Thermo 1 (MEP 261)

Thermodynamics An Engineering Approach

Yunus A. Cengel & Michael A. Boles

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Sheet 2:Chapter 2

2–4C What is total energy? Identify the different forms of energy that constitute the total energy.

2-4C The sum of all forms of the energy a system possesses is called *total energy*. In the absence of magnetic, electrical, and surface tension effects, the total energy of a system consists of the kinetic, potential, and internal energies.

2–8 Consider a river flowing toward a lake at an average velocity of 3 m/s at a rate of 500 m^3/s at a location 90 m above the lake surface. Determine the total mechanical energy of the river water per unit mass and the power generation potential of the entire river at that location.

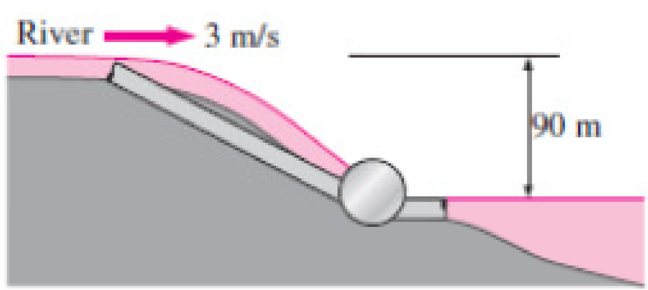
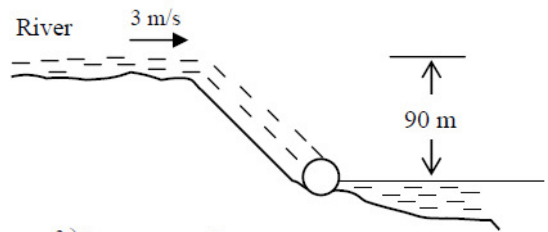


FIGURE P2–8

2-8 A river is flowing at a specified velocity, flow rate, and elevation. The total mechanical energy of the river water per unit mass and the power generation potential of the entire river are to be determined.

Assumptions **1** The elevation given is the elevation of the free surface of the river. **2** The velocity given is the average velocity. **3** The mechanical energy of water at the turbine exit is negligible.

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



Analysis Noting that the sum of the flow energy and the potential energy is constant for a given fluid body, we can take the elevation of the entire river water to be the elevation of the free surface, and ignore the flow energy. Then the total mechanical energy of the river water per unit mass becomes

$$e_{mech} = pe + ke = gh + \frac{V^2}{2} = \left((9.81\,\text{m/s}^2)(90\,\text{m}) + \frac{(3\,\text{m/s})^2}{2} \right) \left(\frac{1\,\text{kJ/kg}}{1000\,\text{m}^2/\text{s}^2} \right) = 0.887\,\text{kJ/kg}$$

The power generation potential of the river water is obtained by multiplying the total mechanical energy by the mass flow rate,

$$\dot{m} = \rho \dot{V} = (1000\,\text{kg/m}^3)(500\,\text{m}^3/\text{s}) = 500{,}000\,\text{kg/s}$$

$$\dot{W}_{max} = \dot{E}_{mech} = \dot{m} e_{mech} = (500{,}000\,\text{kg/s})(0.887\,\text{ kJ/kg}) = 444{,}000\,\text{kW} = \mathbf{444\ MW}$$

Therefore, 444 MW of power can be generated from this river as it discharges into the lake if its power potential can be recovered completely.

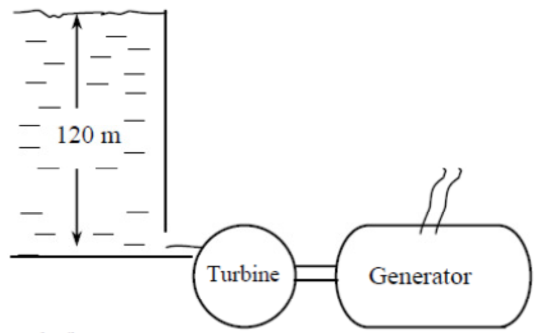
Discussion Note that the kinetic energy of water is negligible compared to the potential energy, and it can be ignored in the analysis. Also, the power output of an actual turbine will be less than 444 MW because of losses and inefficiencies.

