Tutorial 2
Solution(10-8-2016)

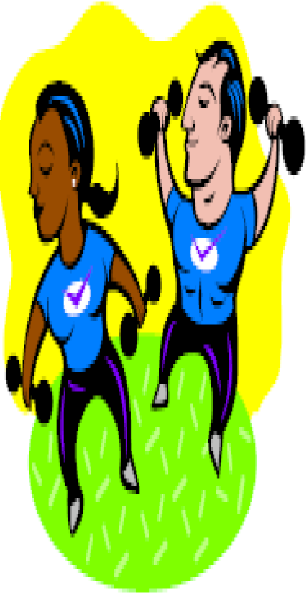
Q.1

Several people are working out in an exercise room. The rate of heat gain from people and the equipment is to be determined.

Assumptions The average rate of heat dissipated by people in an exercise room is 600 W.

Analysis The 6 weight lifting machines do not have any motors, and thus they do not contribute to the internal heat gain directly. The usage factors of the motors of the treadmills are taken to be unity since they are used constantly during peak periods. Noting that 1 hp = 745.7 W, the total heat generated by the motors is

$$\dot{Q}_{\text{motors}} = (\text{No. of motors}) \times \dot{W}_{\text{motor}} \times f_{\text{load}} \times f_{\text{usage}} / \eta_{\text{motor}}$$
$$= 7 \times (2.5 \times 746 \text{ W}) \times 0.70 \times 1.0 / 0.77 = 11{,}870 \text{ W}$$



The heat gain from 14 people is

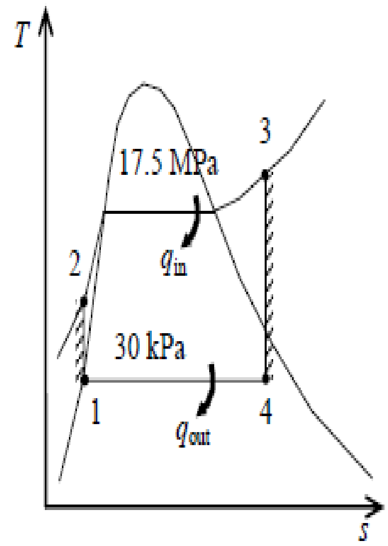
$$\dot{Q}_{\text{people}} = 14 \times (600 \text{ W}) = 8400 \text{ W}$$

Then the total rate of heat gain of the exercise room during peak period becomes

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{motors}} + \dot{Q}_{\text{people}} = 11{,}870 + 8400 = 20{,}270 \text{ W}$$

Q.2

Assumptions 1 Steady operating conditions exist. 2 Kinetic and potential energy changes are negligible.



Analysis From the steam tables (Tables A-4, A-5, and A-6),

$$h_1 = h_{f@\,30\,\text{kPa}} = 289.27\ \text{kJ/kg}$$
$$v_1 = v_{f@\,30\,\text{kPa}} = 0.001022\ \text{m}^3/\text{kg}$$

$$\begin{aligned} w_{p,in} &= v_1(P_2 - P_1) \\ &= (0.001022\ \text{m}^3/\text{kg})(17{,}500 - 30)\text{kPa}\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) \\ &= 17.86\ \text{kJ/kg} \end{aligned}$$
$$h_2 = h_1 + w_{p,in} = 289.27 + 17.86 = 307.13\ \text{kJ/kg}$$

$$\left.\begin{aligned} P_4 &= 30\ \text{kPa} \\ x_4 &= 0.80 \end{aligned}\right\}\ \begin{aligned} h_4 &= h_f + x_4 h_{fg} = 289.27 + (0.80)(2335.3) = 2157.5\ \text{kJ/kg} \\ s_4 &= s_f + x_4 s_{fg} = 0.9441 + (0.80)(6.8234) = 6.4028\ \text{kJ/kg}\cdot\text{K} \end{aligned}$$

$$\left.\begin{aligned} P_3 &= 17.5\ \text{MPa} \\ s_3 &= s_4 = 6.4028\ \text{kJ/kg}\cdot\text{K} \end{aligned}\right\}\ \begin{aligned} h_3 &= 3404.1\ \text{kJ/kg} \\ T_3 &= \mathbf{543^\circ C} \end{aligned}$$

Thus,

$$q_{in} = h_3 - h_2 = 3404.1 - 307.13 = 3097\ \text{kJ/kg}$$
$$q_{out} = h_4 - h_1 = 2157.5 - 289.27 = 1868\ \text{kJ/kg}$$

The thermal efficiency of the cycle is

$$\eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{1868}{3097} = \mathbf{0.397}$$

