Closed System Energy Analysis: Solids and Liquids

4-74 A number of brass balls are to be quenched in a water bath at a specified rate. The rate at which heat needs to be removed from the water in order to keep its temperature constant is to be determined.

Assumptions **1** The thermal properties of the balls are constant. **2** The balls are at a uniform temperature before and after quenching. **3** The changes in kinetic and potential energies are negligible.

Properties The density and specific heat of the brass balls are given to be $\rho = 8522$ kg/m^3 and $c_p = 0.385$ kJ/kg.°C.

Analysis We take a single ball as the system. The energy balance for this closed system can be expressed as

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

Brass balls, 120°C

Water bath, 50°C

$$-Q_{out} = \Delta U_{ball} = m(u_2 - u_1)$$
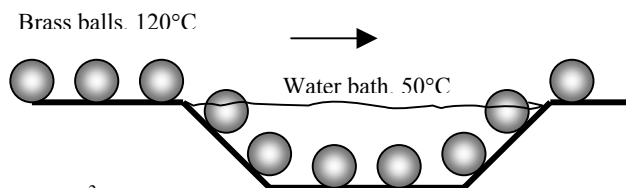
$$Q_{out} = mC(T_1 - T_2)$$

The total amount of heat transfer from a ball is

$$m = \rho V = \rho \frac{\pi D^3}{6} = (8522 \text{ kg/m}^3) \frac{\pi (0.05 \text{ m})^3}{6} = 0.558 \text{ kg}$$

$$Q_{out} = mc(T_1 - T_2) = (0.558 \text{ kg})(0.385 \text{ kJ/kg.°C})(120 - 74)°C = 9.88 \text{ kJ/ball}$$

Then the rate of heat transfer from the balls to the water becomes

$$\dot{Q}_{total} = \dot{n}_{ball} Q_{ball} = (100 \text{ balls/min}) \times (9.88 \text{ kJ/ball}) = \textbf{988 kJ/min}$$

Therefore, heat must be removed from the water at a rate of 988 kJ/min in order to keep its temperature constant at 50°C since energy input must be equal to energy output for a system whose energy level remains constant. That is, $E_{in} = E_{out}$ when $\Delta E_{system} = 0$.

4-75 A number of aluminum balls are to be quenched in a water bath at a specified rate. The rate at which heat needs to be removed from the water in order to keep its temperature constant is to be determined.

Assumptions **1** The thermal properties of the balls are constant. **2** The balls are at a uniform temperature before and after quenching. **3** The changes in kinetic and potential energies are negligible.

Properties The density and specific heat of aluminum at the average temperature of $(120+74)/2 = 97°C = 370$ K are $\rho = 2700$ kg/m^3 and $c_p = 0.937$ kJ/kg.°C (Table A-3).

Analysis We take a single ball as the system. The energy balance for this closed system can be expressed as

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

Aluminum balls,

Water bath, 50°C

$$-Q_{out} = \Delta U_{ball} = m(u_2 - u_1)$$
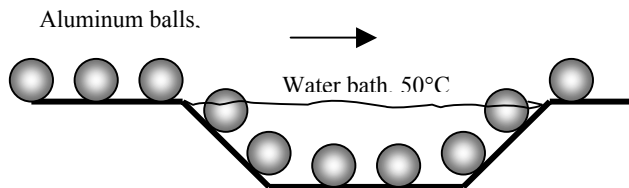
$$Q_{out} = mc(T_1 - T_2)$$

The total amount of heat transfer from a ball is

$$m = \rho V = \rho \frac{\pi D^3}{6} = (2700 \text{ kg/m}^3) \frac{\pi (0.05 \text{ m})^3}{6} = 0.1767 \text{ kg}$$

$$Q_{out} = mc(T_1 - T_2) = (0.1767 \text{ kg})(0.937 \text{ kJ/kg.°C})(120 - 74)°C = 7.62 \text{ kJ/ball}$$

Then the rate of heat transfer from the balls to the water becomes

$$\dot{Q}_{total} = \dot{n}_{ball} Q_{ball} = (100 \text{ balls/min}) \times (7.62 \text{ kJ/ball}) = \textbf{762 kJ/min}$$

Therefore, heat must be removed from the water at a rate of 762 kJ/min in order to keep its temperature constant at 50°C since energy input must be equal to energy output for a system whose energy level remains constant. That is, $E_{in} = E_{out}$ when $\Delta E_{system} = 0$.

4-76E A person shakes a canned of drink in a iced water to cool it. The mass of the ice that will melt by the time the canned drink is cooled to a specified temperature is to be determined.

Assumptions **1** The thermal properties of the drink are constant, and are taken to be the same as those of water. **2** The effect of agitation on the amount of ice melting is negligible. **3** The thermal energy capacity of the can itself is negligible, and thus it does not need to be considered in the analysis.

Properties The density and specific heat of water at the average temperature of $(75+45)/2 = 60°F$ are $\rho = 62.3$ lbm/ft^3, and $c_p = 1.0$ Btu/lbm.°F (Table A-3E). The heat of fusion of water is 143.5 Btu/lbm.

