classmate

Date
Page

Tutorial - 6, 19114018, Ayushman Tripathy

1 (a) By first law,

$$Q = \Delta U + W$$

if $\eta = 1$ {100% efficiency}

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

$\therefore$ this is possible acc. to first law $\rightarrow$ Doesn't violate 1st Law

(b) The second law of thermodynamics is directly violated if $\eta = 1$

As, conversion of all the heat into energy is not possible. $\rightarrow$ Kelvin - Planck Statement
{It contradicts this}

Violates 2nd Law

2 No, the efficiencies of all work producing devices don't necessarily violate K-P statement.

The K-P statement is applicable to devices that produce work by transfer of heat b/w heat sources {thermal reservoirs}

As, hydroelectric power plant doesn't exchange heat with thermal reservoir & produce work from mechanical energy, they and all similar devices are not limited by Kelvin-Planck statement

Date
Page

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

$\dot{Q}_H = \dot{Q}_L + \dot{W}$ $\Rightarrow$ Satisfies first law

$\eta = \frac{2}{6} = \frac{1}{3} < 1$ $\therefore$ 2nd law satisfied

$\Rightarrow Q_L \neq 0$

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

$\dot{Q}_H = \dot{Q}_L + \dot{W}$ $\Rightarrow$ first law satisfied

$\eta = \frac{W}{Q_H} = \frac{6}{6} = 1$ $\Rightarrow$ 2nd law violated

$\Rightarrow Q_L = 0$

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

$\dot{Q}_H = 6\ kW \neq \dot{Q}_L + \dot{W} = 7kW$ $\Rightarrow$ 1st law violated

$\eta = \frac{W}{Q_H} = \frac{5}{6} < 1$ $\Rightarrow$ 2nd law satisfied

$\Rightarrow Q_L \neq 0$

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

$\dot{Q}_H = \dot{Q}_L + \dot{W}$ $\Rightarrow$ 1st law satisfied

$\eta = \frac{\dot{Q}_L}{\dot{W}} = \frac{0}{6} = 0 < 1$ $\Rightarrow$ 2nd law satisfied

$\Rightarrow Q_L \neq 0$

$\eta < 1 \Rightarrow Q_L \neq 0 \rightsquigarrow$ satisfies 2nd law.

(4) $\dot{W} = 500\ kW$ } Given for refrigerator
$COP = 2.5$

$COP = \frac{\text{Heat extracted}}{\text{work done on sys}} = \frac{Q_L}{W} \Rightarrow 2.5 = \frac{\dot{Q}_L}{500}$

$\Rightarrow \boxed{\dot{Q}_L = 1250\ kW}$

$\dot{Q}_H = \dot{Q}_L + \dot{W} = 1250 + 500 = 1750\ kW$

$\therefore$ 1750 kW power is dissipated to surroundings
$\Rightarrow$ net-effect on kitchen air $= \boxed{1750\ kW}$

---

(5) First law would be satisfied as it would state here, work done is by virtue of cooling of air from 20°C to -20°C {loss of heat by air accounts for work},]

Second law would also be satisfied.
This statement concerns KP statement. as it is of a heat engine. and here heat is being rejected to a low temperature reservoir, thus, 2nd law is satisfied.
ie. heat is being converted to work, with some heat being lost to low temp. reservoir
↳ doesn't violate any 2nd law statements

(6) $\frac{dm}{dt} = 60 \text{ tons}/h = 60 \times 10^3 \text{ kg}/h$

$\frac{dQ}{dt} = \frac{dm}{dt} \times \text{heating value} = 60 \times 10^3 \times 30000 \ \frac{kJ}{h} = 1.8 \times 10^9 \ kJ/h$

$= 1.8 \times 10^9 \ kJ/h$

$\Rightarrow \frac{dQ}{dt} = 1.8 \times 10^9 \ kJ/h = \frac{1.8 \times 10^9}{60 \times 60} \ kJ/s$

$= \frac{1}{20} \times 10^7 \ kW = 5 \times 10^5 \ kW = 500 \ MW$

$\therefore \ \hat{Q} = 500 \ MW$

Given $\dot{w} = 150 \ MW$

$\eta = \frac{\dot{w}}{\dot{Q}} = \frac{150}{500} = 0.3 \Rightarrow \%$ efficiency $= 30\%$