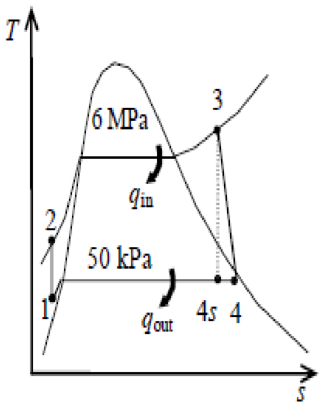
Q. 3

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

Analysis From the steam tables (Tables A-4, A-5, and A-6),

$$\left.\begin{array}{l} P_1 = 50\,\text{kPa} \\ T_1 = T_{\text{sat @ 50kPa}} - 6.3 = 81.3 - 6.3 = 75°\text{C} \end{array}\right\} \begin{array}{l} h_1 \cong h_{f\,@\,75°\text{C}} = 314.03\,\text{kJ/kg} \\ v_1 = v_{f\,@\,75°\text{C}} = 0.001026\,\text{m}^3\text{/kg} \end{array}$$

$$\begin{aligned} w_{\text{p,in}} &= v_1(P_2 - P_1) \\ &= (0.001026\,\text{m}^3\text{/kg})(6000-50)\text{kPa}\left(\frac{1\,\text{kJ}}{1\,\text{kPa}\cdot\text{m}^3}\right) \\ &= 6.10\,\text{kJ/kg} \end{aligned}$$



$$h_2 = h_1 + w_{\text{p,in}} = 314.03 + 6.10 = 320.13\,\text{kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 6000\,\text{kPa} \\ T_3 = 450°\text{C} \end{array}\right\} \begin{array}{l} h_3 = 3302.9\,\text{kJ/kg} \\ s_3 = 6.7219\,\text{kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_4 = 50\,\text{kPa} \\ s_4 = s_3 \end{array}\right\} \begin{array}{l} x_{4s} = \dfrac{s_4 - s_f}{s_{fg}} = \dfrac{6.7219 - 1.0912}{6.5019} = 0.8660 \\ h_{4s} = h_f + x_{4s}h_{fg} = 340.54 + (0.8660)(2304.7) = 2336.4\,\text{kJ/kg} \end{array}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \longrightarrow h_4 = h_3 - \eta_T(h_3 - h_{4s}) = 3302.9 - (0.94)(3302.9 - 2336.4) = 2394.4\,\text{kJ/kg}$$

Thus,

$$\begin{aligned} \dot{Q}_{\text{in}} &= \dot{m}(h_3 - h_2) = (20\,\text{kg/s})(3302.9 - 320.13)\text{kJ/kg} = \mathbf{59{,}660\,kW} \\ \dot{W}_{\text{T,out}} &= \dot{m}(h_3 - h_4) = (20\,\text{kg/s})(3302.9 - 2394.4)\text{kJ/kg} = 18{,}170\,\text{kW} \\ \dot{W}_{\text{P,in}} &= \dot{m}w_{\text{P,in}} = (20\,\text{kg/s})(6.10\,\text{kJ/kg}) = \mathbf{122\,kW} \\ \dot{W}_{\text{net}} &= \dot{W}_{\text{T,out}} - \dot{W}_{\text{P,in}} = 18{,}170 - 122 = \mathbf{18{,}050\,kW} \end{aligned}$$

and

$$\eta_{\text{th}} = \frac{\dot{W}_{\text{net}}}{\dot{Q}_{\text{in}}} = \frac{18{,}050}{59{,}660} = \mathbf{0.3025}$$

Q. 4 Assumptions **1** Air is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of - 141^{o}C and 3.77 MPa.
2 The kinetic and potential energy changes are negligible, $\Delta ke \approx \Delta pe \approx 0$.
3 Constant specific heats at room temperature can be used for air. This assumption results in negligible error in heating and air-conditioning applications.
4 All the doors and windows are tightly closed, and heat transfer through the walls and the windows is disregarded.

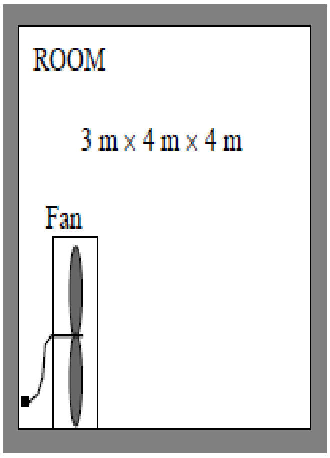
Properties The gas constant of air is $R = 0.287$ kPa.m^3/kg.K (Table A-1). Also, $c_v = 0.718$ kJ/kg.K for air at room temperature (Table A-2).

Analysis We take the room as the system. This is a *closed system* since the doors and the windows are said to be tightly closed, and thus no mass crosses the system boundary during the process. The energy balance for this system can be expressed as

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

$$W_{e,in} = \Delta U$$

$$W_{e,in} = m(u_2 - u_1) \cong mc_v(T_2 - T_1)$$



The mass of air is

$$V = 3 \times 4 \times 4 = 48 \text{ m}^3$$

$$m = \frac{P_1 V}{RT_1} = \frac{(100 \text{ kPa})(48 \text{ m}^3)}{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(293 \text{ K})} = 57.08 \text{ kg}$$

The electrical work done by the fan is

$$W_e = \dot{W}_e \Delta t = (0.100 \text{ kJ/s})(8 \times 3600 \text{ s}) = 2880 \text{ kJ}$$

Substituting and using the c_v value at room temperature,

$$2880 \text{ kJ} = (57.08 \text{ kg})(0.718 \text{ kJ/kg}\cdot°\text{C})(T_2 - 20)°\text{C}$$

$$\mathbf{T_2 = 90.3°C}$$

Discussion Note that a fan actually causes the internal temperature of a confined space to rise. In fact, a 100-W fan supplies a room with as much energy as a 100-W resistance heater.