Analysis We take a canned drink as the system. The energy balance for this closed system can be expressed as

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

Cola
75°F

$$-Q_{out} = \Delta U_{canned\ drink} = m(u_2 - u_1) \longrightarrow Q_{out} = mc(T_1 - T_2)$$
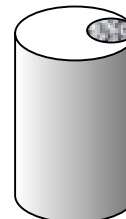
Noting that 1 gal = 128 oz and 1 ft^3 = 7.48 gal = 957.5 oz, the total amount of heat transfer from a ball is

$$m = \rho V = (62.3\ \text{lbm/ft}^3)(12\ \text{oz/can})\left(\frac{1\ \text{ft}^3}{7.48\ \text{gal}}\right)\left(\frac{1\ \text{gal}}{128\ \text{fluid oz}}\right) = 0.781\ \text{lbm/can}$$

$$Q_{out} = mc(T_1 - T_2) = (0.781\ \text{lbm/can})(1.0\ \text{Btu/lbm.°F})(75-45)°F = 23.4\ \text{Btu/can}$$

Noting that the heat of fusion of water is 143.5 Btu/lbm, the amount of ice that will melt to cool the drink is

$$m_{ice} = \frac{Q_{out}}{h_{if}} = \frac{23.4\ \text{Btu/can}}{143.5\ \text{Btu/lbm}} = \textbf{0.163 lbm} \quad \text{(per can of drink)}$$

since heat transfer to the ice must be equal to heat transfer from the can.

Discussion The actual amount of ice melted will be greater since agitation will also cause some ice to melt.

4-77 An iron whose base plate is made of an aluminum alloy is turned on. The minimum time for the plate to reach a specified temperature is to be determined.

Assumptions **1** It is given that 85 percent of the heat generated in the resistance wires is transferred to the plate. **2** The thermal properties of the plate are constant. **3** Heat loss from the plate during heating is disregarded since the minimum heating time is to be determined. **4** There are no changes in kinetic and potential energies. **5** The plate is at a uniform temperature at the end of the process.

Properties The density and specific heat of the aluminum alloy plate are given to be $\rho = 2770$ kg/m^3 and $c_p = 875$ kJ/kg.°C.

Analysis The mass of the iron's base plate is

$$m = \rho V = \rho LA = (2770\ \text{kg/m}^3)(0.005\ \text{m})(0.03\ \text{m}^2) = 0.4155\ \text{kg}$$

Noting that only 85 percent of the heat generated is transferred to the plate, the rate of heat transfer to the iron's base plate is

$$\dot{Q}_{in} = 0.85 \times 1000\ \text{W} = 850\ \text{W}$$

We take plate to be the system. The energy balance for this closed system can be expressed as

Air
22°C

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

$$Q_{in} = \Delta U_{plate} = m(u_2 - u_1) \longrightarrow \dot{Q}_{in}\Delta t = mc(T_2 - T_1)$$

IRON
1000 W

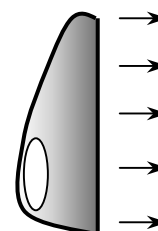Solving for Δt and substituting,

$$\Delta t = \frac{mc\Delta T_{plate}}{\dot{Q}_{in}} = \frac{(0.4155\ \text{kg})(875\ \text{J/kg.°C})(140-22)°C}{850\ \text{J/s}} = \textbf{50.5 s}$$

which is the time required for the plate temperature to reach the specified temperature.

4-78 Stainless steel ball bearings leaving the oven at a specified uniform temperature at a specified rate are exposed to air and are cooled before they are dropped into the water for quenching. The rate of heat transfer from the ball bearing to the air is to be determined.

Assumptions **1** The thermal properties of the bearing balls are constant. **2** The kinetic and potential energy changes of the balls are negligible. **3** The balls are at a uniform temperature at the end of the process
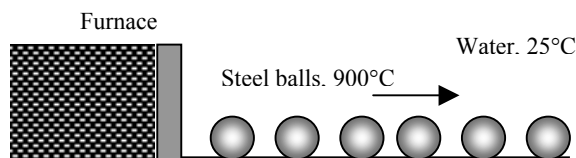
Properties The density and specific heat of the ball bearings are given to be $\rho = 8085$ kg/m^3 and $c_p = 0.480$ kJ/kg.°C.

Analysis We take a single bearing ball as the system. The energy balance for this closed system can be expressed as

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

$$-Q_{out} = \Delta U_{ball} = m(u_2 - u_1)$$

$$Q_{out} = mc(T_1 - T_2)$$

The total amount of heat transfer from a ball is

$$m = \rho V = \rho \frac{\pi D^3}{6} = (8085 \text{ kg/m}^3) \frac{\pi (0.012 \text{ m})^3}{6} = 0.007315 \text{ kg}$$

$$Q_{out} = mc(T_1 - T_2) = (0.007315 \text{ kg})(0.480 \text{ kJ/kg.°C})(900 - 850)°C = 0.1756 \text{ kJ/ball}$$

Then the rate of heat transfer from the balls to the air becomes

$$\dot{Q}_{total} = \dot{n}_{ball} Q_{out \text{ (per ball)}} = (800 \text{ balls/min}) \times (0.1756 \text{ kJ/ball}) = \textbf{140.5 kJ/min} = \textbf{2.34 kW}$$

Therefore, heat is lost to the air at a rate of 2.34 kW.

4-79 Carbon steel balls are to be annealed at a rate of 2500/h by heating them first and then allowing them to cool slowly in ambient air at a specified rate. The total rate of heat transfer from the balls to the ambient air is to be determined.

Assumptions **1** The thermal properties of the balls are constant. **2** There are no changes in kinetic and potential energies. **3** The balls are at a uniform temperature at the end of the process
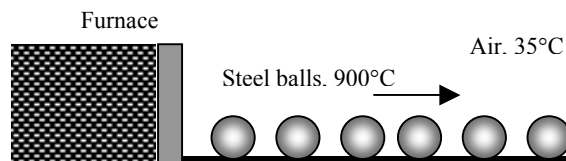
Properties The density and specific heat of the balls are given to be $\rho = 7833$ kg/m^3 and $c_p = 0.465$ kJ/kg.°C.

