MIN 106 - Tutorial 9

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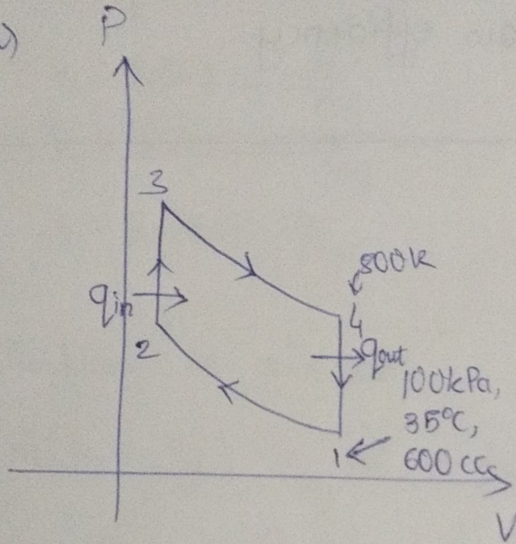
Q.1. (a)



$r = 9.5$;

$C_p = 1.005\ kJ/kgK$

$C_v = 0.718\ kJ/kgK$

$\gamma = 1.4$

Now, $\left(\frac{T_2}{T_1}\right) = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$

$\Rightarrow T_2 = (308.15)(9.5)^{0.4}$

$= \underline{\underline{758.318K}}$

And, $\left(\frac{T_3}{T_4}\right) = \left(\frac{V_4}{V_3}\right)^{\gamma-1}$

$\Rightarrow T_3 = (800)(9.5)^{0.4}$

$\Rightarrow \boxed{T_3 = 1968.699K}$ ← Maximum temperature.

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \Rightarrow \frac{(100)(0.06)}{308.15} = \frac{(P_2)(0.06/9.5)}{758.318}$

$\Rightarrow P_2 = \frac{100 \times 758.318 \times 9.5}{308.15}$

$\Rightarrow P_2 = \underline{\underline{2337.83 kPa}}$

$\frac{P_2}{T_2} = \frac{P_3}{T_3}$

$\Rightarrow P_3 = (2337.53)\left(\frac{1968.699}{768.318}\right)$

$= 6069.332 \text{ kPa}$ ← Maximum pressure

(b) $m = \frac{P_1 V_1}{R T_1}$

$= \frac{100 \times 600 \times 10^{-6}}{0.287 \times 308.16}$

$= 678.43 \times 10^{-6}$ kg

$q_{in} = m C_v (T_3 - T_2)$

$= 678.43 \times 10^{-6} \times 0.718 \times (1968.7 - 768.3)$

$= 0.5896$ kJ

(c) $\eta = 1 - \frac{1}{r^{\gamma - 1}} = 1 - \frac{1}{(9.6)^{0.4}} = 0.5936$

$\Rightarrow \boxed{\eta = 59.36\%}$

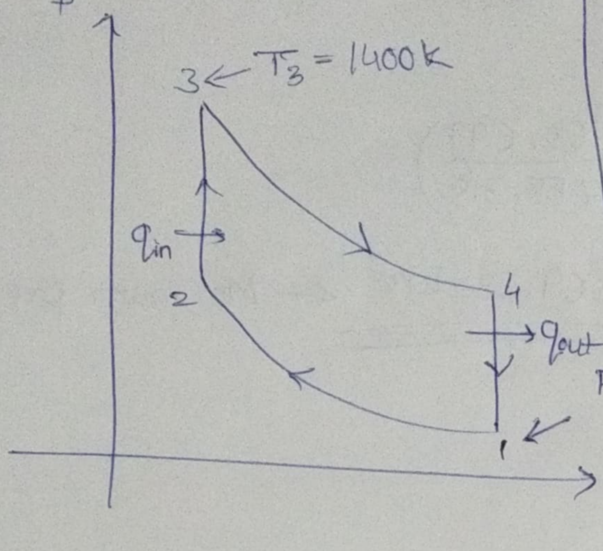
(d) $MEP = \frac{W_{net}}{V_1 - V_2} = \frac{\eta \, q_{in}}{V_1\left(1 - \frac{1}{r}\right)} =$

$= \frac{0.5936 \times 0.5896}{600 \times 10^{-6}\left(1 - \frac{1}{9.6}\right)}$

$= \frac{59.36 \times 58.96 \times 9.6}{6 \times 8.6}$

$= 652$ kPa

Q.2.



