Chapter 2

ENERGY, ENERGY TRANSFER, AND GENERAL ENERGY ANALYSIS

SOLVED PROBLEMS

Forms of Energy

Problem (2- 1C)

2-1C Initially, the rock possesses potential energy relative to the bottom of the sea. As the rock falls, this potential energy is converted into kinetic energy. Part of this kinetic energy is converted to thermal energy as a result of frictional heating due to air resistance, which is transferred to the air and the rock. Same thing happens in water. Assuming the impact velocity of the rock at the sea bottom is negligible, the entire potential energy of the rock is converted to thermal energy in water and air.

Problem (2- 2C)

2-2C Hydrogen is also a fuel, since it can be burned, but it is not an energy source since there are no hydrogen reserves in the world. Hydrogen can be obtained from water by using another energy source, such as solar or nuclear energy, and then the hydrogen obtained can used as a fuel to power cars or generators. Therefore, it is more proper to view hydrogen is an energy carrier than an energy source.

Forms of Energy

Problem (2- 7)

2-7 The specific kinetic energy of a mass whose velocity is given is to be determined.

Analysis Substitution of the given data into the expression for the specific kinetic energy gives

$$\text{ke} = \frac{V^2}{2} = \frac{(30\ \text{m/s})^2}{2}\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right) = \mathbf{0.45\ kJ/kg}$$

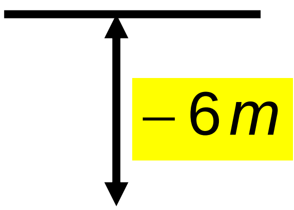
$V = 30\, m/s$

Problem (2- 8)

2-8 The total potential energy of an object that is below a reference level is to be determined.

Analysis Substituting the given data into the potential energy expression gives

$$\text{PE} = mgz = (50\ \text{kg})(9.7\ \text{m/s}^2)(-6\ \text{m})\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right) = \mathbf{-2.91\ kJ}$$



Problem (2- 13)

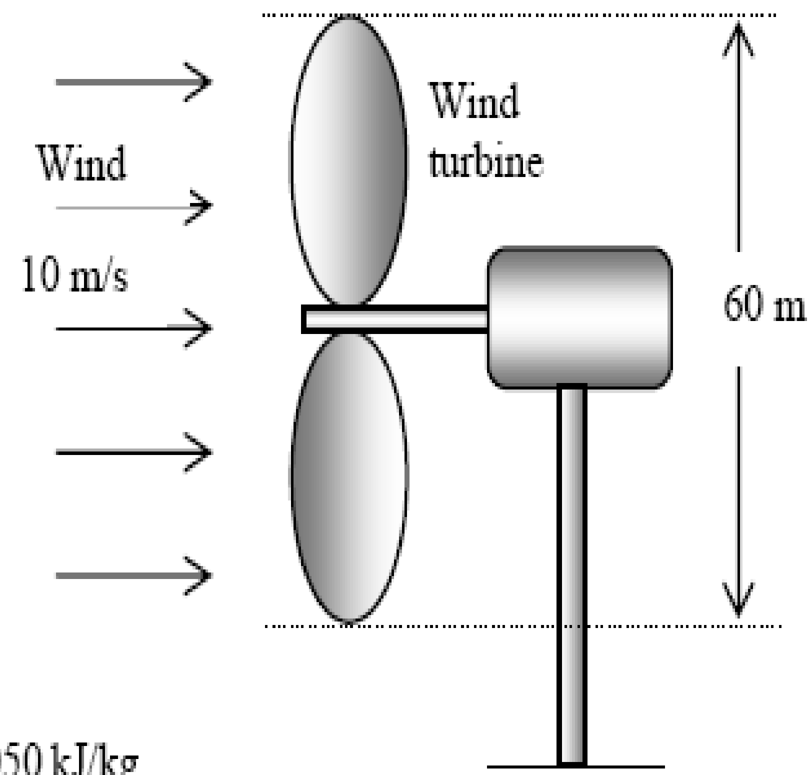
Forms of Energy

2-13 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.

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

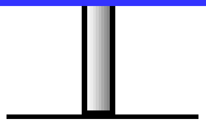
Properties The density of air is given to be $\rho = 1.25\ \text{kg/m}^3$.