(7) $\dot{Q}_H = 15090 \text{ kJ/h}$

$Q_L = 10000 \text{ kJ/h}$

$\dot{W} = 1.5 \text{ kW} = 1.5 \times 3600 \text{ kJ/h} = 5400 \text{ kJ/h}$

A heat pump gives heat to a high temp. reservoir after work is done on it by extracting heat from low 'T' reservoir & maintains it at high T.

$$\Rightarrow COP_{HP} = \frac{\dot{Q}_H}{\dot{W}} = \frac{15090}{5400} = \boxed{2.7944}$$

(8) $COP = \frac{\dot{Q}_L}{W} = 2.5 \Rightarrow \dot{Q}_L = W \cdot COP = 450 \times 2.5\,W = 1125\,W$

Total heat required to be extracted $= \eta(m s \Delta T)$

$= 5 \times 10 \times 4.2 \times (20-8)\ kJ$

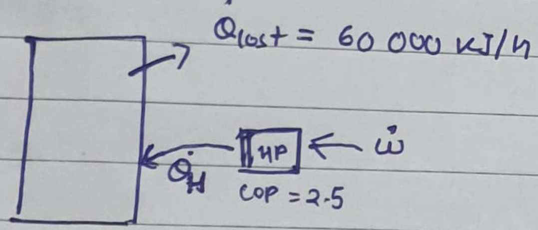
$Q_{total} = 2520\ kJ$

$\Rightarrow \dot{Q}_L \cdot t = Q_{total} \Rightarrow t = \frac{Q_{total}}{\dot{Q}_L} = \frac{2520 \times 10^3}{1125}\ s$

$\boxed{t = 2240s}$

---

(9)



For a heat pump, $COP = \frac{\dot{Q}_H}{\dot{W}} \Rightarrow \dot{Q}_H = \dot{W} \times COP$

$\boxed{\dot{Q}_H = 2.5\,\dot{W}}$

Energy conserv{ 1st law for house} $\Rightarrow \dot{Q}_H + \dot{Q}_{gen} = \dot{Q}_{lost}$

$\Rightarrow 2.5\,\dot{W} + 4000 = 60000$

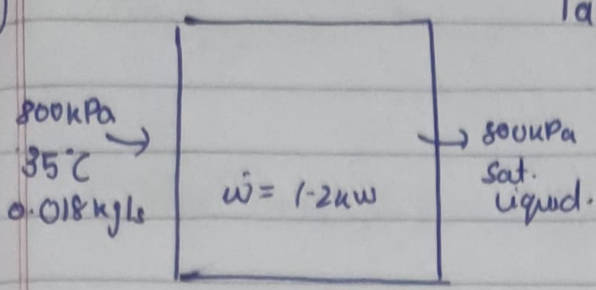
$\Rightarrow \dot{W} = \frac{56000\ kJ/h}{2.5} = 22400\ kJ/h = \frac{22400}{60 \times 60}\ kW$

$\boxed{\dot{W} = 6.222\ kW}$

$\therefore$ required Power input to heat pump $= 6.222\ kW$

(10) Taking R-134-a as refrigerant

(a)



at, T = 34°C & T = 36°C

we have P_{sat} = 863.11 kPa

and P_{sat} = 912.35°C

$\Rightarrow$ P = 800 kPa < P_{sat}

$\left\{ P = \frac{863.11 + 912.35}{2} \right\}$

$\Rightarrow$ Superheated refrigerant initially

~~MPa,~~

At 0.8 MPa for superheated R-134a,

At T = 30°C, $\Rightarrow$ h = 267.34 kJ/kg

At T = 40°C, h = 276.46 kJ/kg

By interpolation, At T = 35°C, $h_1 = \frac{h_{30} + h_{40}}{2}$

$\boxed{h_1 = 271.9 \text{ kJ/kg}}$

Finally saturated liquid at 0.8 MPa

$\Rightarrow$ $h_2 = h_{sat, \text{ at } 0.8 MPa} = h_f = 95.48$ kJ/kg

$\therefore \boxed{h_2 = 95.48 \text{ kJ/kg}}$

$\dot{Q}_H = \dot{m}\,\Delta h = 0.018(271.9 - 95.48) = 3.17556$ kJ/s

$= 3.1755$ kW

$COP_{HP} = \frac{\dot{Q}_H}{\dot{W}} = \frac{3.1755}{1.2} = 2.6463 \Rightarrow \boxed{COP = 2.646}$