$C_p = 1.005$ kJ/kgk

$C_v = 0.718$ kJ/kgk

$R = 0.287$ kJ/kgk

$\gamma = 1.4$

$P_1 = 90$kPa, $T_1 = 300$k, $V_1 = 0.004m^3$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\Rightarrow T_2 = (300)(7)^{0.4} = \underline{\underline{653.37\,k}}$$

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} \Rightarrow T_4 = (1400)(7)^{-0.4}$$

$$= \underline{\underline{642.819\,k}}$$

$$m = \frac{P_1V_1}{RT_1} \Rightarrow m = \frac{(9\cancel{0})^{3}(4\times10^{-3})}{0.287\times \cancel{300}_{10}}$$

$$= \frac{12\times10^{-4}}{0.287} = \underline{\underline{4.18\times10^{-3}\,kg}}$$

$$q_{in} = mC_v(T_3 - T_2)$$

$$= 4.18\times10^{-3}\times0.718(1400 - 653.37) = \underline{\underline{2.24\,kJ}}$$

~~= 2.2367 = 2.2367 kJ~~

$$\eta = 1 - \frac{q_{out}}{q_{in}}, \quad q_{out} = mC_v(T_4 - T_1)$$

$$\Rightarrow q_{out} = 4.18\times10^{-3}\times0.718(642.819 - 300)$$

$$\boxed{q_{out} = \underline{\underline{1.028\,kJ}}}$$

$W = q_{in} - q_{out}$

$= 2.24 - 1.03$

$\boxed{W = 1.21\ kJ}$

$\eta = \dfrac{W}{q_{in}}$

$\Rightarrow \eta = \dfrac{1.21}{2.24} = 0.541$

$\Rightarrow \boxed{\eta = 54.1\%}$

$MEP = \dfrac{W}{V_1 - V_2}$

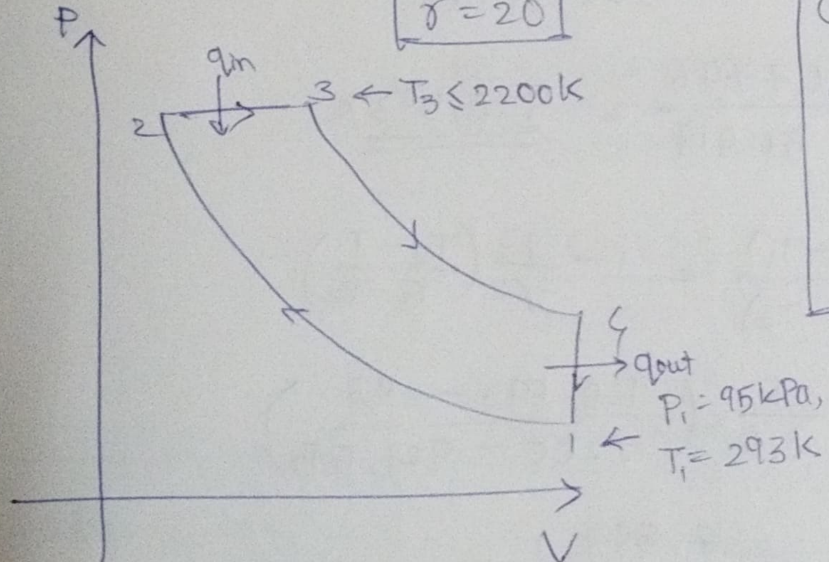
$= \dfrac{1.21}{0.004(1 - \frac{1}{7})}$

$= \dfrac{1.21 \times 7}{0.004 \times 6}$

$= 353.9\ kPa$

Q-3.

