MIN-106 - Tutorial 6

Shashank Aital
19114076 - Batch 04
Branch: CSE

Q.1. (a) The first law of thermodynamics states that,

$$Q = \Delta U + W$$

If $\eta = 1 \Rightarrow Q = W \Rightarrow \boxed{\Delta U = 0}$

$\Rightarrow$ Does not violate first law of thermodynamics.

(b) The second law of thermodynamics ~~states that~~,
~~has~~ is violated by $\boxed{\eta = 1}$
~~As there can be~~
As conversion of all heat into energy is not possible
(It directly contradicts Kelvin-Planck statement)

Q.2. $\rightarrow$ No, the efficiencies of all work-producing devices don't necessarily violate the Kelvin-Planck statement.

$\rightarrow$ The Kelvin-Planck statement is applicable to the devices that produce work by transfer of heat between heat sources (heat engines).

$\Rightarrow \because$ Hydroelectric power plants produce work from water (and not heat sources), they are not limited by Kelvin-Planck statement of the second law.

Q-3. (a) $\dot{Q}_H = 6kW$, $\dot{Q}_L = 4kW$, $\dot{W} = 2kW$

$\because \dot{Q}_H - \dot{Q}_L = \dot{W}$, it satisfies first law.

$\eta = \frac{2}{3} < 1$ & $\dot{Q}_L \neq 0 \Rightarrow$ Second law is satisfied.

(b) $\dot{Q}_H = 6kW$, $\dot{Q}_L = 0kW$, $\dot{W} = 6kW$

$\because \dot{Q}_H - \dot{Q}_L = \dot{W}$, it satisfies first law.

$\because \dot{Q}_L = 0, \Rightarrow$ Second law is violated.

[(Kelvin-Planck statement is violated)

(c) $\dot{Q}_H = 6kW$, $\dot{Q}_L = 2kW$, $\dot{W} = 5kW$

$\because \dot{Q}_H - \dot{Q}_L \neq \dot{W} \Rightarrow$ First Law is violated.

$\because \eta = \frac{5}{6} < 1$ i.e. $\dot{Q}_L \neq 0 \Rightarrow$ Second Law is satisfied.

(d) $\dot{Q}_H = 6kW$, $\dot{Q}_L = 6kW$, $\dot{W} = 0kW$

$\because \dot{Q}_H - \dot{Q}_L = \dot{W}$, $\Rightarrow$ First law is satisfied

Also, $\because \dot{Q}_L \neq 0$ i.e. $\eta < 1 \Rightarrow$ Second law is satisfied

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Q-4. $\dot{W} = 500W$

Now $COP = \frac{\dot{Q}_L}{\dot{W}} \Rightarrow \dot{Q}_L = 2.5 \times 500 = 1250W$

$\Rightarrow$ 1750W of power is dissipated in the surroundings thus, increasing the surrounding temperature.

Q.5. The work necessary for running the car is being produced by the cooling of air.

So, $\Delta U = W$ $\Rightarrow$ First law of thermodynamics is satisfied.

Also, ∵ Heat flows from hot source to cold source, &

so, we could assume hot source as "source" and cold source as "sink"

Therefore, the second law of thermodynamics is satisfied.

Q.6. $\dot{W} = 150\,MW$ $\dot{m} = 60\times10^3\,kg/h$ Heating value $= 30\times10^3\,KJ/kg$

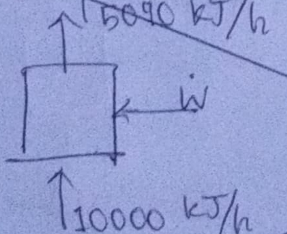
$$\Rightarrow \cancel{\eta = \frac{\dot{W}}{\dot{Q}_H} = \frac{150\times10^6 \times 3600}{60\times10^3 \times 30\times10^3 \times 3600} = \frac{150\times36}{6\times3}}$$

$$\dot{Q}_H = \frac{60\times10^3}{3600} \times 30\times10^3\ KJ/sec$$

$$= \frac{1}{2}\times10^6\ kJ/sec = \frac{10^3}{2}\ MJ/sec = \frac{10^3}{2}\ MW$$

$$\eta = \frac{150}{10^3}\times 2 = 0.3 = 30\%$$

Q.7.