(b) Rate of heat absorption = $\dot{Q}_H - \dot{W}$ = $\boxed{1.9755 \text{ kW}}$

(ii) $COP_{refrigerator} = \frac{\dot{Q}_L}{\dot{W}} \Rightarrow \frac{\dot{Q}_L}{450} = 1.2 \Rightarrow \dot{Q}_L = 540\ W$

$\therefore$ ~~heat~~ Power extracted $= 540\ W$

$\Rightarrow \dot{m}(\Delta h) = 540\ W = 540 \times 10^{-3}\ kW$

$h_1 = (h_f + x h_{fg})$ at 120 kPa

$= 22.47 + 0.2 \times 214.52$

$= 65.374\ kJ/kg$

$h_2 =$ At $-20°C$, 120 kPa $\Rightarrow T_{sat} = -22.32$

$\Rightarrow$ Superheated refrigerant

$\Rightarrow$ By interpolation, $\frac{120 - 100}{180 - 100} = \frac{h - h_{100\,kPa}}{h_{180\,kPa} - h_{100\,kPa}}$ at $-20°C$

$\Rightarrow \frac{20}{80} = \frac{h - 239.52}{242.90 - 239.52}$

$\Rightarrow h = 240.365\ kJ/kg$

$\therefore \dot{m}(240.365 - 65.374) = 540 \times 10^{-3}$

$\Rightarrow \boxed{\dot{m} = 3.08587\ kg/s \times 10^{-3}}$

$\boxed{\dot{m} = 0.0030857\ kg/s} \approx \boxed{0.0031\ kg/s}$

(b) $\dot{Q}_H = \dot{Q}_L + \dot{W} = 0.540 + 0.450 = 0.990\ kW$

$\boxed{\dot{Q}_H = 990 W}$

heat rejected to kitchen air

(12) For a completely reversible heat engine,

$$\eta = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H} = 1 - \frac{280}{800} = 0.65$$

$$\eta = \frac{W}{Q_{given}} = \frac{4\,kW}{Q_{given}} = 0.65$$

$$\Rightarrow \quad Q_{given} = 6.1538\ kW$$

$$= 6.1538 \times 3600\ kJ/h$$

$$Q_{given} = 22153.846\ kJ/h$$

(13) $T_H = 160^\circ C = 433 K$

$T_L = 25^\circ C = 25+273 = 298 K$

$\dot{W} = 22 MW$

$\dot{Q}_H = \dot{m}\,\Delta h$

$h_1 = h_f$ at $160^\circ C = 675.47$ kJ/kg

$h_2 = h_f$ at $25^\circ C = 108.77$ kJ/kg {Borgnakke}

$\dot{Q}_H = \dot{m}\,\Delta h = 440 \times (675.47 - 108.77)$

$= 440 \times 566.7$ kW

$= 249348$ kW $= 24.9348$ MW

(a) $\eta = \frac{\dot{W}}{\dot{Q}_H} = \frac{22}{24.9348} = 0.08823 = 8.823\%$

$\boxed{\approx 8.8\%}$

(b) $\eta_{max} = 1 - \frac{T_L}{T_H}$ {$= \eta_{reversible}$}

$= 1 - \frac{298}{433} = 0.311778$

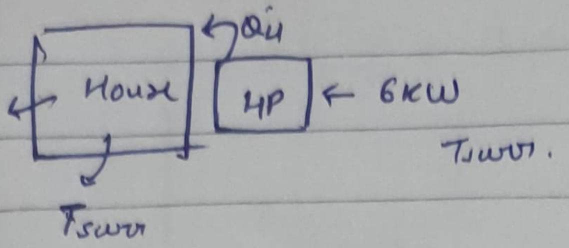
$= 31.1778\% \approx 31.2\%$

(c) $\dot{Q}_L = \dot{Q}_H - \dot{W} = 249348 - 22000$ kW

$= 227348$ kW

$\boxed{\dot{Q}_L = 227.348 \text{ MW}}$

(14)