Analysis We take a single ball as the system. The energy balance for this closed system can be expressed as

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

$$-Q_{out} = \Delta U_{ball} = m(u_2 - u_1)$$

$$Q_{out} = mc(T_1 - T_2)$$

(*b*) The amount of heat transfer from a single ball is

$$m = \rho V = \rho \frac{\pi D^3}{6} = (7833 \text{ kg/m}^3) \frac{\pi (0.008 \text{ m})^3}{6} = 0.00210 \text{ kg}$$

$$Q_{out} = mc_p(T_1 - T_2) = (0.0021 \text{ kg})(0.465 \text{ kJ/kg.°C})(900 - 100)°C = 0.781 \text{ kJ (per ball)}$$

Then the total rate of heat transfer from the balls to the ambient air becomes

$$\dot{Q}_{out} = \dot{n}_{ball} Q_{out} = (2500 \text{ balls/h}) \times (0.781 \text{ kJ/ball}) = 1,953 \text{ kJ/h} = \textbf{542 W}$$

4-80 An electronic device is on for 5 minutes, and off for several hours. The temperature of the device at the end of the 5-min operating period is to be determined for the cases of operation with and without a heat sink.

Assumptions **1** The device and the heat sink are isothermal. **2** The thermal properties of the device and of the sink are constant. **3** Heat loss from the device during on time is disregarded since the highest possible temperature is to be determined.

Properties The specific heat of the device is given to be c_p = 850 J/kg.°C. The specific heat of aluminum at room temperature of 300 K is 902 J/kg.°C (Table A-3).

Analysis We take the device to be the system. Noting that electrical energy is supplied, the energy balance for this closed system can be expressed as

Electronic
device, 25°C

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

$$W_{\text{e,in}} = \Delta U_{\text{device}} = m(u_2 - u_1)$$

$$\dot{W}_{\text{e,in}}\Delta t = mc(T_2 - T_1)$$
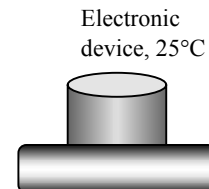
Substituting, the temperature of the device at the end of the process is determined to be

$$(30 \text{ J/s})(5 \times 60 \text{ s}) = (0.020 \text{ kg})(850 \text{ J/kg.}°\text{C})(T_2 - 25)°\text{C} \quad \rightarrow \quad T_2 = \textbf{554}°\textbf{C} \quad \text{(without the heat sink)}$$

Case 2 When a heat sink is attached, the energy balance can be expressed as

$$W_{\text{e,in}} = \Delta U_{\text{device}} + \Delta U_{\text{heat sink}}$$

$$\dot{W}_{\text{e,in}}\Delta t = mc(T_2 - T_1)_{\text{device}} + mc(T_2 - T_1)_{\text{heat sink}}$$

Substituting, the temperature of the device-heat sink combination is determined to be

$$(30 \text{ J/s})(5 \times 60 \text{ s}) = (0.020 \text{ kg})(850 \text{ J/kg.}°\text{C})(T_2 - 25)°\text{C} + (0.200 \text{ kg})(902 \text{ J/kg.}°\text{C})(T_2 - 25)°\text{C}$$

$$T_2 = \textbf{70.6}°\textbf{C} \quad \text{(with heat sink)}$$

Discussion These are the maximum temperatures. In reality, the temperatures will be lower because of the heat losses to the surroundings.

4-81 EES Problem 4-80 is reconsidered. The effect of the mass of the heat sink on the maximum device temperature as the mass of heat sink varies from 0 kg to 1 kg is to be investigated. The maximum temperature is to be plotted against the mass of heat sink.

Analysis The problem is solved using EES, and the solution is given below.

"Knowns:"
"T_1 is the maximum temperature of the device"
Q_dot_out = 30 [W]
m_device=20 [g]
Cp_device=850 [J/kg-C]
A=5 [cm^2]
DELTAt=5 [min]
T_amb=25 [C]
{m_sink=0.2 [kg]}
"Cp_al taken from Table A-3(b) at 300K"
Cp_al=0.902 [kJ/kg-C]
T_2=T_amb

"Solution:"
"The device without the heat sink is considered to be a closed system."
"Conservation of Energy for the closed system:"
"E_dot_in - E_dot_out = DELTAE_dot, we neglect DELTA KE and DELTA PE for the system, the device."
E_dot_in - E_dot_out = DELTAE_dot
E_dot_in =0
E_dot_out = Q_dot_out
"Use the solid material approximation to find the energy change of the device."
DELTAE_dot= m_device*convert(g,kg)*Cp_device*(T_2-T_1_device)/(DELTAt*convert(min,s))
"The device with the heat sink is considered to be a closed system."
"Conservation of Energy for the closed system:"
"E_dot_in - E_dot_out = DELTAE_dot, we neglect DELTA KE and DELTA PE for the device with the heat sink."
E_dot_in - E_dot_out = DELTAE_dot_combined
"Use the solid material approximation to find the energy change of the device."
DELTAE_dot_combined= (m_device*convert(g,kg)*Cp_device*(T_2-T_1_device&sink)+m_sink*Cp_al*(T_2-T_1_device&sink)*convert(kJ,J))/(DELTAt*convert(min,s))

