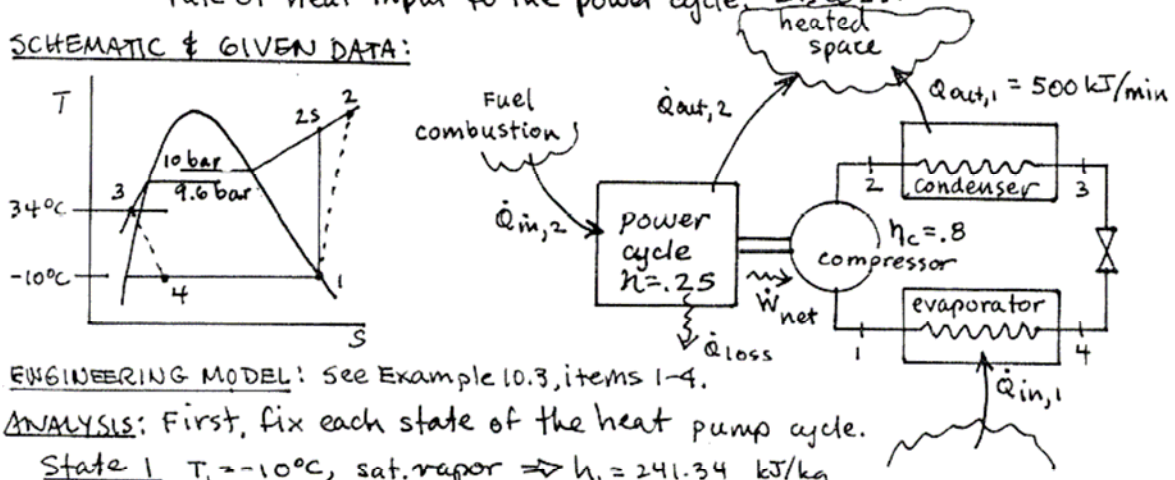
PROBLEM 10.40

KNOWN: Refrigerant 134a is the working fluid in a vapor-compression heat pump driven by a power cycle. Operating data are specified for the heat pump and the power cycle.

FIND: Determine (a) the heat pump compressor power and (b) the ratio of the total rate heat is delivered to the heated space to the rate of heat input to the power cycle. Discuss.

SCHEMATIC & GIVEN DATA:



ENGINEERING MODEL: See Example 10.3, items 1-4.

ANALYSIS: First, fix each state of the heat pump cycle.

State 1 $T_1 = -10°C$, sat. vapor $\Rightarrow h_1 = 241.34$ kJ/kg
$s_1 = .9253$ kJ/kg·K

State 2 For isentropic compression, $p_2 = 10$ bar, $s_{2s} = s_1 \Rightarrow h_{2s} = 274.63$ kJ/kg
Using the compressor efficiency

$$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1} \Rightarrow h_2 = h_1 + \left(\frac{h_{2s} - h_1}{\eta_c}\right) = 282.95 \text{ kJ/kg}$$

State 3 $p_3 = 9.6$ bar, $T_3 = 34°C \Rightarrow$ comp. liq.; $h_3 \approx h_f(34°C) = 97.31$ kJ/kg

State 4 Throttling process $\Rightarrow h_4 = h_3 = 97.31$ kJ/kg

(a) The mass flow rate of refrigerant is

$$\dot{m} = \frac{\dot{Q}_{out,1}}{h_2 - h_3} = \frac{(500 \text{ kJ/min})}{(282.95 - 97.31)\text{ kJ/kg}} \left|\frac{1 \text{ min}}{60 \text{ s}}\right| = 0.04489 \text{ kg/s}$$

The compressor power becomes

$$\dot{W}_c = \dot{m}(h_2 - h_1) = \left(.04489 \frac{\text{kg}}{\text{s}}\right)(282.95 - 241.34)\frac{\text{kJ}}{\text{kg}}\left|\frac{1 \text{ kW}}{1 \text{ kJ/s}}\right|$$

$$= 1.868 \text{ kW} \leftarrow \dot{W}_c$$

(b) For the power cycle, $\eta = 0.25$. With $\dot{W}_{\substack{power\\cycle}} = \dot{W}_{\substack{heat\\pump}} = 1.868$ kW

$$\dot{Q}_{in,2} = \frac{\dot{W}_{cycle}}{\eta} = 7.472 \text{ kW}$$

The total heat rejected is, $\dot{Q}_{rej} = 7.472 \text{ kW} - 1.868 \text{ kW} = 5.604$ kW

Thus, $\dot{Q}_{out,2} = (.8)\dot{Q}_{rej} = 4.483$ kW

Finally,

$$\frac{\dot{Q}_{out,1} + \dot{Q}_{out,2}}{\dot{Q}_{in,2}} = \frac{(500/60) + 4.483}{7.472} = 1.687 \leftarrow \text{(b)}$$

Discussion: The engin-driven heat pump delivers more energy to the heated space than could be obtained by burning the fuel directly.

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