2–9 Electric power is to be generated by installing a hydraulic turbine–generator at a site 120 m below the free surface of a large water reservoir that can supply water at a rate of 1500 kg/s steadily. Determine the power generation potential.

2-9 A hydraulic turbine-generator is to generate electricity from the water of a large reservoir. The power generation potential is 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 The total mechanical energy 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.



$$e_{\text{mech}} = pe = gz = (9.81\,\text{m/s}^2)(120\,\text{m})\left(\frac{1\,\text{kJ/kg}}{1000\,\text{m}^2/\text{s}^2}\right) = 1.177\,\text{kJ/kg}$$

Then the power generation potential becomes

$$\dot{W}_{\max} = \dot{E}_{\text{mech}} = \dot{m}e_{\text{mech}} = (1500\,\text{kg/s})(1.177\,\text{kJ/kg})\left(\frac{1\,\text{kW}}{1\,\text{kJ/s}}\right) = \mathbf{1766\,kW}$$

Therefore, the reservoir has the potential to generate 1766 kW of power.

Discussion This problem can also be solved by considering a point 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.

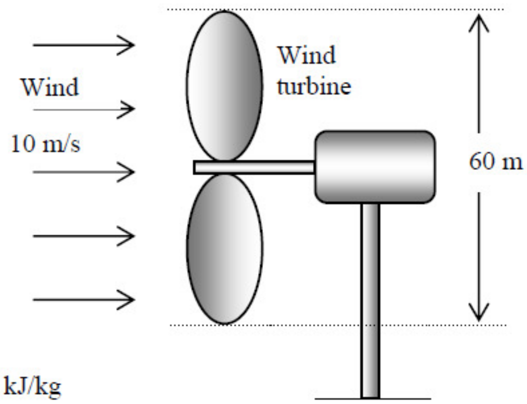
2–10 At a certain location, wind is blowing steadily at 10 m/s. Determine the mechanical energy of air per unit mass and the power generation potential of a wind turbine with 60-m-diameter blades at that location. Take the air density to be 1.25 kg/m^3.

Solution Wind is blowing steadily at a certain velocity. The mechanical energy of air per unit mass and the power generation potential are to be determined.

Assumption The wind is blowing steadily at a constant uniform velocity.

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:



$$e_{\text{mech}} = ke = \frac{V^2}{2} = \frac{(10\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = 0.050\text{ kJ/kg}$$

$$\dot{m} = \rho VA = \rho V\frac{\pi D^2}{4} = (1.25\text{ kg/m}^3)(10\text{ m/s})\frac{\pi(60\text{ m})^2}{4} = 35{,}340\text{ kg/s}$$

$$\dot{W}_{\max} = \dot{E}_{\text{mech}} = \dot{m}e_{\text{mech}} = (35{,}340\text{ kg/s})(0.050\text{ kJ/kg}) = \mathbf{1770\ kW}$$

Therefore, 1770 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.

2–15C In what forms can energy cross the boundaries of a closed system?

2-15C Energy can cross the boundaries of a closed system in two forms: heat and work.

2–20C A room is heated as a result of solar radiation coming in through the windows. Is this a heat or work interaction for the room?

2-20C It is a heat interaction since it is due to the temperature difference between the sun and the room.

2–22C What are point and path functions? Give some examples.

2-22C Point functions depend on the state only whereas the path functions depend on the path followed during a process. Properties of substances are point functions, heat and work are path functions.

2–24C A car is accelerated from rest to 85 km/h in 10 s. Would the energy transferred to the car be different if it were accelerated to the same speed in 5 s?

2-24C The work done is the same, but the power is different.

2–26 Determine the energy required to accelerate an 800-kg car from rest to 100 km/h on a level road. *Answer: 309 kJ*

2-26 A car is accelerated from rest to 100 km/h. The work needed to achieve this is to be determined.