m_{sink} [kg]	$T_{1,device\&sink}$ [C]
0	554.4
0.1	109
0.2	70.59
0.3	56.29
0.4	48.82
0.5	44.23
0.6	41.12
0.7	38.88
0.8	37.19
0.9	35.86
1	34.79
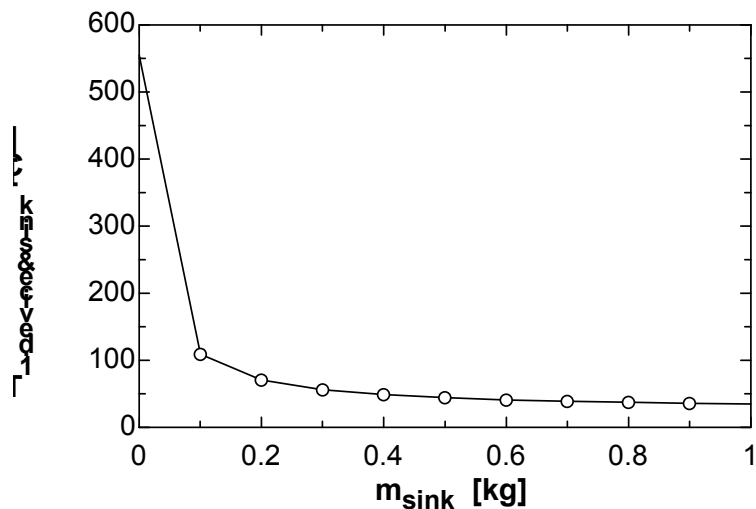
4-82 An egg is dropped into boiling water. The amount of heat transfer to the egg by the time it is cooked is to be determined.

Assumptions **1** The egg is spherical in shape with a radius of $r_0 = 2.75$ cm. **2** The thermal properties of the egg are constant. **3** Energy absorption or release associated with any chemical and/or phase changes within the egg is negligible. **4** There are no changes in kinetic and potential energies.

Properties The density and specific heat of the egg are given to be $\rho = 1020$ kg/m^3 and $c_p = 3.32$ kJ/kg.°C.

Analysis We take the egg as the system. This is a closes system since no mass enters or leaves the egg. The energy balance for this closed system can be expressed as
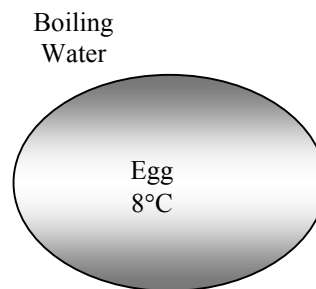
$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$Q_{in} = \Delta U_{egg} = m(u_2 - u_1) = mc(T_2 - T_1)$$

Then the mass of the egg and the amount of heat transfer become

$$m = \rho V = \rho\frac{\pi D^3}{6} = (1020\,\text{kg/m}^3)\frac{\pi(0.055\,\text{m})^3}{6} = 0.0889\,\text{kg}$$

$$Q_{in} = mc_p(T_2 - T_1) = (0.0889\,\text{kg})(3.32\,\text{kJ/kg.°C})(80 - 8)°C = \textbf{21.2 kJ}$$

Boiling
Water

Egg
8°C

4-83E Large brass plates are heated in an oven at a rate of 300/min. The rate of heat transfer to the plates in the oven is to be determined.

Assumptions **1** The thermal properties of the plates are constant. **2** The changes in kinetic and potential energies are negligible.

Properties The density and specific heat of the brass are given to be $\rho = 532.5$ lbm/ft^3 and $c_p = 0.091$ Btu/lbm.°F.

Analysis We take the plate to be the system. The energy balance for this closed system can be expressed as

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

$$Q_{in} = \Delta U_{plate} = m(u_2 - u_1) = mc(T_2 - T_1)$$

Plates
75°F

The mass of each plate and the amount of heat transfer to each plate is

$$m = \rho V = \rho LA = (532.5\,\text{lbm/ft}^3)[(1.2/12\,\text{ft})(2\,\text{ft})(2\,\text{ft})] = 213\,\text{lbm}$$

$$Q_{in} = mc(T_2 - T_1) = (213\,\text{lbm/plate})(0.091\,\text{Btu/lbm.°F})(1000 - 75)°F = 17,930\,\text{Btu/plate}$$

Then the total rate of heat transfer to the plates becomes

$$\dot{Q}_{total} = \dot{n}_{plate}Q_{in,\,per\,plate} = (300\,\text{plates/min}) \times (17,930\,\text{Btu/plate}) = \textbf{5,379,000 Btu/min} = \textbf{89,650 Btu/s}$$
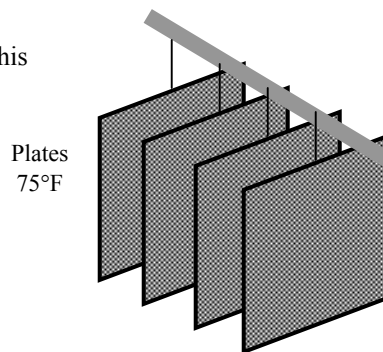
4-84 Long cylindrical steel rods are heat-treated in an oven. The rate of heat transfer to the rods in the oven is to be determined.

Assumptions **1** The thermal properties of the rods are constant. **2** The changes in kinetic and potential energies are negligible.

Properties The density and specific heat of the steel rods are given to be ρ = 7833 kg/m^3 and c_p = 0.465 kJ/kg.°C.

