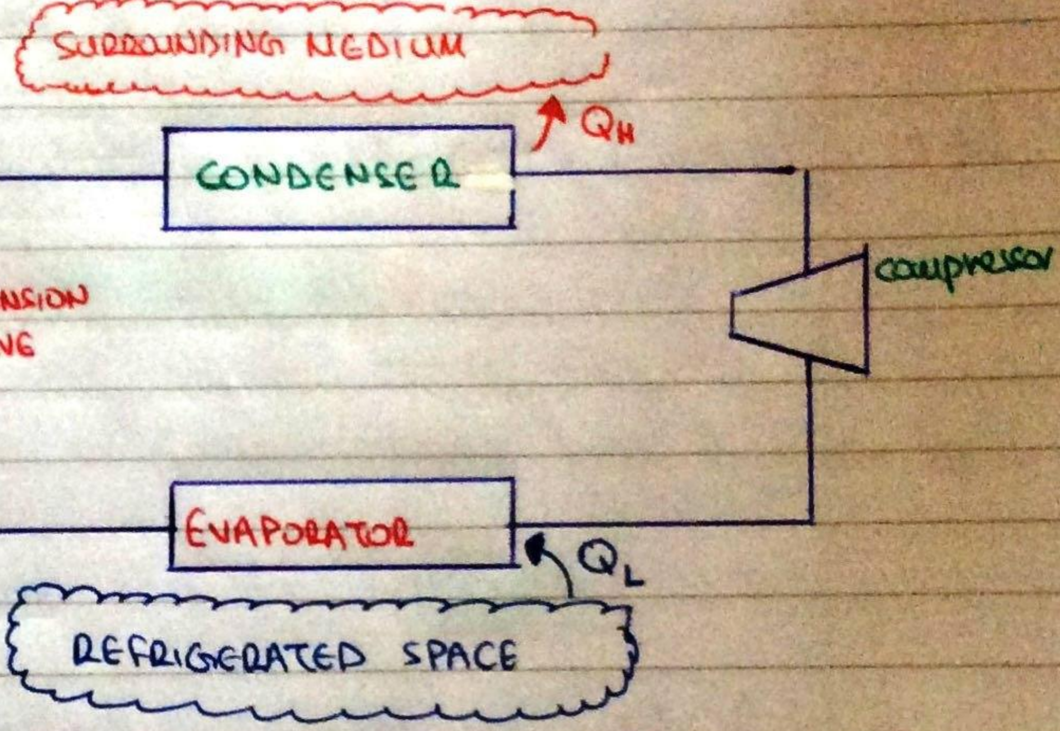
Tutorial 3: Thermodynamics [Solutions]

Question 1:

a) The basic components of a refrigerator system are presented below:



b) By using the definition of the COP_R, the power input to the refrigerator is determined as:

$$COP_R = \frac{\text{Desired Output}}{\text{Required Input}} = \frac{Q_L}{W_{net,in}} \Rightarrow COP_R = \frac{\dot{Q}_L}{\dot{W}_{net,in}} \quad [\text{Rate form}]$$

$$\dot{W}_{net,in} = \frac{\dot{Q}_L}{COP_R} = \frac{85\ [kJ/min]}{1,4} \Rightarrow \boxed{\dot{W}_{net,in} = 60,7\ kJ/min}$$

c) From the energy balance will have the following:

$$\dot{Q}_H = \dot{Q}_L + \dot{W}_{net,in} = 85\ [kJ/min] + 60,7\ [kJ/min] =$$
$$= \boxed{145,7\ [kJ/min]}$$

Question 2:

