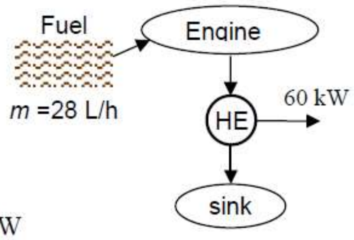
6–21 An automobile engine consumes fuel at a rate of 28 L/h and delivers 60 kW of power to the wheels. If the fuel has a heating value of 44,000 kJ/kg and a density of 0.8 g/cm^3, determine the efficiency of this engine. *Answer:* 21.9 percent

6-21 The power output and fuel consumption rate of a car engine are given. The thermal efficiency of the engine is to be determined.

Assumptions The car operates steadily.

Properties The heating value of the fuel is given to be 44,000 kJ/kg.



Analysis The mass consumption rate of the fuel is

$$\dot{m}_{\text{fuel}} = (\rho \dot{V})_{\text{fuel}} = (0.8 \text{ kg/L})(28 \text{ L/h}) = 22.4 \text{ kg/h}$$

The rate of heat supply to the car is

$$\dot{Q}_H = \dot{m}_{\text{coal}} u_{\text{coal}} = (22.4 \text{ kg/h})(44{,}000 \text{ kJ/kg}) = 985{,}600 \text{ kJ/h} = 273.78 \text{ kW}$$

Then the thermal efficiency of the car becomes

$$\eta_{\text{th}} = \frac{\dot{W}_{\text{net,out}}}{\dot{Q}_H} = \frac{60 \text{ kW}}{273.78 \text{ kW}} = 0.219 = \mathbf{21.9\%}$$

6–28 A coal-burning steam power plant produces a net power of 300 MW with an overall thermal efficiency of 32 percent. The actual gravimetric air–fuel ratio in the furnace is calculated to be 12 kg air/kg fuel. The heating value of the coal is 28,000 kJ/kg. Determine (*a*) the amount of coal consumed during a 24-hour period and (*b*) the rate of air flowing through the furnace. *Answers:* (*a*) 2.89 × 10^6 kg, (*b*) 402 kg/s

6-28 A coal-burning power plant produces 300 MW of power. The amount of coal consumed during a one-day period and the rate of air flowing through the furnace are to be determined.

Assumptions **1** The power plant operates steadily. **2** The kinetic and potential energy changes are zero.

Properties The heating value of the coal is given to be 28,000 kJ/kg.

Analysis (*a*) The rate and the amount of heat inputs to the power plant are

$$\dot{Q}_{\text{in}} = \frac{\dot{W}_{\text{net,out}}}{\eta_{\text{th}}} = \frac{300 \text{ MW}}{0.32} = 937.5 \text{ MW}$$

$$Q_{\text{in}} = \dot{Q}_{\text{in}} \Delta t = (937.5 \text{ MJ/s})(24 \times 3600 \text{ s}) = 8.1 \times 10^7 \text{ MJ}$$

The amount and rate of coal consumed during this period are

$$m_{\text{coal}} = \frac{Q_{\text{in}}}{q_{\text{HV}}} = \frac{8.1 \times 10^7 \text{ MW}}{28 \text{ MJ/kg}} = \mathbf{2.893 \times 10^6 \text{ kg}}$$

$$\dot{m}_{\text{coal}} = \frac{m_{\text{coal}}}{\Delta t} = \frac{2.893 \times 10^6 \text{ kg}}{24 \times 3600 \text{ s}} = 33.48 \text{ kg/s}$$

(*b*) Noting that the air-fuel ratio is 12, the rate of air flowing through the furnace is

$$\dot{m}_{\text{air}} = (\text{AF})\dot{m}_{\text{coal}} = (12 \text{ kg air/kg fuel})(33.48 \text{ kg/s}) = \mathbf{401.8 \text{ kg/s}}$$

6–43 A household refrigerator that has a power input of 450 W and a COP of 2.5 is to cool five large watermelons, 10 kg each, to 8°C. If the watermelons are initially at 20°C, determine how long it will take for the refrigerator to cool them. The watermelons can be treated as water whose specific heat is 4.2 kJ/kg · °C. Is your answer realistic or optimistic? Explain. *Answer: 2240 s*

6-43 The COP and the power consumption of a refrigerator are given. The time it will take to cool 5 watermelons is to be determined.

Assumptions **1** The refrigerator operates steadily. **2** The heat gain of the refrigerator through its walls, door, etc. is negligible. **3** The watermelons are the only items in the refrigerator to be cooled.

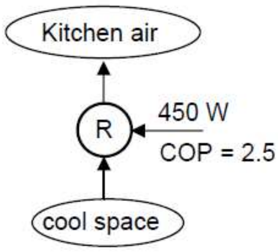
Properties The specific heat of watermelons is given to be c = 4.2 kJ/kg.°C.