Analysis Noting that the rods enter the oven at a velocity of 3 m/min and exit at the same velocity, we can say that a 3-m long section of the rod is heated in the oven in 1 min. Then the mass of the rod heated in 1 minute is

$$m = \rho V = \rho LA = \rho L(\pi D^2 / 4) = (7833 \text{ kg/m}^3)(3 \text{ m})[\pi(0.1 \text{ m})^2 / 4] = 184.6 \text{ kg}$$

We take the 3-m section of the rod in the oven as the system. The energy balance for this closed system can be expressed as

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

$$Q_{in} = \Delta U_{rod} = m(u_2 - u_1) = mc(T_2 - T_1)$$

Substituting,
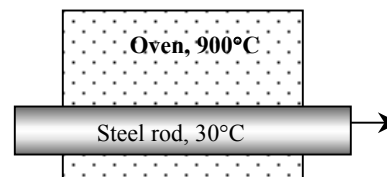
$$Q_{in} = mc(T_2 - T_1) = (184.6 \text{ kg})(0.465 \text{ kJ/kg.°C})(700 - 30)°C = 57,512 \text{ kJ}$$

Noting that this much heat is transferred in 1 min, the rate of heat transfer to the rod becomes

$$\dot{Q}_{in} = Q_{in} / \Delta t = (57,512 \text{ kJ})/(1 \text{ min}) = 57,512 \text{ kJ/min} = \textbf{958.5 kW}$$

Special Topic: Biological Systems

4-85C Metabolism refers to the chemical activity in the cells associated with the burning of foods. The basal metabolic rate is the metabolism rate of a resting person, which is 84 W for an average man.

4-86C The energy released during metabolism in humans is used to maintain the body temperature at 37°C.

4-87C The food we eat is not entirely metabolized in the human body. The fraction of metabolizable energy contents are 95.5% for carbohydrates, 77.5% for proteins, and 97.7% for fats. Therefore, the metabolizable energy content of a food is not the same as the energy released when it is burned in a bomb calorimeter.

4-88C Yes. Each body rejects the heat generated during metabolism, and thus serves as a heat source. For an average adult male it ranges from 84 W at rest to over 1000 W during heavy physical activity. Classrooms are designed for a large number of occupants, and thus the total heat dissipated by the occupants must be considered in the design of heating and cooling systems of classrooms.

4-89C 1 kg of natural fat contains almost 8 times the metabolizable energy of 1 kg of natural carbohydrates. Therefore, a person who fills his stomach with carbohydrates will satisfy his hunger without consuming too many calories.

4-90 Six people are fast dancing in a room, and there is a resistance heater in another identical room. The room that will heat up faster is to be determined.

Assumptions **1** The rooms are identical in every other aspect. **2** Half of the heat dissipated by people is in sensible form. **3** The people are of average size.

Properties An average fast dancing person dissipates 600 Cal/h of energy (sensible and latent) (Table 4-2).

Analysis Three couples will dissipate

$$E = (6 \text{ persons})(600 \text{ Cal/h.person})(4.1868 \text{ kJ/Cal}) = 15{,}072 \text{ kJ/h} = 4190 \text{ W}$$

of energy. (About half of this is sensible heat). Therefore, the room with the **people dancing** will warm up much faster than the room with a 2-kW resistance heater.

4-91 Two men are identical except one jogs for 30 min while the other watches TV. The weight difference between these two people in one month is to be determined.

Assumptions The two people have identical metabolism rates, and are identical in every other aspect.

Properties An average 68-kg person consumes 540 Cal/h while jogging, and 72 Cal/h while watching TV (Table 4-2).

Analysis An 80-kg person who jogs 0.5 h a day will have jogged a total of 15 h a month, and will consume

$$\Delta E_{\text{consumed}} = [(540 - 72) \text{ Cal/h}](15 \text{ h})\left(\frac{4.1868 \text{ kJ}}{1 \text{ Cal}}\right)\left(\frac{80 \text{ kg}}{68 \text{ kg}}\right) = 34{,}578 \text{ kJ}$$

more calories than the person watching TV. The metabolizable energy content of 1 kg of fat is 33,100 kJ. Therefore, the weight difference between these two people in 1-month will be

$$\Delta m_{\text{fat}} = \frac{\Delta E_{\text{consumed}}}{\text{Energy content of fat}} = \frac{34{,}578 \text{ kJ}}{33{,}100 \text{ kJ/kg}} = \textbf{1.045 kg}$$

4-92 A classroom has 30 students, each dissipating 100 W of sensible heat. It is to be determined if it is necessary to turn the heater on in the room to avoid cooling of the room.

Properties Each person is said to be losing sensible heat to the room air at a rate of 100 W.

Analysis We take the room is losing heat to the outdoors at a rate of

$$\dot{Q}_{loss} = (20{,}000 \text{ kJ/h})\left(\frac{1 \text{ h}}{3600 \text{ s}}\right) = 5.56 \text{ kW}$$

The rate of sensible heat gain from the students is

$$\dot{Q}_{gain} = (100 \text{ W/student})(30 \text{ students}) = 3000 \text{ W} = 3 \text{ kW}$$

which is less than the rate of heat loss from the room. Therefore, it is **necessary** to turn the heater on to prevent the room temperature from dropping.

4-93 A bicycling woman is to meet her entire energy needs by eating 30-g candy bars. The number of candy bars she needs to eat to bicycle for 1-h is to be determined.

Assumptions The woman meets her entire calorie needs from candy bars while bicycling.

Properties An average 68-kg person consumes 639 Cal/h while bicycling, and the energy content of a 20-g candy bar is 105 Cal (Tables 4-1 and 4-2).

Analysis Noting that a 20-g candy bar contains 105 Calories of metabolizable energy, a 30-g candy bar will contain

$$E_{candy} = (105 \text{ Cal})\left(\frac{30 \text{ g}}{20 \text{ g}}\right) = 157.5 \text{ Cal}$$

of energy. If this woman is to meet her entire energy needs by eating 30-g candy bars, she will need to eat

$$N_{candy} = \frac{639 \text{Cal/h}}{157.5 \text{Cal}} \cong \mathbf{4 candy bars/h}$$

4-94 A 55-kg man eats 1-L of ice cream. The length of time this man needs to jog to burn off these calories is to be determined.