$\dot{W}_{net,in} = 450\ W$

$COP_R = 2{,}5$

$m_{tot} = 5 \cdot 10 = 50\ kg$

$T_L = 8^\circ C$

$T_{in} = 20^\circ C$

$C_p = 4{,}2\ kJ/kg \cdot K$

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

$$Q_L = [m \cdot C \cdot \Delta T] = 50\,[\cancel{kg}] \cdot 4{,}2 \left[\frac{kJ}{\cancel{kg} \cdot \cancel{K}}\right] \cdot 12\,[\cancel{K}]$$

$$\# \boxed{Q_L = 2520\ kJ} \#$$

The rate that the refrigerator removes heat is given by:

$$\dot{Q}_L = (COP_R) \cdot \dot{W}_{net,in} = 2{,}5 \cdot 450 = \boxed{1125\ W}$$

The total time required to remove 2520 kJ of heat

$$\Delta t = \frac{Q_L}{\dot{Q}_L} = \frac{2520\ kJ}{1{,}125\ \frac{kJ}{s}} \Rightarrow \boxed{\Delta t = 37{,}3\ min}$$

Question 3:

$Q_H = 700\ kJ$

$T_H = 500\ K$

$W_{net} = 300\ kJ$

$T_L = 290\ K$

The maximum efficiency of a heat engine is given by

$$\eta_{th,max} = 1 - \frac{T_L}{T_H} = 1 - \frac{290}{500} = 0{,}42\ [42\%]$$

The actual thermal efficiency is given by the following expression

$$\eta_{th} = \frac{W_{net}}{Q_H} = \frac{300\ kJ}{700\ kJ} = \boxed{42{,}9\%}$$

The claim is false as $\eta_{th} > \eta_{th,max}$.

Question 4:

$T = 160°C$

$\dot{m}_g = 440\ kg/s$

$\dot{W}_{net,out} = 22\ MW$

$T_L = 25°C$

$\left.\begin{matrix} T_{source}: 160°C \\ x_{source} = 0 \end{matrix}\right\} h_{source} = 675{,}47\ kJ/kg$

$\left.\begin{matrix} T_{sink}: 25°C \\ x_{sink} = 0 \end{matrix}\right\} h_{sink} = 104{,}83\ kJ/kg$

a) The rate of heat input to the plant is taken as the enthalpy difference between the source and the sink

$$\dot{Q}_{in} = \dot{m}_g \cdot [h_{source} - h_{sink}] = 440 [\cancel{kg}/s] \cdot 570{,}64 [kJ/\cancel{kg}]$$

$$\dot{Q}_{in} = 251081{,}6 \left[\frac{kJ}{s}\right] = \boxed{251.082\ [kW]}$$

So, the actual thermal efficiency $\eta_{th} = \frac{\dot{W}_{net,out}}{\dot{Q}_{in}} = \frac{22\ MW}{251\ MW} \Rightarrow$

$\boxed{\eta_{th} = 8{,}8\%}$

b) The maximum thermal efficiency is given by the following:

$$\eta_{th,max} = 1 - \frac{T_L}{T_H} = 1 - \frac{(25+273)\ K}{(160+273)\ K} \Rightarrow \boxed{\eta_{th,max} = 31{,}2\%}$$

c) The heat rejection is $\boxed{\dot{Q}_{out} = \dot{Q}_{in} - \dot{W}_{net,out} = 229{,}1\ MW}$

Question 5:

The COP of the heat pump will be maximum when the heat pump operates in a reversible manner. So, it should be

$$COP_{HP,rev} = \frac{1}{1 - \frac{T_L}{T_H}} = \frac{1}{1 - \left[\frac{283}{293}\right]} = 29{,}3 \quad \text{for outdoor } 10°C$$

$$COP_{HP,rev} = \frac{1}{1 - \frac{T_L}{T_H}} = \frac{1}{1 - \left[\frac{268}{293}\right]} = 11{,}7 \quad \text{for outdoor } -5°C$$

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Finally: $COP_{HP,rev} = \dfrac{1}{1 - \frac{T_L}{T_H}} = \dfrac{1}{1 - \left(\frac{243}{293}\right)} = 5,86$ for outdoor: $-30°C$