes are negligible. **3** The changes in kinetic energy are negligible. **4** The elevation difference across the pump is negligible.

Properties We take the density of water to be $\rho = 1000\ \text{kg/m}^3$.



Analysis (*a*) We take the free surface of the lake to be point 1 and the free surfaces of the storage tank to be point 2. We also take the lake surface as the reference level ($z_1 = 0$), and thus the potential energy at points 1 and 2 are $pe_1 = 0$ and $pe_2 = gz_2$. The flow energy at both points is zero since both 1 and 2 are open to the atmosphere ($P_1 = P_2 = P_{atm}$). Further, the kinetic energy at both points is zero ($ke_1 = ke_2 = 0$) since the water at both locations is essentially stationary. The mass flow rate of water and its potential energy at point 2 are

$$\dot{m} = \rho\dot{V} = (1000\ \text{kg/m}^3)(0.070\ \text{m}^3/\text{s}) = 70\ \text{kg/s}$$

$$pe_2 = gz_2 = (9.81\ \text{m/s}^2)(20\ \text{m})\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right) = 0.196\ \text{kJ/kg}$$

Then the rate of increase of the mechanical energy of water becomes

$$\Delta\dot{E}_{\text{mech,fluid}} = \dot{m}(e_{\text{mech,out}} - e_{\text{mech,in}}) = \dot{m}(pe_2 - 0) = \dot{m}pe_2 = (70\ \text{kg/s})(0.196\ \text{kJ/kg}) = 13.7\ \text{kW}$$

The overall efficiency of the combined pump-motor unit is determined from its definition,

$$\eta_{\text{pump-motor}} = \frac{\Delta\dot{E}_{\text{mech,fluid}}}{\dot{W}_{\text{elect,in}}} = \frac{13.7\ \text{kW}}{20.4\ \text{kW}} = 0.672 \quad \text{or} \quad \mathbf{67.2\%}$$

(*b*) Now we consider the pump. The change in the mechanical energy of water as it flows through the pump consists of the change in the flow energy only since the elevation difference across the pump and the change in the kinetic energy are negligible. Also, this change must be equal to the useful mechanical energy supplied by the pump, which is 13.7 kW:

$$\Delta\dot{E}_{\text{mech,fluid}} = \dot{m}(e_{\text{mech,out}} - e_{\text{mech,in}}) = \dot{m}\frac{P_2 - P_1}{\rho} = \dot{V}\Delta P$$

Solving for ΔP and substituting,

$$\Delta P = \frac{\Delta\dot{E}_{\text{mech,fluid}}}{\dot{V}} = \frac{13.7\ \text{kJ/s}}{0.070\ \text{m}^3/\text{s}}\left(\frac{1\ \text{kPa}\cdot\text{m}^3}{1\ \text{kJ}}\right) = \mathbf{196\ kPa}$$

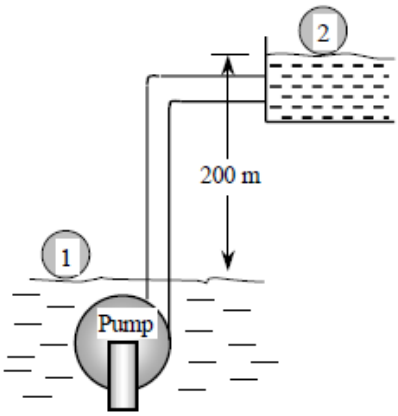
Therefore, the pump must boost the pressure of water by 196 kPa in order to raise its elevation by 20 m.

Discussion Note that only two-thirds of the electric energy consumed by the pump-motor is converted to the mechanical energy of water; the remaining one-third is wasted because of the inefficiencies of the pump and the motor.

#

2–70 A geothermal pump is used to pump brine whose density is 1050 kg/m³ at a rate of 0.3 m³/s from a depth of 200 m. For a pump efficiency of 74 percent, determine the required power input to the pump. Disregard frictional losses in the pipes, and assume the geothermal water at 200 m depth to be exposed to the atmosphere.

2-70 Geothermal water is raised from a given depth by a pump at a specified rate. For a given pump efficiency, the required power input to the pump is to be determined.