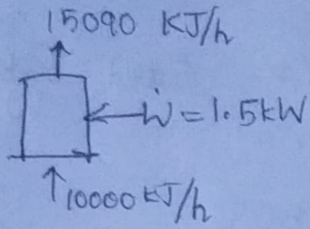
$\Rightarrow$ By first law,

$\dot{W} = 5090\ kJ/h$

$\Rightarrow COP = \frac{\dot{Q}_H}{\dot{W}} = \frac{\cancel{10000}}{\cancel{5090}}\ \frac{1509}{509}$

$=$

Q.7



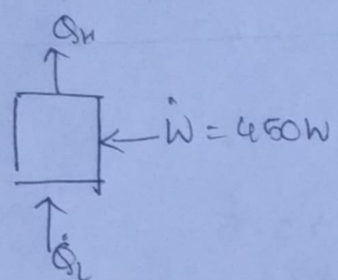
For a heat engine, $COP = \frac{\dot{Q}_H}{\dot{W}}$

$\Rightarrow \cancel{\dot{W} = 15090}$ KJ/h

$\Rightarrow \cancel{COP = \frac{15090}{5090}} =$

$\Rightarrow COP = \frac{15090}{1.5 \times 3600} = \underline{2.79}$

Q.8.



Now, $COP = \frac{\dot{Q}_L}{\dot{W}}$ (For refrigerator)

$\Rightarrow \dot{Q}_L = 450 \times 2.5 = 1125\,W$

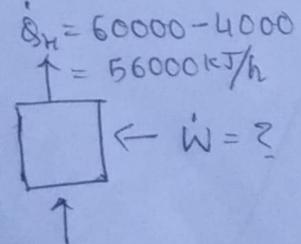
Now, $\dot{Q}_L t = mc\Delta T$

$\Rightarrow t = \frac{5 \times 10 \times 4.2 \times 10^3 \times (20-12)}{1125}$

$\Rightarrow \boxed{t = 2240 \text{ sec}}$

→ This calculation is optimistic because there will be heat due to surroundings and non-ideal phenomenon.
→ This is the best case time (time in ideal scenario)

Q.9.

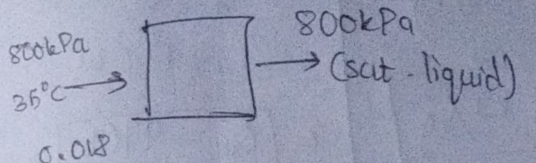


$COP = \frac{\dot{Q}_H}{\dot{W}}$

$\Rightarrow \dot{W} = \frac{56000}{3600 \times 2.5}$

$= \underline{6.22\,kW}$.

10. Using values for R134-a,



Initial condition: Superheated

At $P = 0.8\,MPa$,

$T_{sat} = 31.33°C$ & $h_{sat} = 264.15\,kJ/kg$

$T = 40°C \Rightarrow h = 273.66\,kJ/kg$

Using interpolation,

$$h_1 = 264.15 + \frac{35 - 31.33}{40 - 31.33} \times (273.66 - 264.15)$$

$$= 264.15 + \frac{3.67}{8.67} \times (273.66 - 264.15)$$

$$= 268.17557\,kJ/kg$$

$h_2 = 93.42\,kJ/kg$ (h_{sat} at 0.8 MPa) (for liquid)

$$\Rightarrow \dot{Q}_H = \dot{m}(\Delta h)$$

$$= 0.018(268.17557 - 93.42)$$

$$= 3.1456\,kW$$

(a) Now, COP for Heat pump $= \dfrac{\dot{Q}_H}{\dot{W}} = \dfrac{3.1456}{1.2} = \underline{\underline{2.63}}$