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:



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

Forms of Energy



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

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

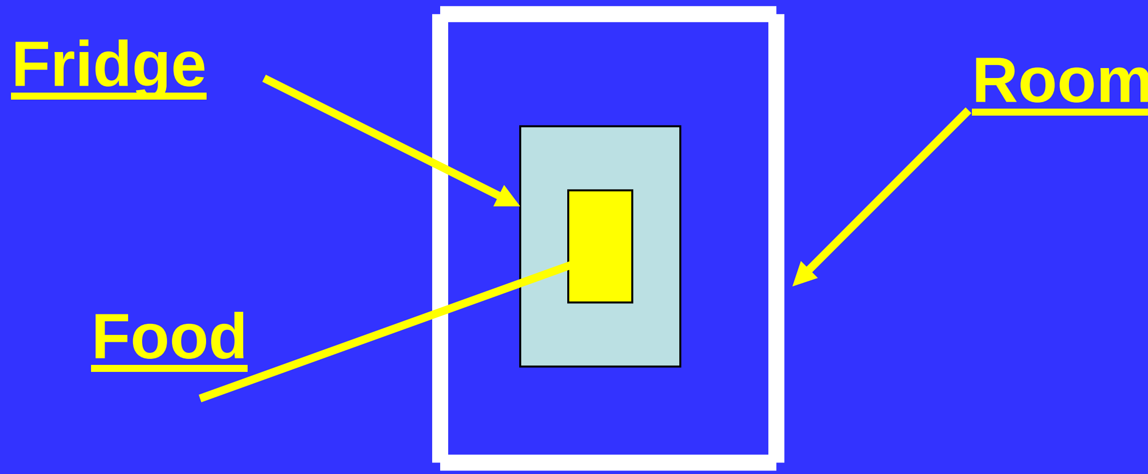
$$\dot{W}_{max} = \dot{E}_{mech} = \dot{m}e_{mech} = (35{,}340\ \text{kg/s})(0.050\ \text{kJ/kg}) = \mathbf{1770\ kW}$$

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.

Problem (2- 25C)

Energy Transfer



2-25C (*a*) From the perspective of the contents, heat must be removed in order to reduce and maintain the content's temperature. Heat is also being added to the contents from the room air since the room air is hotter than the contents.

(*b*) Considering the system formed by the refrigerator box when the doors are closed, there are three interactions, electrical work and two heat transfers. There is a transfer of heat from the room air to the refrigerator through its walls. There is also a transfer of heat from the hot portions of the refrigerator (i.e., back of the compressor where condenser is placed) system to the room air. Finally, electrical work is being added to the refrigerator through the refrigeration system. **(Compressor)**

(*c*) Heat is transferred through the walls of the room from the warm room air to the cold winter air. Electrical work is being done on the room through the electrical wiring leading into the room.

Problem (2-31)

Mechanical Forms of Work

$M_{man} = 100\,kg, \quad M_{Cart} = 100\,kg$ L = 100m

2-31 A man is pushing a cart with its contents up a ramp that is inclined at an angle of 20° from the horizontal. The work needed to move along this ramp is to be determined considering (a) the man and (b) the cart and its contents as the system.

Analysis (*a*) Considering the man as the system, letting *l* be the displacement along the ramp, and letting θ be the inclination angle of the ramp,

$$W = Fl\sin\theta = mgl\sin\theta = (100+100\text{ kg})(9.8\text{ m/s}^2)(100\text{ m})\sin(20)\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = \mathbf{67.0\ kJ}$$

This is work that the man must do to raise the weight of the cart and contents, plus his own weight, a distance of $l\sin\theta$.

(*b*) Applying the same logic to the cart and its contents gives

$$W = Fl\sin\theta = mgl\sin\theta = (100\text{ kg})(9.8\text{ m/s}^2)(100\text{ m})\sin(20)\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = \mathbf{33.5\ kJ}$$

Problem (2-35)

$K = 3.5\, kN/cm,$

$F_{\text{int}\,ial} = 0.45 kN$

Energy Transfer

2-35 The work required to compress a spring is to be determined. **(Another 1 cm)**

Analysis The force at any point during the deflection of the spring is given by $F = F_0 + kx$, where F_0 is the initial force and x is the deflection as measured from the point where the initial force occurred. From the perspective of the spring, this force acts in the direction opposite to that in which the spring is deflected. Then,