Assumptions The man meets his entire calorie needs from the ice cream while jogging.

Properties An average 68-kg person consumes 540 Cal/h while jogging, and the energy content of a 100-ml of ice cream is 110 Cal (Tables 4-1 and 4-2).

Analysis The rate of energy consumption of a 55-kg person while jogging is

$$\dot{E}_{consumed} = (540 \text{ Cal/h})\left(\frac{55 \text{ kg}}{68 \text{ kg}}\right) = 437 \text{ Cal/h}$$

Noting that a 100-ml serving of ice cream has 110 Cal of metabolizable energy, a 1-liter box of ice cream will have 1100 Calories. Therefore, it will take

$$\Delta t = \frac{1100 \text{ Cal}}{437 \text{ Cal / h}} = \mathbf{2.5 \text{ h}}$$

of jogging to burn off the calories from the ice cream.

4-95 A man with 20-kg of body fat goes on a hunger strike. The number of days this man can survive on the body fat alone is to be determined.

Assumptions **1** The person is an average male who remains in resting position at all times. **2** The man meets his entire calorie needs from the body fat alone.

Properties The metabolizable energy content of fat is 33,100 Cal/kg. An average resting person burns calories at a rate of 72 Cal/h (Table 4-2).

Analysis The metabolizable energy content of 20 kg of body fat is

$$E_{fat} = (33,100 \text{ kJ/kg})(20 \text{ kg}) = 662,000 \text{ kJ}$$

The person will consume

$$E_{consumed} = (72 \text{ Cal/h})(24 \text{ h})\left(\frac{4.1868 \text{ kJ}}{1 \text{ Cal}}\right) = 7235 \text{ kJ/day}$$

Therefore, this person can survive

$$\Delta t = \frac{662,000 \text{ kJ}}{7235 \text{ kJ / day}} = \textbf{91.5 days}$$

on his body fat alone. This result is not surprising since people are known to survive over 100 days without any food intake.

4-96 Two 50-kg women are identical except one eats her baked potato with 4 teaspoons of butter while the other eats hers plain every evening. The weight difference between these two woman in one year is to be determined.

Assumptions **1** These two people have identical metabolism rates, and are identical in every other aspect. **2** All the calories from the butter are converted to body fat.

Properties The metabolizable energy content of 1 kg of body fat is 33,100 kJ. The metabolizable energy content of 1 teaspoon of butter is 35 Calories (Table 4-1).

Analysis A person who eats 4 teaspoons of butter a day will consume

$$E_{consumed} = (35 \text{ Cal/teaspoon})(4 \text{ teaspoons/day})\left(\frac{365 \text{ days}}{1 \text{ year}}\right) = 51,100 \text{ Cal/year}$$

Therefore, the woman who eats her potato with butter will gain

$$m_{fat} = \frac{51,100 \text{ Cal}}{33,100 \text{ kJ/kg}}\left(\frac{4.1868 \text{ kJ}}{1 \text{ Cal}}\right) = \textbf{6.5 kg}$$

of additional body fat that year.

4-97 A woman switches from 1-L of regular cola a day to diet cola and 2 slices of apple pie. It is to be determined if she is now consuming more or less calories.

Properties The metabolizable energy contents are 300 Cal for a slice of apple pie, 87 Cal for a 200-ml regular cola, and 0 for the diet drink (Table 4-3).

Analysis The energy contents of 2 slices of apple pie and 1-L of cola are

$$E_{pie} = 2 \times (300 \text{ Cal}) = 600 \text{ Cal}$$
$$E_{cola} = 5 \times (87 \text{ Cal}) = 435 \text{ Cal}$$

Therefore, the woman is now consuming **more calories**.

4-98 A man switches from an apple a day to 200-ml of ice cream and 20-min walk every day. The amount of weight the person will gain or lose with the new diet is to be determined.

Assumptions All the extra calories are converted to body fat.

Properties The metabolizable energy contents are 70 Cal for a an apple and 220 Cal for a 200-ml serving of ice cream (Table 4-1). An average 68-kg man consumes 432 Cal/h while walking (Table 4-2). The metabolizable energy content of 1 kg of body fat is 33,100 kJ.

Analysis The person who switches from the apple to ice cream increases his calorie intake by

$$E_{extra} = 220 - 70 = 150\text{Cal}$$

The amount of energy a 60-kg person uses during a 20-min walk is

$$E_{consumed} = (432 \text{ Cal/h})(20 \text{ min})\left(\frac{1 \text{ h}}{60 \text{ min}}\right)\left(\frac{60 \text{ kg}}{68 \text{ kg}}\right) = 127 \text{ Cal}$$

Therefore, the man now has a net gain of 150 - 127 = 23 Cal per day, which corresponds to 23×30 = 690 Cal per month. Therefore, the man will gain

$$m_{fat} = \frac{690 \text{ Cal}}{33,100 \text{ kJ/kg}}\left(\frac{4.1868 \text{ kJ}}{1 \text{ Cal}}\right) = \textbf{0.087 kg}$$

of body fat per month with the new diet. (Without the exercise the man would gain 0.569 kg per month).

4-99 The average body temperature of the human body rises by 2°C during strenuous exercise. The increase in the thermal energy content of the body as a result is to be determined.

Properties The average specific heat of the human body is given to be 3.6 kJ/kg.°C.