Assumptions **1** The pump operates steadily. **2** Frictional losses in the pipes are negligible. **3** The changes in kinetic energy are negligible. **4** The geothermal water is exposed to the atmosphere and thus its free surface is at atmospheric pressure.

Properties The density of geothermal water is given to be $\rho = 1050\ \text{kg/m}^3$.

Analysis The elevation of geothermal water and thus its potential energy changes, but it experiences no changes in its velocity and pressure. Therefore, the change in the total mechanical energy of geothermal water is equal to the change in its potential energy, which is gz per unit mass, and $\dot{m}gz$ for a given mass flow rate. That is,

$$\Delta\dot{E}_{\text{mech}} = \dot{m}\Delta e_{\text{mech}} = \dot{m}\Delta pe = \dot{m}g\Delta z = \rho\dot{V}g\Delta z$$

$$= (1050\ \text{kg/m}^3)(0.3\ \text{m}^3/\text{s})(9.81\ \text{m/s}^2)(200\ \text{m})\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kW}}{1000\ \text{N}\cdot\text{m/s}}\right) = 618.0\ \text{kW}$$

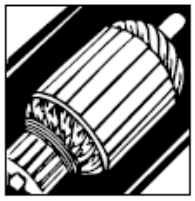
Then the required power input to the pump becomes

$$\dot{W}_{\text{pump, elect}} = \frac{\Delta\dot{E}_{\text{mech}}}{\eta_{\text{pump-motor}}} = \frac{618\ \text{kW}}{0.74} = \mathbf{835\ kW}$$

Discussion The frictional losses in piping systems are usually significant, and thus a larger pump will be needed to overcome these frictional losses.

2–71 Consider an electric motor with a shaft power output of 20 kW and an efficiency of 88 percent. Determine the rate at which the motor dissipates heat to the room it is in when the motor operates at full load. In winter, this room is normally heated by a 2-kW resistance heater. Determine if it is necessary to turn the heater on when the motor runs at full load.

2-71 An electric motor with a specified efficiency operates in a room. The rate at which the motor dissipates heat to the room it is in when operating at full load and if this heat dissipation is adequate to heat the room in winter are to be determined.



Assumptions The motor operates at full load.

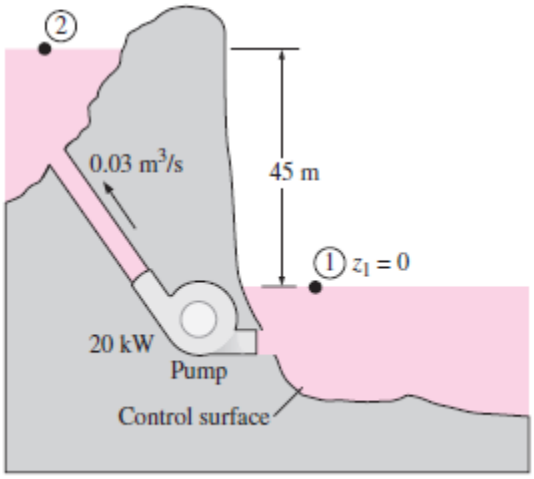
Analysis The motor efficiency represents the fraction of electrical energy consumed by the motor that is converted to mechanical work. The remaining part of electrical energy is converted to thermal energy and is dissipated as heat.

$$\dot{Q}_{\text{dissipated}} = (1-\eta_{\text{motor}})\dot{W}_{\text{in, electric}} = (1-0.88)(20\ \text{kW}) = \mathbf{2.4\ kW}$$

which is larger than the rating of the heater. Therefore, the heat dissipated by the motor alone is sufficient to heat the room in winter, and there is no need to turn the heater on.

Discussion Note that the heat generated by electric motors is significant, and it should be considered in the determination of heating and cooling loads.

2–74 Water is pumped from a lower reservoir to a higher reservoir by a pump that provides 20 kW of shaft power. The free surface of the upper reservoir is 45 m higher than that of the lower reservoir. If the flow rate of water is measured to be 0.03 m^3/s, determine mechanical power that is converted to thermal energy during this process due to frictional effects.