$\boxed{r = 20}$



$C_p = 1.005\ kJ/kgK$

$C_v = 0.718\ kJ/kgK$

$R = 0.287\ kJ/kgK$

$\gamma = 1.4$

$\left(\dfrac{T_2}{T_1}\right) = \left(\dfrac{V_1}{V_2}\right)^{\gamma-1} \Rightarrow T_2 = (293)(20)^{0.4}$

$= 971.135K$

$\left(\dfrac{T_4}{T_3}\right) = \left(\dfrac{V_3}{V_4}\right)^{\gamma-1} \Rightarrow T_4 = 2200\left(\dfrac{1}{20}\right)^{0.4}$

$= 663.759K$

$\eta = 1 - \dfrac{q_{out}}{q_{in}} = 1 - \dfrac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)} = 1 - \dfrac{1}{\gamma}\left(\dfrac{T_4 - T_1}{T_3 - T_2}\right)$

$= 1 - \dfrac{1}{1.4}\left(\dfrac{663.759 - 293}{2200 - 971.135}\right)$

$=$

Now, $V_4 = V_1$ & $V_3 = T_3\left(\frac{V_2}{T_2}\right)$

$$\Rightarrow \frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$$

$$\Rightarrow T_4 = \cancel{(2200)} \; T_3\left(\frac{T_3 V_2}{T_2 V_4}\right)^{\gamma-1}$$

$$\Rightarrow T_4 = T_3^{\gamma}\left(\frac{1}{\gamma T_2}\right)^{\gamma-1}$$

$$= (2200)^{1.4}\left(\frac{1}{20\times 971.135}\right)^{0.4}$$

$$\Rightarrow T_4 = \frac{47796}{51.919} = \underline{\underline{920.593\,K}}$$

$$\eta = 1 - \frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)} = 1 - \frac{1}{\gamma}\left(\frac{T_4 - T_1}{T_3 - T_2}\right)$$

$$\Rightarrow \eta = 1 - \frac{1}{1.4}\times\left(\frac{920.593 - 293}{2200 - 971.135}\right)$$

$$= 1 - \frac{657.593}{1.4 \times 1228.865}$$

$$= 0.635$$

$$\Rightarrow \boxed{\eta = 63.5\%}$$

~~(b) MEP = $\frac{W}{V_1 - V_2}$ = $\frac{\eta q_{in}}{V_1(1 - \frac{1}{\gamma})}$ = ... $m = \frac{P_1 V_1}{RT_1}$ = 95×~~

~~$q_{in} = mC_p \Delta T$~~

(b) $m = \dfrac{P_1 V_1}{R T_1}$

$$MEP = \frac{W}{V_1 - V_2}$$

$$= \frac{\eta q_{in}}{V_1 - V_2} = \frac{\eta (m C_p (T_3 - T_2))}{V_1 - V_2}$$

$$= \eta C_p \left(\frac{P_1 V_1}{R T_1}\right) \left(\frac{T_3 - T_2}{V_1 - V_2}\right)$$

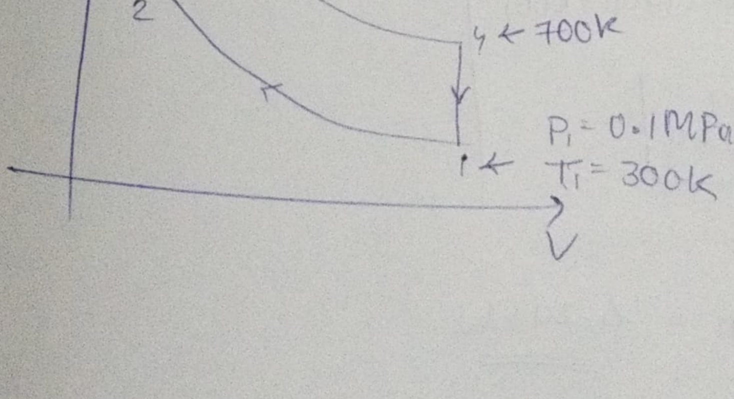
$$= \frac{\eta C_p}{R} \times \frac{P_1}{T_1} \left(\frac{T_3 - T_2}{1 - \frac{1}{\gamma}}\right)$$