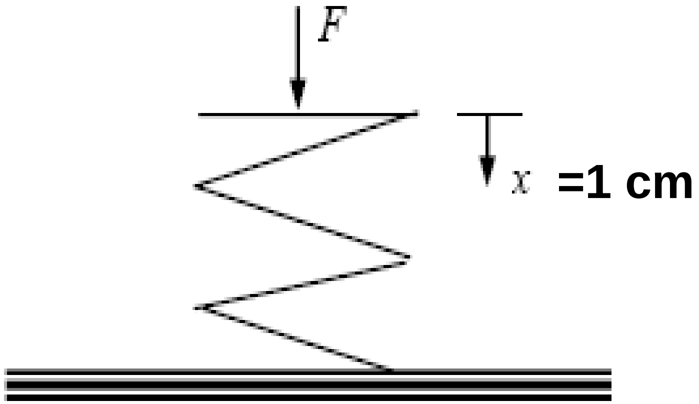
$$W = \int_1^2 F ds = \int_1^2 (F_0 + kx) dx$$

$$= F_0 (x_2 - x_1) + \frac{k}{2}(x_2^2 - x_1^2)$$

$$= (0.45\,\text{kN})[(1-0)\text{cm}] + \frac{3.5\,\text{kN/cm}}{2}(1^2 - 0^2)\text{cm}^2$$

$$= 2.2\,\text{kN}\cdot\text{cm}\left(\frac{1\,\text{m}}{100\,\text{cm}}\right) = 0.022\,\text{kN}\cdot\text{m}$$

$$= \mathbf{0.022\,kJ}$$



Problem (2.47) Ist Law of Thermodynamics

2-47 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

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

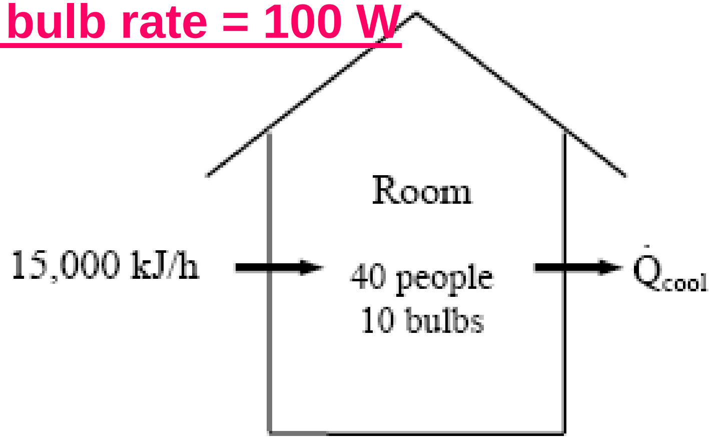
1. **Each person dissipate heat = 360 kJ/kg**
2. **Each bulb rate = 100 W**

where

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

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

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



Room is maintained at 21 degree

Substituting,

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

Thus the number of air-conditioning units required is

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

Problem 2.51 Ist Law of Thermodynamics

2-51 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 $\rho = 1.18\ \text{kg/m}^3$.

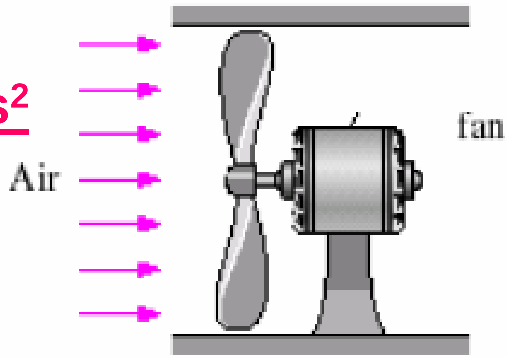
Analysis A fan transmits the mechanical energy of the shaft (shaft power) to mechanical energy of air (kinetic energy). For a control volume that encloses the fan, the energy balance can be written as

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

Q = 4m³/s

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

V=10m/s²



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

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

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.

Problem 2.51 Ist Law of Thermodynamics

No. of People = 30, 75kg each

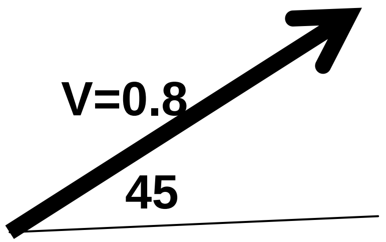
Escalator speed = 0.8m/s at 45 degrees

2-54 An inclined escalator is to move a certain number of people upstairs at a constant velocity. The minimum power required to drive this escalator is to be determined.

Assumptions 1 Air drag and friction are negligible. 2 The average mass of each person is 75 kg. 3 The escalator operates steadily, with no acceleration or breaking. 4 The mass of escalator itself is negligible.