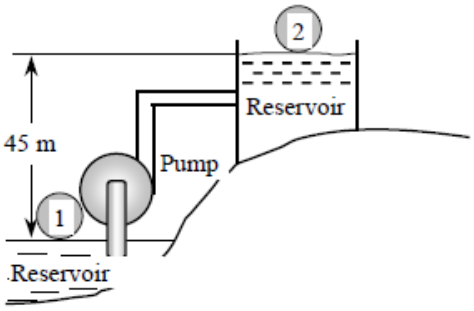


2-74 Water is pumped from a lower reservoir to a higher reservoir at a specified rate. For a specified shaft power input, the power that is converted to thermal energy is to be determined.

Assumptions **1** The pump operates steadily. **2** The elevations of the reservoirs remain constant. **3** The changes in kinetic energy are negligible.

Properties We take the density of water to be ρ = 1000 kg/m^3.

Analysis The elevation of water and thus its potential energy changes during pumping, but it experiences no changes in its velocity and pressure. Therefore, the change in the total mechanical energy of water is equal to the change in its potential energy, which is gz per unit mass, and $\dot{m}gz$ for a given mass flow rate. That is,



$$\Delta\dot{E}_{mech} = \dot{m}\Delta e_{mech} = \dot{m}\Delta pe = \dot{m}g\Delta z = \rho\dot{V}g\Delta z$$

$$= (1000\ kg/m^3)(0.03\ m^3/s)(9.81\ m/s^2)(45\ m)\left(\frac{1\ N}{1\ kg\cdot m/s^2}\right)\left(\frac{1\ kW}{1000\ N\cdot m/s}\right) = 13.2\ kW$$

Then the mechanical power lost because of frictional effects becomes

$$\dot{W}_{frict} = \dot{W}_{pump,in} - \Delta\dot{E}_{mech} = 20 - 13.2\ kW = \mathbf{6.8\ kW}$$

Discussion The 6.8 kW of power is used to overcome the friction in the piping system. The effect of frictional losses in a pump is always to convert mechanical energy to an equivalent amount of thermal energy, which results in a slight rise in fluid temperature. Note that this pumping process could be accomplished by a 13.2 kW pump (rather than 20 kW) if there were no frictional losses in the system. In this ideal case, the pump would function as a turbine when the water is allowed to flow from the upper reservoir to the lower reservoir and extract 13.2 kW of power from the water.

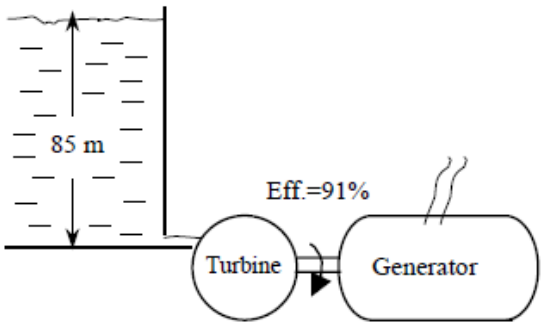
2–76 A hydraulic turbine has 85 m of elevation difference available at a flow rate of 0.25 m³/s, and its overall turbine–generator efficiency is 91 percent. Determine the electric power output of this turbine.

2-76 The available head of a hydraulic turbine and its overall efficiency are given. The electric power output of this turbine is to be determined.

Assumptions **1** The flow is steady and incompressible. **2** The elevation of the reservoir remains constant.

Properties We take the density of water to be $\rho = 1000\ \text{kg/m}^3$.

Analysis The total mechanical energy the water in a reservoir possesses is equivalent to the potential energy of water at the free surface, and it can be converted to work entirely. Therefore, the power potential of water is its potential energy, which is gz per unit mass, and $\dot{m}gz$ for a given mass flow rate. Therefore, the actual power produced by the turbine can be expressed as