$$= \frac{0.635 \times 1.005 \times 95}{0.287 \times 293} \left(\frac{2200 - 971.135}{1 - \frac{1}{20}}\right)$$

$$= \frac{60.626625}{84.091} \times \frac{1228.865 \times 20}{19}$$

$$= \underline{\underline{932.598 \text{ kPa}}}$$

Q.4. Otto cycle-



$C_p = 1.005$ kJ/kgk, $C_v = 0.718$ kJ/kgk

$R = 0.287$ kJ/kgk, $\gamma = 1.4$

Compression ratio $= r = \dfrac{V_4}{V_3}$

$$\Rightarrow r = \left(\frac{T_3}{T_4}\right)^{\frac{1}{\gamma - 1}}$$

$$\Rightarrow r = \left(\frac{1400}{700}\right)^{\frac{1}{0.4}}$$

$$\Rightarrow r = 2^{0.4}$$

$$\Rightarrow \boxed{r = 5.6568}$$

$\cancel{P_3 V_2}$ $V_2 = V_3 = \gamma V_4 = \gamma V_1$

Now $\cancel{\frac{P_3 V_2}{T_2}}$ $\frac{P_3 V_3}{T_3} = \frac{P_4 V_4}{T_4}$

$\Rightarrow P_3 = P_{max} = \frac{T_3}{T_4} \times P_4 \times \left(\frac{V_4}{V_3}\right)$

$\frac{P_1}{T_1} = \frac{P_4}{T_4}$

$\Rightarrow P_4 = \frac{P_1 T_4}{T_1}$

$\Rightarrow P_3 = \frac{1400}{700} \times 0.1 \times \frac{700}{300} \times 5.6568$

$= \frac{1.4 \times 5.6568}{3} = \underline{\underline{2.63984 \text{ MPa}}}$

↑ Max pressure

$\eta = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{1}{\gamma^{\gamma-1}}$

$\cancel{\Rightarrow \eta = 1 - \frac{1}{(5.5668}}$ $\Rightarrow \eta = 1 - \frac{1}{(5.6568)^{0.4}}$

$\Rightarrow \eta = 0.5$

$\Rightarrow \boxed{\eta = 50\%}$

$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$

$\Rightarrow T_2 = (300)(5.6568)^{0.4}$

$= 600\text{K}$

$m = \frac{P_1 V_1}{RT_1}$ & $W = \eta q_{in}$

$\Rightarrow W = \eta C_v (T_3 - T_2)$

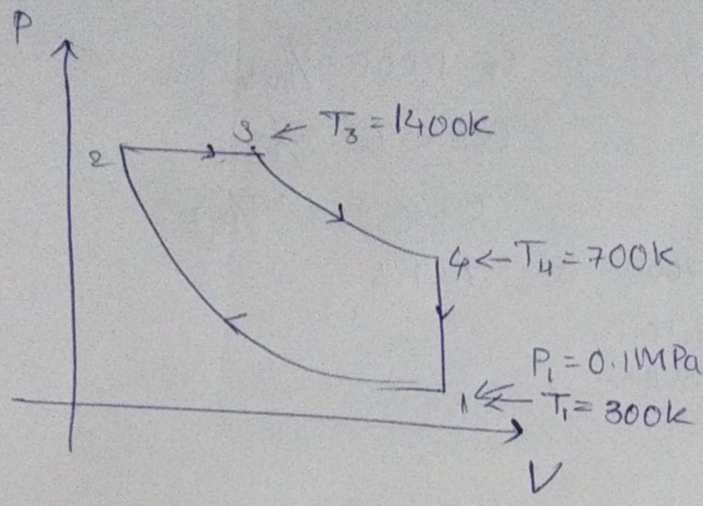
$\Rightarrow W = \frac{1}{2} \times 0.718 \times (1400 - 600)$