Analysis The total amount of heat that needs to be removed from the watermelons is

$$Q_L = (mc\Delta T)_{\text{watermelons}} = 5\times(10\text{ kg})(4.2\text{ kJ/kg}\cdot{}^\circ\text{C})(20-8)^\circ\text{C} = 2520\text{ kJ}$$

The rate at which this refrigerator removes heat is

$$\dot{Q}_L = (\text{COP}_\text{R})(\dot{W}_{\text{net,in}}) = (2.5)(0.45\text{ kW}) = 1.125\text{ kW}$$

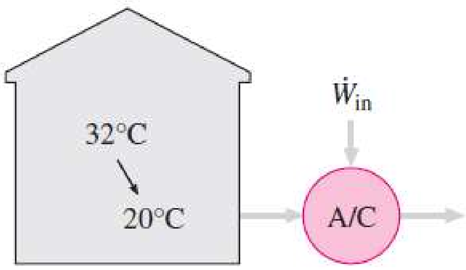


That is, this refrigerator can remove 1.125 kJ of heat per second. Thus the time required to remove 2520 kJ of heat is

$$\Delta t = \frac{Q_L}{\dot{Q}_L} = \frac{2520\text{ kJ}}{1.125\text{ kJ/s}} = 2240\text{ s} = \mathbf{37.3\text{ min}}$$

This answer is optimistic since the refrigerated space will gain some heat during this process from the surrounding air, which will increase the work load. Thus, in reality, it will take longer to cool the watermelons.

6–44 When a man returns to his well-sealed house on a summer day, he finds that the house is at 32°C. He turns on the air conditioner, which cools the entire house to 20°C in 15 min. If the COP of the air-conditioning system is 2.5, determine the power drawn by the air conditioner. Assume the entire mass within the house is equivalent to 800 kg of air for which c_v = 0.72 kJ/kg · °C and c_p = 1.0 kJ/kg · °C.



6-44 [*Also solved by EES on enclosed CD*] An air conditioner with a known COP cools a house to desired temperature in 15 min. The power consumption of the air conditioner is to be determined.

Assumptions **1** The air conditioner operates steadily. **2** The house is well-sealed so that no air leaks in or out during cooling. **3** Air is an ideal gas with constant specific heats at room temperature.

Properties The constant volume specific heat of air is given to be $c_v = 0.72$ kJ/kg.°C.

Analysis Since the house is well-sealed (constant volume), the total amount of heat that needs to be removed from the house is

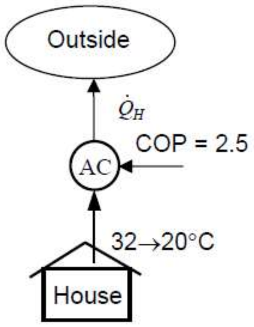
$$Q_L = (mc_v \Delta T)_{\text{House}} = (800\text{ kg})(0.72\text{ kJ/kg}\cdot{}^\circ\text{C})(32-20)^\circ\text{C} = 6912\text{ kJ}$$

This heat is removed in 15 minutes. Thus the average rate of heat removal from the house is

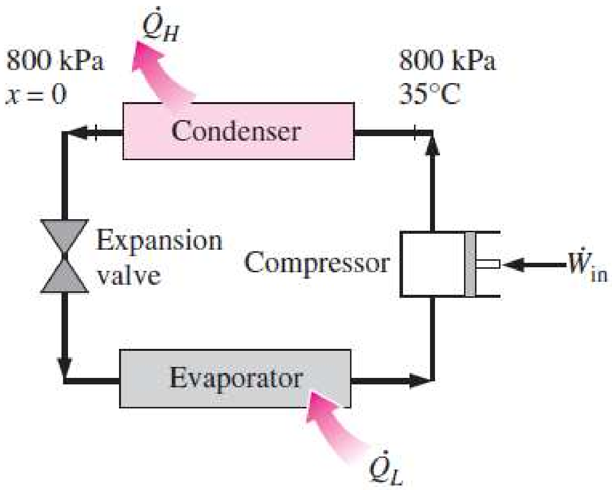
$$\dot{Q}_L = \frac{Q_L}{\Delta t} = \frac{6912\text{ kJ}}{15 \times 60\text{ s}} = 7.68\text{ kW}$$

Using the definition of the coefficient of performance, the power input to the air-conditioner is determined to be

$$\dot{W}_{\text{net,in}} = \frac{\dot{Q}_L}{\text{COP}_\text{R}} = \frac{7.68\text{ kW}}{2.5} = \mathbf{3.07\text{ kW}}$$