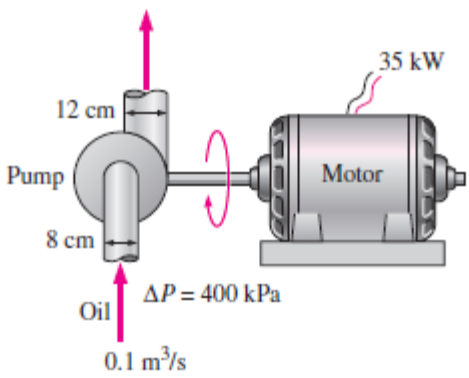
$$\dot{W}_{\text{turbine}} = \eta_{\text{turbine}}\dot{m}gh_{\text{turbine}} = \eta_{\text{turbine}}\rho\dot{V}gh_{\text{turbine}}$$

Substituting,

$$\dot{W}_{\text{turbine}} = (0.91)(1000\ \text{kg/m}^3)(0.25\ \text{m}^3/\text{s})(9.81\ \text{m/s}^2)(85\ \text{m})\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kW}}{1000\ \text{N}\cdot\text{m/s}}\right) = \mathbf{190\ kW}$$

Discussion Note that the power output of a hydraulic turbine is proportional to the available elevation difference (turbine head) and the flow rate.

2–77 An oil pump is drawing 35 kW of electric power while pumping oil with $\rho = 860\ \text{kg/m}^3$ at a rate of 0.1 m³/s. The inlet and outlet diameters of the pipe are 8 cm and 12 cm, respectively. If the pressure rise of oil in the pump is measured to be 400 kPa and the motor efficiency is 90 percent, determine the mechanical efficiency of the pump.



2-77 A pump is pumping oil at a specified rate. The pressure rise of oil in the pump is measured, and the motor efficiency is specified. The mechanical efficiency of the pump is to be determined.

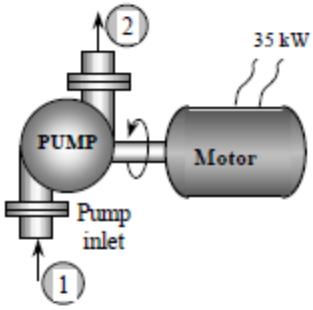
Assumptions **1** The flow is steady and incompressible. **2** The elevation difference across the pump is negligible.

Properties The density of oil is given to be $\rho = 860\ \text{kg/m}^3$.

Analysis Then the total mechanical energy of a fluid is the sum of the potential, flow, and kinetic energies, and is expressed per unit mass as $e_{mech} = gh + Pv + V^2/2$. To determine the mechanical efficiency of the pump, we need to know the increase in the mechanical energy of the fluid as it flows through the pump, which is

$$\Delta \dot{E}_{mech,fluid} = \dot{m}(e_{mech,out} - e_{mech,in}) = \dot{m}\left((Pv)_2 + \frac{V_2^2}{2} - (Pv)_1 - \frac{V_1^2}{2}\right) = \dot{V}\left((P_2 - P_1) + \rho\frac{V_2^2 - V_1^2}{2}\right)$$

since $\dot{m} = \rho\dot{V} = \dot{V}/v$, and there is no change in the potential energy of the fluid. Also,



$$V_1 = \frac{\dot{V}}{A_1} = \frac{\dot{V}}{\pi D_1^2/4} = \frac{0.1\ \text{m}^3/\text{s}}{\pi(0.08\ \text{m})^2/4} = 19.9\ \text{m/s}$$

$$V_2 = \frac{\dot{V}}{A_2} = \frac{\dot{V}}{\pi D_2^2/4} = \frac{0.1\ \text{m}^3/\text{s}}{\pi(0.12\ \text{m})^2/4} = 8.84\ \text{m/s}$$

Substituting, the useful pumping power is determined to be

$$\dot{W}_{pump,u} = \Delta\dot{E}_{mech,fluid}$$

$$= (0.1\ \text{m}^3/\text{s})\left(400\ \text{kN/m}^2 + (860\ \text{kg/m}^3)\frac{(8.84\ \text{m/s})^2 - (19.9\ \text{m/s})^2}{2}\left(\frac{1\ \text{kN}}{1000\ \text{kg}\cdot\text{m/s}^2}\right)\right)\left(\frac{1\ \text{kW}}{1\ \text{kN}\cdot\text{m/s}}\right)$$