$\Rightarrow \boxed{W = 287.2 \text{ kJ/kg}}$

$\Rightarrow \dot{W} = \dot{m} w$

$= \underline{\underline{287.2 \text{ kJ/min}}} = \underline{\underline{4.79 \text{ kW}}}$

Diesel cycle-



$C_p = 1.005$ kJ/kgK

$C_v = 0.718$ kJ/kgK

$R = 0.287$ kJ/kgK

$\gamma = 1.4$

$$\frac{V_2}{T_2} = \frac{V_3}{T_3} \quad ; \quad V_4 = V_1$$

Now, $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$

$$= \left(\frac{T_3}{T_2} \times \frac{V_4}{V_3}\right)^{\gamma-1}$$

$$\Rightarrow T_2^{\gamma} = T_1\left(\frac{T_3 V_4}{V_3}\right)^{\gamma-1}$$

$$= T_1\left(T_3 . \left(\frac{T_3}{T_4}\right)^{\frac{1}{\gamma-1}}\right)^{\gamma-1}$$

$$\Rightarrow T_2^{\gamma} = T_1 T_3^{\gamma-1} . \frac{T_3}{T_4}$$

$$\Rightarrow T_2 = T_3\left(\frac{T_1}{T_4}\right)^{\frac{1}{\gamma}}$$

$$\Rightarrow T_2 = (1400)\left[\frac{300}{700}\right]^{\frac{1}{1.4}} = \underline{\underline{764.34 \text{ K}}}$$

$$r = \frac{V_1}{V_2} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{\gamma-1}}$$

$$= \left(\frac{764.34}{300}\right)^{\frac{1}{0.4}}$$

$\Rightarrow \boxed{r = 10.36}$ ← Compression ratio.

$P_{max} = P_2 = P_3$

$$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$$

$$\Rightarrow P_2 = (0.1)\left(\frac{764.34}{300}\right)^{\frac{1.4}{0.4}}$$

$$\Rightarrow \boxed{P_2 = 2.6398\ MPa} \leftarrow \text{Maximum pressure}$$

$$\eta = 1 - \frac{q_{out}}{q_{in}} \Rightarrow \eta = 1 - \frac{1}{\gamma}\left(\frac{T_4 - T_1}{T_3 - T_2}\right)$$