Analysis The change in the sensible internal energy of the body is

$$\Delta U = mc\Delta T = (80 \text{ kg})(3.6 \text{ kJ/kg°C})(2°C) = \textbf{576 kJ}$$

as a result of body temperature rising 2°C during strenuous exercise.

4-100E An average American adult switches from drinking alcoholic beverages to drinking diet soda. The amount of weight the person will lose per year as a result of this switch is to be determined.

Assumptions **1** The diet and exercise habits of the person remain the same other than switching from alcoholic beverages to diet drinks. **2** All the excess calories from alcohol are converted to body fat.

Properties The metabolizable energy content of body fat is 33,100 Cal/kg (text).

Analysis When the person switches to diet drinks, he will consume 210 fewer Calories a day. Then the annual reduction in the calories consumed by the person becomes

Reduction in energy intake: $E_{reduced} = (210 \text{ Cal}/\text{day})(365 \text{ days}/\text{year}) = 76,650 \text{ Cal}/\text{year}$

Therefore, assuming all the calories from the alcohol would be converted to body fat, the person who switches to diet drinks will lose

$$\text{Reduction in weight} = \frac{\text{Reduction in energy intake}}{\text{Enegy content of fat}} = \frac{E_{reduced}}{e_{fat}} = \frac{76,650 \text{ Cal/yr}}{33,100 \text{ kJ/kg}}\left(\frac{4.1868 \text{ kJ}}{1 \text{ Cal}}\right) = \textbf{9.70 kg/yr}$$

or about **21 pounds** of body fat that year.

4-101 A person drinks a 12-oz beer, and then exercises on a treadmill. The time it will take to burn the calories from a 12-oz can of regular and light beer are to be determined.

Assumptions The drinks are completely metabolized by the body.

Properties The metabolizable energy contents of regular and light beer are 150 and 100 Cal, respectively. Exercising on a treadmill burns calories at an average rate of 700 Cal/h (given).

Analysis The exercising time it will take to burn off beer calories is determined directly from

(*a*) Regular beer: $\qquad \Delta t_{\text{regular beer}} = \dfrac{150 \text{ Cal}}{700 \text{ Cal/h}} = 0.214 \text{ h} = \textbf{12.9 min}$

(*b*) Light beer: $\qquad \Delta t_{\text{light beer}} = \dfrac{100 \text{ Cal}}{700 \text{ Cal/h}} = 0.143 \text{ h} = \textbf{8.6 min}$

4-102 A person has an alcoholic drink, and then exercises on a cross-country ski machine. The time it will take to burn the calories is to be determined for the cases of drinking a bloody mary and a martini.

Assumptions The drinks are completely metabolized by the body.

Properties The metabolizable energy contents of bloody mary and martini are 116 and 156 Cal, respectively. Exercising on a cross-country ski machine burns calories at an average rate of 600 Cal/h (given).

Analysis The exercising time it will take to burn off beer calories is determined directly from

(*a*) Bloody mary: $\qquad \Delta t_{\text{Bloody Mary}} = \dfrac{116 \text{ Cal}}{600 \text{ Cal / h}} = 0.193 \text{ h} = \textbf{11.6 min}$

(*b*) Martini: $\qquad \Delta t_{\text{martini}} = \dfrac{156 \text{ Cal}}{600 \text{ Cal / h}} = 0.26 \text{ h} = \textbf{15.6 min}$

4-103E A man and a woman have lunch at Burger King, and then shovel snow. The shoveling time it will take to burn off the lunch calories is to be determined for both.

Assumptions The food intake during lunch is completely metabolized by the body.

Properties The metabolizable energy contents of different foods are as given in the problem statement. Shoveling snow burns calories at a rate of 360 Cal/h for the woman and 480 Cal/h for the man (given).

Analysis The total calories consumed during lunch and the time it will take to burn them are determined for both the man and woman as follows:

Man: Lunch calories = 720+400+225 = 1345 Cal.

$\qquad$ Shoveling time: $\Delta t_{\text{shoveling, man}} = \dfrac{1345 \text{ Cal}}{480 \text{ Cal / h}} = \textbf{2.80 h}$

Woman: Lunch calories = 330+400+0 = 730 Cal.

$\qquad$ Shoveling time: $\Delta t_{\text{shoveling, woman}} = \dfrac{730 \text{ Cal}}{360 \text{ Cal / h}} = \textbf{2.03 h}$

4-104 Two friends have identical metabolic rates and lead identical lives, except they have different lunches. The weight difference between these two friends in a year is to be determined.

Assumptions **1** The diet and exercise habits of the people remain the same other than the lunch menus. **2** All the excess calories from the lunch are converted to body fat.

Properties The metabolizable energy content of body fat is 33,100 Cal/kg (text). The metabolizable energy contents of different foods are given in problem statement.

Analysis The person who has the double whopper sandwich consumes $1600 - 800 = 800$ Cal more every day. The difference in calories consumed per year becomes

Calorie consumption difference $= (800 \text{ Cal/day})(365 \text{ days/year}) = 292,000 \text{ Cal/year}$

Therefore, assuming all the excess calories to be converted to body fat, the weight difference between the two persons after 1 year will be

$$\text{Weight difference} = \frac{\text{Calorie intake difference}}{\text{Enegy content of fat}} = \frac{\Delta E_{\text{intake}}}{e_{\text{fat}}} = \frac{292,000 \text{ Cal/yr}}{33,100 \text{ kJ/kg}} \left(\frac{4.1868 \text{ kJ}}{1 \text{ Cal}} \right) = \textbf{36.9 kg/yr}$$

or about 80 pounds of body fat per year.