Analysis The work needed to accelerate a body the change in kinetic energy of the body,

$$W_a = \frac{1}{2}m(V_2^2 - V_1^2) = \frac{1}{2}(800\text{ kg})\left(\left(\frac{100{,}000\text{ m}}{3600\text{ s}}\right)^2 - 0\right)\left(\frac{1\text{ kJ}}{1000\text{ kg}\cdot\text{m}^2/\text{s}^2}\right) = \mathbf{309\ kJ}$$

2–29 Determine the work required to deflect a linear spring with a spring constant of 70 kN/m by 20 cm from its rest position.

Solution A linear spring is elongated by 20 cm from its rest position. The work done is to be determined.

Analysis The spring work can be determined from

$$W_{spring} = \frac{1}{2}k(x_2^2 - x_1^2) = \frac{1}{2}(70\text{ kN/m})(0.2^2 - 0)\text{ m}^2 = 1.4\text{ kN}\cdot\text{m} = \mathbf{1.4\ \ kJ}$$

2–32 Determine the power required for a 2000-kg car to climb a 100-m-long uphill road with a slope of 30° (from horizontal) in 10 s (*a*) at a constant velocity, (*b*) from rest to

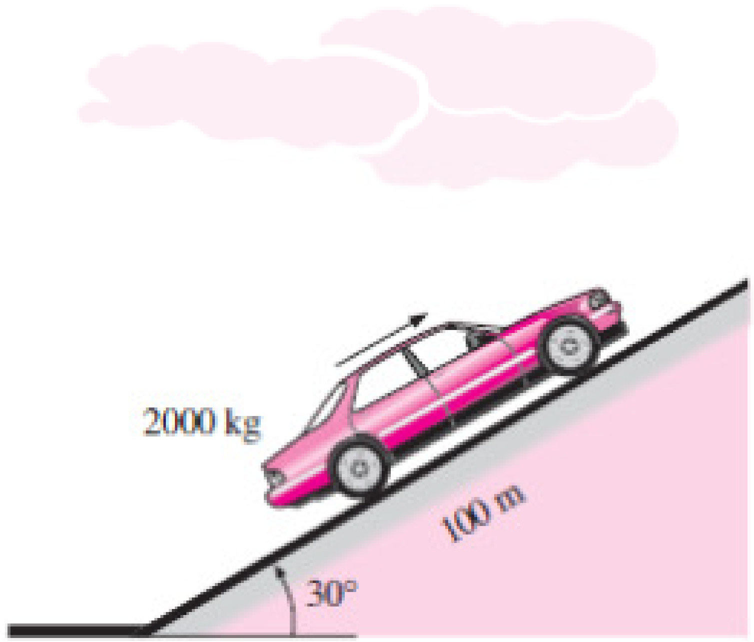


FIGURE P2–32

a final velocity of 30 m/s, and (*c*) from 35 m/s to a final velocity of 5 m/s. Disregard friction, air drag, and rolling resistance. *Answers:* (*a*) 98.1 kW, (*b*) 188 kW, (*c*) −21.9 kW

Solution A car is to climb a hill in 10 s. The power needed is to be determined for three different cases.

Assumption Air drag, friction, and rolling resistance are negligible.

Analysis The total power required for each case is the sum of the rates of changes in potential and kinetic energies. That is,

$$\dot{W}_{\text{total}} = \dot{W}_a + \dot{W}_g$$

(*a*) $\dot{W}_a = 0$ since the velocity is constant. Also, the vertical rise is h = (100 m)(sin 30°) = 50 m. Thus,

$$\dot{W}_g = mg(z_2 - z_1)/\Delta t = (2000 \text{ kg})(9.81 \text{ m/s}^2)(50 \text{ m})\left(\frac{1 \text{ kJ}}{1000 \text{ kg}\cdot\text{m}^2/\text{s}^2}\right)/(10 \text{ s}) = 98.1 \text{ kW}$$

and $\dot{W}_{\text{total}} = \dot{W}_a + \dot{W}_g = 0 + 98.1 = \mathbf{98.1\ kW}$