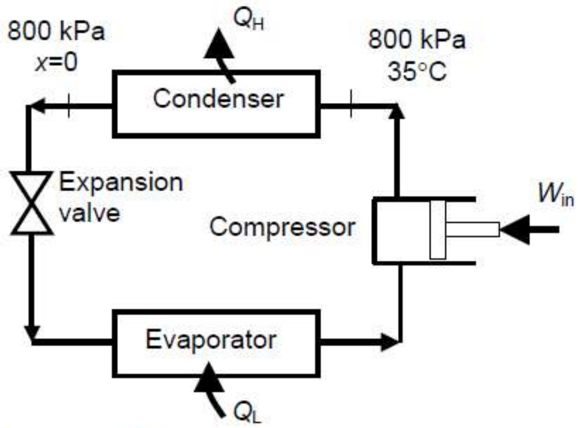


6–54 Refrigerant-134a enters the condenser of a residential heat pump at 800 kPa and 35°C at a rate of 0.018 kg/s and leaves at 800 kPa as a saturated liquid. If the compressor consumes 1.2 kW of power, determine (*a*) the COP of the heat pump and (*b*) the rate of heat absorption from the outside air.



6-54 Refrigerant-134a flows through the condenser of a residential heat pump unit. For a given compressor power consumption the COP of the heat pump and the rate of heat absorbed from the outside air are to be determined.

Assumptions **1** The heat pump operates steadily. **2** The kinetic and potential energy changes are zero.



Properties The enthalpies of R-134a at the condenser inlet and exit are

$$\left.\begin{array}{l} P_1 = 800\text{ kPa} \\ T_1 = 35°\text{C} \end{array}\right\} h_1 = 271.22\text{ kJ/kg}$$

$$\left.\begin{array}{l} P_2 = 800\text{ kPa} \\ x_2 = 0 \end{array}\right\} h_2 = 95.47\text{ kJ/kg}$$

Analysis (*a*) An energy balance on the condenser gives the heat rejected in the condenser

$$\dot{Q}_H = \dot{m}(h_1 - h_2) = (0.018\text{ kg/s})(271.22 - 95.47)\text{ kJ/kg} = 3.164\text{ kW}$$

The COP of the heat pump is

$$\text{COP} = \frac{\dot{Q}_H}{\dot{W}_{in}} = \frac{3.164\text{ kW}}{1.2\text{ kW}} = \mathbf{2.64}$$

(*b*) The rate of heat absorbed from the outside air

$$\dot{Q}_L = \dot{Q}_H - \dot{W}_{in} = 3.164 - 1.2 = \mathbf{1.96\text{ kW}}$$

6–80 A geothermal power plant uses geothermal water extracted at 160°C at a rate of 440 kg/s as the heat source and produces 22 MW of net power. If the environment temperature is 25°C, determine (*a*) the actual thermal efficiency, (*b*) the maximum possible thermal efficiency, and (*c*) the actual rate of heat rejection from this power plant.

6-80 A geothermal power plant uses geothermal liquid water at 160ºC at a specified rate as the heat source. The actual and maximum possible thermal efficiencies and the rate of heat rejected from this power plant are to be determined.

Assumptions **1** The power plant operates steadily. **2** The kinetic and potential energy changes are zero. **3** Steam properties are used for geothermal water.

Properties Using saturated liquid properties, the source and the sink state enthalpies of geothermal water are (Table A-4)

$$\left.\begin{array}{l} T_{\text{source}} = 160°\text{C} \\ x_{\text{source}} = 0 \end{array}\right\} h_{\text{source}} = 675.47\ \text{kJ/kg}$$

$$\left.\begin{array}{l} T_{\text{sink}} = 25°\text{C} \\ x_{\text{sink}} = 0 \end{array}\right\} h_{\text{sink}} = 104.83\ \text{kJ/kg}$$

Analysis (*a*) The rate of heat input to the plant may be taken as the enthalpy difference between the source and the sink for the power plant

$$\dot{Q}_{\text{in}} = \dot{m}_{\text{geo}}(h_{\text{source}} - h_{\text{sink}}) = (440\ \text{kg/s})(675.47 - 104.83)\ \text{kJ/kg} = 251{,}083\ \text{kW}$$

The actual thermal efficiency is

$$\eta_{\text{th}} = \frac{\dot{W}_{\text{net,out}}}{\dot{Q}_{\text{in}}} = \frac{22\ \text{MW}}{251.083\ \text{MW}} = \mathbf{0.0876 = 8.8\%}$$

(*b*) The maximum thermal efficiency is the thermal efficiency of a reversible heat engine operating between the source and sink temperatures

$$\eta_{\text{th,max}} = 1 - \frac{T_L}{T_H} = 1 - \frac{(25+273)\ \text{K}}{(160+273)\ \text{K}} = \mathbf{0.312 = 31.2\%}$$

(*c*) Finally, the rate of heat rejection is

$$\dot{Q}_{\text{out}} = \dot{Q}_{\text{in}} - \dot{W}_{\text{net,out}} = 251.1 - 22 = \mathbf{229.1\ MW}$$