4-105E A person eats dinner at a fast-food restaurant. The time it will take for this person to burn off the dinner calories by climbing stairs is to be determined.

Assumptions The food intake from dinner is completely metabolized by the body.

Properties The metabolizable energy contents are 270 Cal for regular roast beef, 410 Cal for big roast beef, and 150 Cal for the drink. Climbing stairs burns calories at a rate of 400 Cal/h (given).

Analysis The total calories consumed during dinner and the time it will take to burn them by climbing stairs are determined to be

Dinner calories $= 270 + 410 + 150 = 830$ Cal.

Stair climbing time: $\Delta t = \dfrac{830 \text{ Cal}}{400 \text{ Cal/h}} = \textbf{2.08 h}$

4-106 Three people have different lunches. The person who consumed the most calories from lunch is to be determined.

Properties The metabolizable energy contents of different foods are 530 Cal for the Big Mac, 640 Cal for the whopper, 350 Cal for french fries, and 5 for each olive (given).

Analysis The total calories consumed by each person during lunch are:

Person 1**:**   Lunch calories $= 530$ Cal

Person 2**:**   Lunch calories $= \textbf{640 Cal}$

Person 3**:**   Lunch calories $= 350 + 5 \times 50 = 600$ Cal

Therefore, the person with the Whopper will consume the most calories.

4-107 A 100-kg man decides to lose 5 kg by exercising without reducing his calorie intake. The number of days it will take for this man to lose 5 kg is to be determined.

Assumptions **1** The diet and exercise habits of the person remain the same other than the new daily exercise program. **2** The entire calorie deficiency is met by burning body fat.

Properties The metabolizable energy content of body fat is 33,100 Cal/kg (text).

Analysis The energy consumed by an average 68-kg adult during fast-swimming, fast dancing, jogging, biking, and relaxing are 860, 600, 540, 639, and 72 Cal/h, respectively (Table 4-2). The daily energy consumption of this 100-kg man is

$$\left[(860 + 600 + 540 + 639 \text{ Cal/h})(1\text{h}) + (72 \text{ Cal/h})(20 \text{ h})\right]\left(\frac{100 \text{ kg}}{68 \text{ kg}}\right) = 5999 \text{ Cal}$$

Therefore, this person burns 5999-3000 = 2999 more Calories than he takes in, which corresponds to

$$m_{\text{fat}} = \frac{2999 \text{ Cal}}{33,100 \text{ kJ/kg}}\left(\frac{4.1868 \text{ kJ}}{1 \text{ Cal}}\right) = 0.379 \text{ kg}$$

of body fat per day. Thus it will take only

$$\Delta t = \frac{5 \text{ kg}}{0.379 \text{ kg}} = \textbf{13.2 days}$$

for this man to lose 5 kg.

4-108E The range of healthy weight for adults is usually expressed in terms of the *body mass index* (BMI) in SI units as $\text{BMI} = \dfrac{W(\text{kg})}{H^2(\text{m}^2)}$. This formula is to be converted to English units such that the weight is in pounds and the height in inches.

Analysis Noting that 1 kg = 2.2 lbm and 1 m =39.37 in, the weight in lbm must be divided by 2.2 to convert it to kg, and the height in inches must be divided by 39.37 to convert it to m before inserting them into the formula. Therefore,

$$\text{BMI} = \frac{W(\text{kg})}{H^2(\text{m}^2)} = \frac{W(\text{lbm})/2.2}{H^2(\text{in}^2)/(39.37)^2} = 705\frac{W(\text{lbm})}{H^2(\text{in}^2)}$$

Every person can calculate their own BMI using either SI or English units, and determine if it is in the healthy range.

4-109 A person changes his/her diet to lose weight. The time it will take for the body mass index (BMI) of the person to drop from 30 to 25 is to be determined.

Assumptions The deficit in the calori intake is made up by burning body fat.

Properties The metabolizable energy contents are 350 Cal for a slice of pizza and 87 Cal for a 200-ml regular cola. The metabolizable energy content of 1 kg of body fat is 33,100 kJ.

Analysis The lunch calories before the diet is

$$E_{old} = 3 \times e_{pizza} + 2 \times e_{coke} = 3 \times (350\,\text{Cal}) + 2 \times (87\,\text{Cal}) = 1224\,\text{Cal}$$

The lunch calories after the diet is

$$E_{old} = 2 \times e_{pizza} + 1 \times e_{coke} = 2 \times (350\,\text{Cal}) + 1 \times (87\,\text{Cal}) = 787\,\text{Cal}$$

The calorie reduction is

$$E_{reduction} = 1224 - 787 = 437\,\text{Cal}$$

The corresponding reduction in the body fat mass is

$$m_{fat} = \frac{437\,\text{Cal}}{33,100\,\text{kJ/kg}} \left(\frac{4.1868\,\text{kJ}}{1\,\text{Cal}} \right) = 0.05528\,\text{kg}$$

The weight of the person before and after the diet is

$$W_1 = \text{BMI}_1 \times h^2{}_{pizza} = 30 \times (1.7\,\text{m})^2 = 86.70\,\text{kg}$$
$$W_2 = \text{BMI}_2 \times h^2{}_{pizza} = 25 \times (1.7\,\text{m})^2 = 72.25\,\text{kg}$$

Then it will take

$$\text{Time} = \frac{W_1 - W_2}{m_{fat}} = \frac{(86.70 - 72.25)\,\text{kg}}{0.05528\,\text{kg/day}} = \textbf{261.4 days}$$

for the BMI of this person to drop to 25.