$$\Rightarrow \eta = 1 - \frac{1}{1.4}\left[\frac{700-300}{1400-764.34}\right]$$

$$\Rightarrow \eta = 1 - \frac{1}{1.4} \times \frac{400}{635.66}$$

~~$\Rightarrow \eta = 0.6262 \Rightarrow \boxed{\eta = 62.62\%}$~~

~~$w = \eta q_{in} = \eta C_p(T_3 - T_2)$~~

~~$\Rightarrow w = 0.6262 \times 1.005(1400 - 764.34)$~~

~~$\boxed{w = 400\ kJ/kg}$~~

~~$\dot{W} = \dot{m}w = 1 \times 400 = 400\ kJ/min = \underline{6.67\ kW}$~~

$$\Rightarrow \eta = 0.5505 \Rightarrow \boxed{\eta = 55.05\%}$$

$$w = \eta q_{in} = \eta C_p(T_3 - T_2)$$

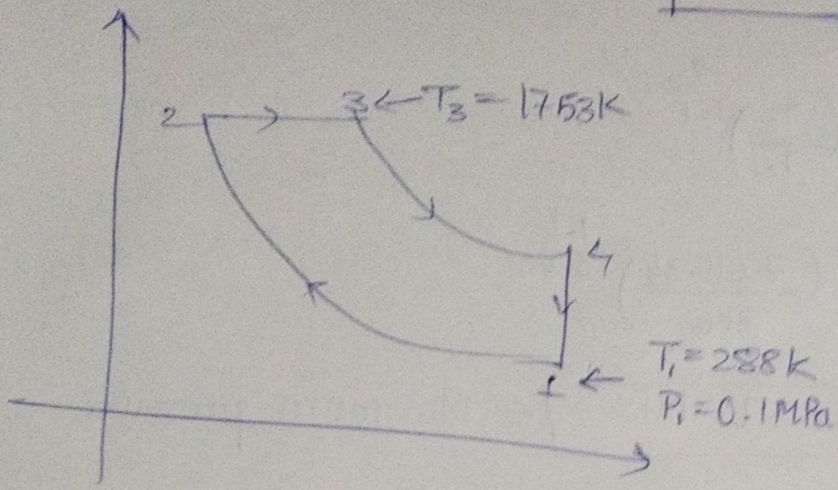
$$\Rightarrow w = 0.5505 \times 1.005(1400 - 764.34)$$

$$\boxed{w = 351.68\ kJ/kg}$$

$$\Rightarrow \dot{W} = 351.68\ kJ/min = \underline{\underline{5.861\ kW}}$$

Q.5.

$\boxed{r = 16}$



(a) $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$

$= r^{\gamma-1}$

$\Rightarrow T_2 = (288)(16)^{0.4} = \underline{\underline{873.053K}}$

$r_c = \frac{V_3}{V_2} = \frac{T_3}{T_2} = \frac{1753}{873.053} = \underline{\underline{2.0079}}$

↑ Cut off ratio

(b) $\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{V_3}{V_1}\right)^{\gamma-1}$ $\qquad \frac{V_2}{T_2} = \frac{V_3}{T_3}$

$\Rightarrow \frac{T_4}{T_3} = \left(\frac{1}{V_1} \times \frac{V_2 T_3}{T_2}\right)^{\gamma-1}$

$\Rightarrow T_4 = T_3\left(\frac{1}{T_2} \times \frac{1}{r}\right)^{\gamma-1}$

$= (1753)\left(\frac{1753}{873.053} \times \frac{1}{16}\right)^{0.4}$

$\Rightarrow T_4 = 764.24K$

$\Rightarrow q_{out} = C_v(T_4 - T_1) = (0.718)(764.24 - 288)$

$\boxed{q_{out} = 341.94 \text{ kJ/kg}}$

(c) $\eta = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{1}{\gamma}\left[\frac{T_4 - T_1}{T_3 - T_2}\right]$

$= 1 - \frac{1}{1.4}\left[\frac{764.24 - 288}{1753 - 873.053}\right]$

$= 0.6134$

$\Rightarrow \boxed{\eta = 61.34\%}$

(d) $MEP = \frac{W}{V_1 - V_2}$

$\Rightarrow MEP = \frac{\eta q_{in}}{V_1\left(1 - \frac{1}{\gamma}\right)}$

$= \frac{\eta m C_p (T_3 - T_2)}{V_1\left(1 - \frac{1}{\gamma}\right)}$ But $\frac{P_1 V_1}{R T_1} = m$

$\Rightarrow MEP = \eta C_p \times \frac{P_1}{R T_1} \frac{(T_3 - T_2)}{\left(1 - \frac{1}{\gamma}\right)}$

$\Rightarrow MEP = \frac{0.6134 \times 1.005 \times 0.1}{0.287 \times 288} \frac{(1753 - 873.053)}{\left(1 - \frac{1}{16}\right)}$

$= 0.69859$

$\Rightarrow \cancel{\boxed{MEP = 69.89\,kPa}} \Rightarrow \boxed{MEP = 698.59\,kPa}$