ME354
Thermodynamics 2

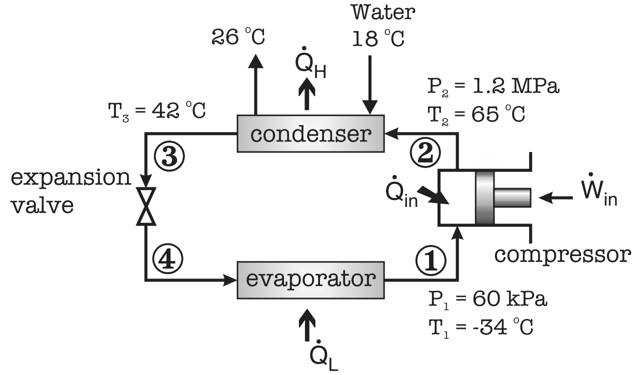
Quiz #3 - T02:

Name:	____________________
ID #:	____________________

Problem: A commercial refrigerator with refrigerant- $\mathbf{134a}$ as the working fluid is used to keep the refrigerated space at $\mathbf{-30\ ^\circ C}$ by rejecting its waste heat to cooling water that enters the condenser at $\mathbf{18\ ^\circ C}$ at a rate of $\mathbf{0.25\ kg/s}$ and leaves at $\mathbf{26\ ^\circ C}$. The refrigerant enters the condenser at $\mathbf{1.2\ MPa}$ and $\mathbf{65\ ^\circ C}$ and leaves at $\mathbf{42\ ^\circ C}$. The inlet state of the compressor is $\mathbf{60\ kPa}$ and $\mathbf{-34\ ^\circ C}$ and the compressor is estimated to gain a net heat of $\mathbf{450\ W}$ from the surroundings.

Determine:

(a) the quality of the refrigerant at the evaporator inlet,
(b) the refrigeration load, $[\mathbf{kW}]$
(c) the COP of the refrigerator,



Assumptions

1. $\boldsymbol{SS - SF}$
2. $\boldsymbol{KE = PE \rightarrow 0}$
3. properties are constant

Part a)

state	T $(^\circ C)$	P (kPa)	h (kJ/kg)	s $(kJ/kg \cdot K)$	comment
1	-34	60	230.05		
2	65	1200	295.13		Table A-13
3	42	1200	111.37		
4		60	111.37		$h_4 = h_3$

1 mark

State 1

We first notice from Table A-12, our temperature at 1 is above the saturation temperature at $\mathbf{60\ kPa}$, therefore state point 1 is in the superheated region. From Table A-13 at $P_1 = \mathbf{0.06\ MPa}$ we need to interpolate.

$$h_1 = 0.826(227.79) + 0.174(240.76) = 230.05\ kJ/kg$$

1 mark

State 3

We notice from Table A-12, our temperature at 3 is below the saturation temperature $1200\ kPa$, therefore state point 3 is in the sub cooled region. From Table A-11 we can determine

$$h_3 = h_f(T) + v_f(T)[P - P_{sat}(T)] = 111.26 + 0.0008786(1200 - 1072.8) = 111.37\ kJ/kg$$

1 mark

State 4

State point 4 is under the dome with pressure and entropy known, therefore from Table A-12

$$x_4 = \frac{111.37 - 3.841}{227.79 - 3.841} = 0.4802 \Leftarrow$$

1 mark

Part b)

The mass flow rate of the refrigerant can be determined by applying a 1st law energy balance across the condenser.

The water properties can be obtained by using a saturated liquid at the given temperature

$$\begin{aligned} h_{w1} &= h_{f@18\,^\circ C} = 75.54\ kJ/kg \\ h_{w2} &= h_{f@26\,^\circ C} = 109.01\ kJ/kg \end{aligned}$$

1 mark

$$\begin{aligned} \dot{m}_R(h_2 - h_3) &= \dot{m}_w(h_{w2} - h_{w1}) \\ \dot{m}_R(295.13 - 111.37)\ kJ/kg &= (0.25\ kg/s)(109.01 - 75.54)\ kJ/kg \\ \dot{m}_R &= 0.0455\ kg/s \end{aligned}$$

2 marks

The refrigeration load is given as

$$\dot{Q}_L = \dot{m}_R(h_1 - h_4) = (0.0455\ kg/s)(230.03 - 111.37)\ kJ/kg = 5.39\ kW \Leftarrow$$

1 mark

Note: Cengel calculates the refrigeration load as $\dot{Q}_H - \dot{W}_{in}$. This includes the Q_{in} of the compressor in addition to the enthalpy of the evaporator and provides a $\dot{Q}_L = 5.85\ kW$. While not technically the cooling load, I will accept this answer.

Part c)

The specific work into the compressor can be determined as

$$w_{in} = (h_2 - h_1) - \frac{\dot{Q}_{in}}{\dot{m}_R} = (295.13 - 230.03)\ kJ/kg - \frac{0.450\ kJ/s}{0.0455\ kg/s} = 55.21\ kJ/kg$$

1 mark

The COP is determined as

$$COP = \frac{\dot{q}_L}{\dot{w}_{in}} = \frac{h_1 - h_4}{w_{in}} = \frac{(230.03 - 111.37)\ kJ/kg}{55.21\ kJ/kg} = 2.14 \Leftarrow$$

1 mark

Note: I have calculated q_L as the actual heat gain across the evaporator. Cengel calculates $q_L = q_H - w_{in}$. Since w_{in} is biased by the heat gain at the compressor this leads to a $COP = 2.33$. I will accept this as a valid solution although, the COP should only be based on the actual energy gain which is $h_1 - h_4$.