$$= 26.3\ \text{kW}$$

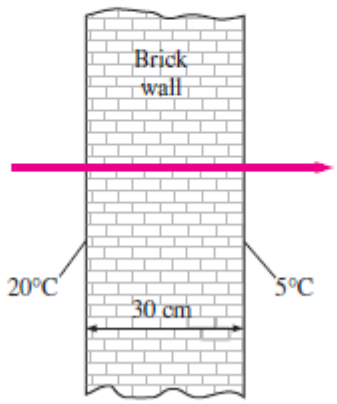
Then the shaft power and the mechanical efficiency of the pump become

$$\dot{W}_{pump,shaft} = \eta_{motor}\dot{W}_{electric} = (0.90)(35\ \text{kW}) = 31.5\ \text{kW}$$

$$\eta_{pump} = \frac{\dot{W}_{pump,u}}{\dot{W}_{pump,shaft}} = \frac{26.3\ \text{kW}}{31.5\ \text{kW}} = 0.836 = \mathbf{83.6\%}$$

Discussion The overall efficiency of this pump/motor unit is the product of the mechanical and motor efficiencies, which is 0.9×0.836 = 0.75.

2–95 The inner and outer surfaces of a 5-m × 6-m brick wall of thickness 30 cm and thermal conductivity 0.69 W/m · °C are maintained at temperatures of 20°C and 5°C, respectively. Determine the rate of heat transfer through the wall, in W.

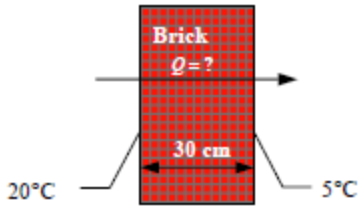


2-95 The inner and outer surfaces of a brick wall are maintained at specified temperatures. The rate of heat transfer through the wall is to be determined.

Assumptions 1 Steady operating conditions exist since the surface temperatures of the wall remain constant at the specified values. 2 Thermal properties of the wall are constant.

Properties The thermal conductivity of the wall is given to be k = 0.69 W/m·°C.

Analysis Under steady conditions, the rate of heat transfer through the wall is

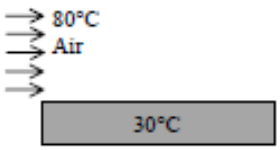


$$\dot{Q}_{cond} = kA\frac{\Delta T}{L} = (0.69\ \text{W/m}\cdot{}^\circ\text{C})(5\times 6\ \text{m}^2)\frac{(20-5)^\circ\text{C}}{0.3\ \text{m}} = \mathbf{1035\ W}$$

2–102 Hot air at 80°C is blown over a 2-m × 4-m flat surface at 30°C. If the convection heat transfer coefficient is 55 W/m² · °C, determine the rate of heat transfer from the air to the plate, in kW.

2-102 Hot air is blown over a flat surface at a specified temperature. The rate of heat transfer from the air to the plate is to be determined.

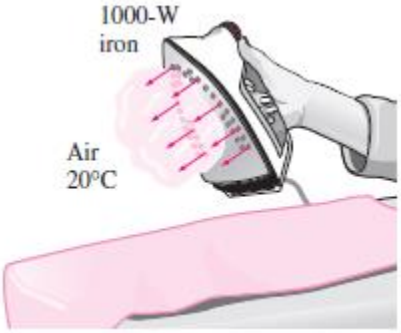
Assumptions 1 Steady operating conditions exist. 2 Heat transfer by radiation is not considered. 3 The convection heat transfer coefficient is constant and uniform over the surface.



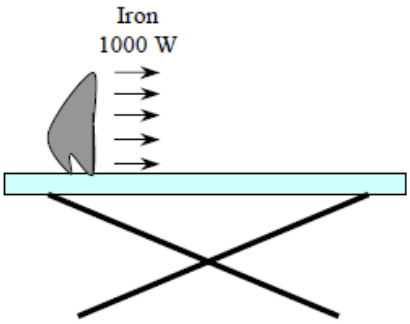
Analysis Under steady conditions, the rate of heat transfer by convection is

$$\dot{Q}_{conv} = hA\Delta T = (55\ \text{W/m}^2\cdot{}^\circ\text{C})(2\times 4\ \text{m}^2)(80-30)^\circ\text{C} = \mathbf{22{,}000\ W = 22\ kW}$$

2–103 A 1000-W iron is left on the ironing board with its base exposed to the air at 20°C. The convection heat transfer coefficient between the base surface and the surrounding air is 35 W/m² · °C. If the base has an emissivity of 0.6 and a surface area of 0.02 m², determine the temperature of the base of the iron.