(*b*) The power needed to accelerate is

$$\dot{W}_a = \frac{1}{2}m(V_2^2 - V_1^2)/\Delta t = \frac{1}{2}(2000 \text{ kg})\left[(30 \text{ m/s})^2 - 0\right]\left(\frac{1 \text{ kJ}}{1000 \text{ kg}\cdot\text{m}^2/\text{s}^2}\right)/(10 \text{ s}) = 90 \text{ kW}$$

and $\dot{W}_{\text{total}} = \dot{W}_a + \dot{W}_g = 90 + 98.1 = \mathbf{188.1\ kW}$

(*c*) The power needed to decelerate is

$$\dot{W}_a = \frac{1}{2}m(V_2^2 - V_1^2)/\Delta t = \frac{1}{2}(2000 \text{ kg})\left[(5 \text{ m/s})^2 - (35 \text{ m/s})^2\right]\left(\frac{1 \text{ kJ}}{1000 \text{ kg}\cdot\text{m}^2/\text{s}^2}\right)/(10 \text{ s}) = -120 \text{ kW}$$

and $\dot{W}_{\text{total}} = \dot{W}_a + \dot{W}_g = -120 + 98.1 = \mathbf{-21.9\ kW}$ (breaking power)

2–35C On a hot summer day, a student turns his fan on when he leaves his room in the morning. When he returns in the evening, will the room be warmer or cooler than the neighboring rooms? Why? Assume all the doors and windows are kept closed.

Solution Warmer. Because energy is added to the room air in the form of electrical work.

2–36C What are the different mechanisms for transferring energy to or from a control volume?

Solution Energy can be transferred to or from a control volume as heat, various forms of work, and by mass transport.

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*

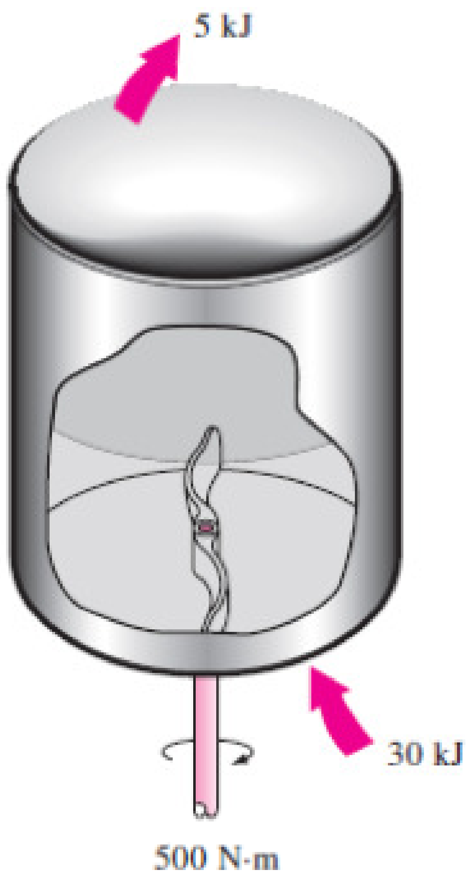


FIGURE P2–37

Solution 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.

Assumption 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.

2–44 A fan is to accelerate quiescent air to a velocity of 10 m/s at a rate of 4 m³/s. Determine the minimum power that must be supplied to the fan. Take the density of air to be 1.18 kg/m³. *Answer: 236 W*

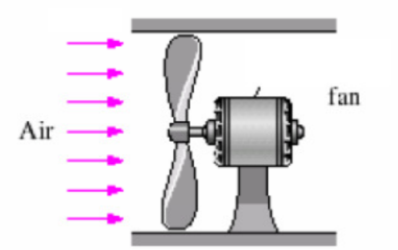
Solution A fan is to accelerate quiescent air to a specified velocity at a specified flow rate. The minimum power that must be supplied to the fan is to be determined.

Assumption The fan operates steadily.

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

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

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



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

where

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

Substituting, the minimum power input required is determined to be

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

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.

2–51 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*

Solution A car cruising at a constant speed is 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 than 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

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

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

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

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.