$$COP_{max} = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_L}$$

$$= \frac{T_H}{T_H - T_L}$$

$$= \frac{21+273}{21+273 - T_L}$$

$$= \frac{294}{294 - T_L}$$

Given, $\frac{d\dot{Q}_H}{dT} = 5400 \text{ kJ/h}^\circ C$

{as equilibrium of house}

$\Rightarrow \dot{Q}_H = 1.5 \text{ kW} \times (294 - T_L)$

$$\Rightarrow COP_{max} = \frac{\dot{Q}_H}{W} = \frac{294}{294 - T_L}$$

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

$\Rightarrow 294 - T_L = \sqrt{294 \times 4} \Rightarrow T_L = 294 - 34.29$

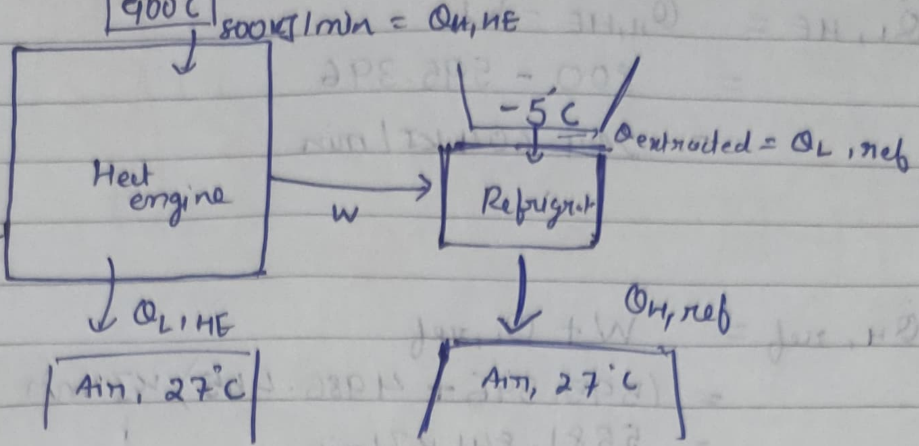
$= 259.707 K$

$\Rightarrow T_L = (259.707 - 273)^\circ C$

$= -13.2928^\circ C$

$\boxed{T_L \approx -13.3^\circ C}$

15



For maximum values, we have to assume reversible

$$\Rightarrow \eta_{HE} = 1 - \frac{T_{L,HE}}{T_{H,HE}} = 1 - \frac{(27+273)}{(900+273)}$$

$$= 1 - 0.25575$$

$$\boxed{\eta_{HE} = 0.744245}$$

COD

$$= \beta_{max} = \frac{\dot{Q}_L}{\dot{W}} = \frac{\dot{Q}_L}{\dot{Q}_H - \dot{Q}_L} = \frac{T_L}{T_H - T_L} = \frac{273-5}{(273+27)-(273-5)}$$

$$= \frac{268}{300-268} = 8.375$$

$$\therefore \boxed{\beta_{ref} = 8.375}$$

$$\eta_{HE} = \frac{\dot{W}}{\dot{Q}_{H,HE}} = \frac{\dot{W}}{800} = 0.744245 \Rightarrow W = 595.396 \text{ kJ/min}$$

$$\beta_{ref} = \frac{\dot{Q}_{L,ref}}{\dot{W}} = \frac{\dot{Q}_{removed}}{595.396} = 8.375 \Rightarrow Q_{removed} = 4986.4415 \text{ kJ/min}$$

$$\boxed{\therefore \dot{Q}_{removed} \approx 4986.4 \text{ kJ/min}}$$

classmate

Date

Page

(b) $\dot{Q}_{L,HE} = Q_{H,HE} - W$

$= 800 - 595.396$

$= 204.604 \text{ kJ/min}$

$\dot{Q}_{H,ref} = W + Q_{L,ref}$

$= (595.396 + 4986.445) \text{ kJ/min}$

$= 5581.841 \text{ kJ/min}$

$\therefore \dot{Q}_{\text{to ambient air}} = Q_{H,ref} + Q_{L,HE}$

$= 5786.445 \text{ kJ/min}$

$\therefore$ Total rate of heat rejection to air

$\boxed{Q_{rej} = 5786.44 \text{ kJ/min}}$