2-103 A 1000-W iron is left on the iron board with its base exposed to the air at 20°C. The temperature of the base of the iron is to be determined in steady operation.



Assumptions **1** Steady operating conditions exist. **2** The thermal properties of the iron base and the convection heat transfer coefficient are constant and uniform. **3** The temperature of the surrounding surfaces is the same as the temperature of the surrounding air.

Properties The emissivity of the base surface is given to be ε = 0.6.

Analysis At steady conditions, the 1000 W of energy supplied to the iron will be dissipated to the surroundings by convection and radiation heat transfer. Therefore,

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}} = 1000 \text{ W}$$

where $\dot{Q}_{\text{conv}} = hA\Delta T = (35 \text{ W/m}^2 \cdot \text{K})(0.02 \text{ m}^2)(T_s - 293 \text{ K}) = 0.7(T_s - 293 \text{ K}) \text{ W}$

and

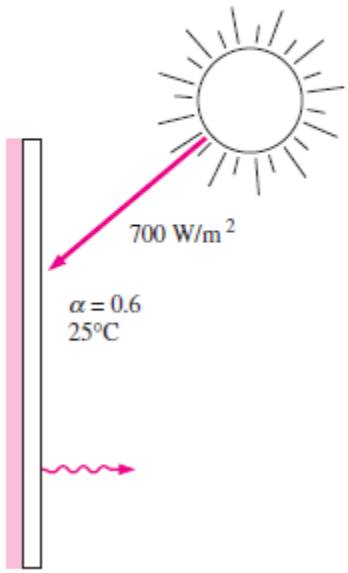
$$\dot{Q}_{\text{rad}} = \varepsilon\sigma A(T_s^4 - T_o^4) = 0.6(0.02 \text{ m}^2)(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)[T_s^4 - (293 \text{ K})^4]$$
$$= 0.06804 \times 10^{-8}[T_s^4 - (293 \text{ K})^4] \text{ W}$$

Substituting, $1000 \text{ W} = 0.7(T_s - 293 \text{ K}) + 0.06804 \times 10^{-8}[T_s^4 - (293 \text{ K})^4]$

Solving by trial and error gives $T_s =$ **947 K = 674°C**

Discussion We note that the iron will dissipate all the energy it receives by convection and radiation when its surface temperature reaches 947 K.

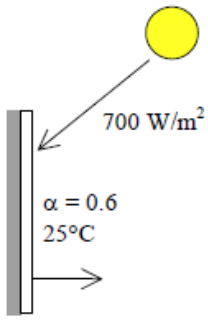
2–104 A thin metal plate is insulated on the back and exposed to solar radiation on the front surface. The exposed surface of the plate has an absorptivity of 0.6 for solar radiation. If solar radiation is incident on the plate at a rate of



2-104 The backside of the thin metal plate is insulated and the front side is exposed to solar radiation. The surface temperature of the plate is to be determined when it stabilizes.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer through the insulated side of the plate is negligible. **3** The heat transfer coefficient is constant and uniform over the plate. **4** Heat loss by radiation is negligible.

Properties The solar absorptivity of the plate is given to be $\alpha = 0.6$.



Analysis When the heat loss from the plate by convection equals the solar radiation absorbed, the surface temperature of the plate can be determined from

$$\dot{Q}_{\text{solarabsorbed}} = \dot{Q}_{\text{conv}}$$

$$\alpha \dot{Q}_{\text{solar}} = hA(T_s - T_o)$$

$$0.6 \times A \times 700\text{W/m}^2 = (50\text{W/m}^2 \cdot {}^\circ\text{C})A(T_s - 25)$$

Canceling the surface area A and solving for T_s gives

$$T_s = \mathbf{33.4\,^\circ C}$$