(b) Rate of heat absorption from the air $= \dot{Q}_L = \dot{Q}_H - \dot{W}$

$$= 3.1456 - 1.2$$

$$= \underline{\underline{1.9456\,kW}}$$

(Answers vary slightly because of the preference of thermodynamic properties table chosen)

Q.11. At 120 kPa, $h_f = 21.32$ kJ/kg

$h_{fg} = 212.54$ kJ/kg

$x = 0.2 \Rightarrow \boxed{h_1 = 63.828 \text{ kJ/kg}}$

$\boxed{h_2 = 237.46 \text{ kJ/kg}}$

$\Rightarrow \dot{m}(\Delta h) = \dot{Q}_L$

$\Rightarrow 540 \times 10^{-3} = \dot{m}(237.46 - 63.828)$

$\Rightarrow \dot{m} = \dfrac{540}{173.63\cancel{4}2} \times 10^{-3}$

$\Rightarrow \dot{m} = \underline{0.00311 \text{ kg/s}}$.

$\dot{W} = 450$ W

$\Rightarrow \dot{Q}_L = (COP)(\dot{W})$

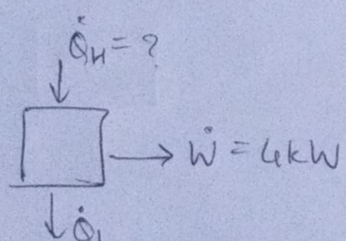
$= 540$ W

& $\boxed{\dot{Q}_H = 990 \text{W}}$ $(= \dot{Q}_L + \dot{W})$

→ The rate of heat rejected to the kitchen air

$= \underline{990 \text{W}}$ $(= \dot{Q}_H)$

Q.12.



Now, $\dfrac{T_L}{T_H} = \dfrac{\dot{Q}_L}{\dot{Q}_H} = 1 - \dfrac{\dot{W}}{\dot{Q}_H}$

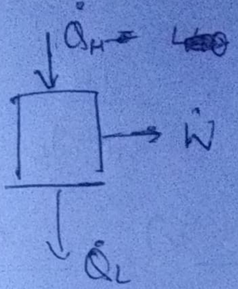
$\Rightarrow \dfrac{\dot{W}}{\dot{Q}_H} = 1 - \dfrac{28\cancel{0}}{80\cancel{0}} = \dfrac{52}{80}$

$\Rightarrow \dot{Q}_H = \dfrac{4 \times 80}{52} = \dfrac{80}{13}$ kW

$\Rightarrow \dot{Q}_H = \dfrac{80}{13} \times 3600$ kJ/h

$= \underline{22153.846 \text{ kJ/h}}$

Q. 13.



$T_H = 160°C = 443 K$

$T_C = 25°C = 298 K$

$\dot{W} = 22 MW$

$\dot{Q}_H = \dot{m}(\Delta h)$

$h_1 = 675.47$ kJ/kg (h_f at 160°C)

$h_2 = 108.77$ kJ/kg (h_f at 25°C)

$\Delta h = 566.7$ kJ/kg

$\Rightarrow \dot{Q}_H = 440 \times 556.7$ kW

$= \underline{\underline{249.348 \text{ MW}}}$

(a) $\Rightarrow \eta = \dfrac{\dot{W}}{\dot{Q}_H} = \dfrac{22}{249.348} = 0.08823 = \underline{\underline{8.823\%}}$.

(b) $\Rightarrow \eta_{max} = 1 - \dfrac{T_L}{T_H} = 1 - \dfrac{298}{443} = 0.311778$

$= \underline{\underline{31.2\%}}$.