Analysis At design conditions, the total mass moved by the escalator at any given time is

$$\text{Mass} = (30 \text{ persons})(75 \text{ kg/person}) = 2250 \text{ kg}$$



The vertical component of escalator velocity is

$$V_{\text{vert}} = V \sin 45° = (0.8 \text{ m/s})\sin 45°$$

Under stated assumptions, the power supplied is used to increase the potential energy of people. Taking the people on elevator as the closed system, the energy balance in the rate form can be written as

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

$$\dot{W}_{in} = \frac{\Delta PE}{\Delta t} = \frac{mg\Delta z}{\Delta t} = mgV_{vert}$$

That is, under stated assumptions, the power input to the escalator must be equal to the rate of increase of the potential energy of people. Substituting, the required power input becomes

$$\dot{W}_{in} = mgV_{vert} = (2250\text{ kg})(9.81\text{ m/s}^2)(0.8\text{ m/s})\sin 45° \left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = 12.5\text{ kJ/s} = \mathbf{12.5\ kW}$$

When the escalator velocity is doubled to $V = 1.6$ m/s, the power needed to drive the escalator becomes

$$\dot{W}_{in} = mgV_{vert} = (2250\text{ kg})(9.81\text{ m/s}^2)(1.6\text{ m/s})\sin 45° \left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = 25.0\text{ kJ/s} = \mathbf{25.0\ kW}$$

Discussion Note that the power needed to drive an escalator is proportional to the escalator velocity.

Problem 2.59 Energy Conversion Efficiencies

2-59 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

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

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

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

3 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

$$\dot{Q}_{input,\ gas} = \frac{\dot{Q}_{utilized}}{\text{Efficiency}} = \frac{2.19\text{ kW}}{0.38} = \mathbf{5.76\ kW}$$

Therefore, a gas burner should have a rating of at least 5.76 kW to perform as well as the electric unit.

Noting that 1 therm = 105,500 kJ = 29.3 kWh, the unit cost of utilized energy in the case of gas burner is determined the same way to be

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

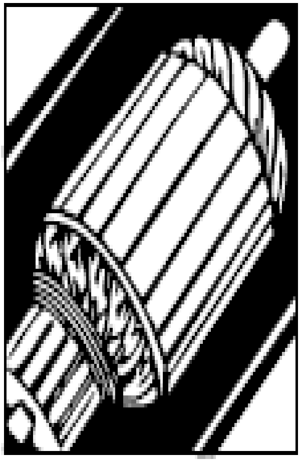
Problem 2.61 Energy Conversion Efficiencies

2-61 An electric car is powered by an electric motor mounted in the engine compartment. The rate of heat supply by the motor to the engine compartment at full load conditions is to be determined.

Assumptions The motor operates at full load so that the load factor is 1.

Analysis The heat generated by a motor is due to its inefficiency, and is equal to the difference between the electrical energy it consumes and the shaft power it delivers,

90 hp, 91%



$$\dot{W}_{\text{in, electric}} = \dot{W}_{\text{shaft}} / \eta_{\text{motor}} = (90\text{ hp})/0.91 = 98.90\text{ hp}$$

$$\dot{Q}_{\text{generation}} = \dot{W}_{\text{in, electric}} - \dot{W}_{\text{shaft out}} = 98.90 - 90 = 8.90\text{ hp} = \mathbf{6.64\ kW}$$

since 1 hp = 0.746 kW.

Discussion Note that the electrical energy not converted to mechanical power is converted to heat.

Problem 2.86

Energy and Environment

2-86 A household uses fuel oil for heating, and electricity for other energy needs. Now the household reduces its energy use by **15%**. The reduction in the CO_2 production this household is responsible for is to be determined.

Properties The amount of CO_2 produced is 0.70 kg per kWh and 3.2 kg per liter of fuel oil (given).

Analysis Noting that this household consumes 11,000 kWh of electricity and 5700 liters of fuel oil per year, the amount of CO_2 production this household is responsible for is

$$\begin{aligned} \text{Amount of } CO_2 \text{ produced} &= (\text{Amount of electricity consumed})(\text{Amount of } CO_2 \text{ per kWh}) \\ &\quad + (\text{Amount of fuel oil consumed})(\text{Amount of } CO_2 \text{ per gallon}) \\ &= (11{,}000 \text{ kWh/yr})(0.70 \text{ kg/kWh}) + (5700 \text{ L/yr})(3.2 \text{ kg/L}) \\ &= 25{,}940 \; CO_2 \text{ kg/year} \end{aligned}$$

Then reducing the electricity and fuel oil usage by 15% will reduce the annual amount of CO_2 production by this household by

$$\begin{aligned} \text{Reduction in } CO_2 \text{ produced} &= (0.15)(\text{Current amount of } CO_2 \text{ production}) \\ &= (0.15)(25{,}940 \; CO_2 \text{ kg/year}) \\ &= \mathbf{3891 \; CO_2 \; kg/year} \end{aligned}$$

Therefore, any measure that saves energy also reduces the amount of pollution emitted to the environment.

Household consumes

- **11000 kWh / year**
- **5700L of fuel**

Average CO2 produced

3.2kg/L

0.70 kg/kWh

THE END