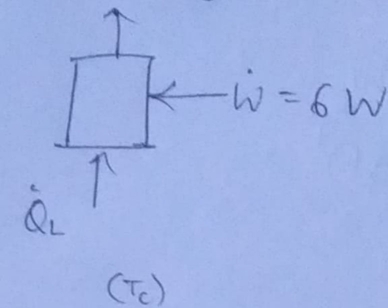
(c) $\dot{Q}_C = \dot{Q}_H - \dot{W}$

$= 249.348 - 22$

$= \underline{\underline{227.348 \text{ MW}}}$

Q.14. $(T_H = 294K)$

$$\dot{Q}_H = \frac{5400}{3600}(294 - T_c)$$



$$\beta = \frac{\dot{Q}_H}{\dot{W}} = \frac{T_H}{T_H - T_c}$$

$$\Rightarrow \frac{1.5(294 - T_c)}{6} = \frac{294}{294 - T_c}$$

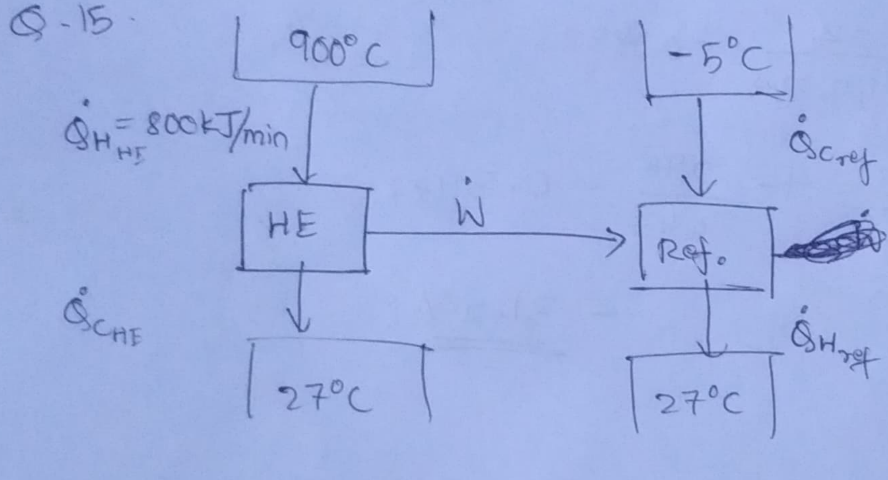
$$\Rightarrow 294 - T_c = \sqrt{4 \times 294}$$

$$\Rightarrow T_c = 294 - \sqrt{4 \times 294}$$

$$\Rightarrow T_c(°C) = 21 - \sqrt{4 \times 294}$$

$$= \underline{\underline{-13.2928\ °C}}$$

Q.15.



$$\eta_{HE} = 1 - \frac{T_c}{T_H} = 1 - \frac{273 + 27}{273 + 900}$$

$$= 1 - \frac{300}{1173} = \underline{\underline{0.7442}}$$

~~$\dot{Q}_H = \frac{800}{60}$ kJ/sec $= \frac{40}{3}$ kW~~ $\quad \dot{Q}_h = 800\,kJ/\cancel{sec}\ min$

$$\dot{W} = \eta_{HE}\,\dot{Q}_{H_{HE}} = 800 \times 0.7442 =$$

$$= 595.36\ kJ/min$$

$$\beta_{ref} = \frac{\dot{Q}_c}{\dot{W}} = \frac{T_c}{T_H - T_c} = \frac{273-5}{32}$$

(a) $\Rightarrow \dot{Q}_{c_{ref}} = \frac{268}{32} \times \overset{595.36}{\cancel{9.9227}} = \underline{\underline{4986.14 \text{ kJ/min}}}$

$\cong \underline{\underline{4982 \text{ kJ/min}}}$ = (Max. rate of heat removal)

(b) $\Rightarrow \dot{Q}_{CHE} = \dot{Q}_{HHE} - \dot{W}$

$= 800 - 595.36$

$= 204.64$ kJ/min

$\dot{Q}_{Href} = \dot{Q}_{Cref} + \dot{W}$

$= 4982 + 595.36$

$= 5577.36$ kJ/min

$\Rightarrow$ Total heat dissipated to ambient air $= 204.64 + 5577.36$

$= \underline{\underline{5782.0 \text{ kJ/min}}}$