Problems :

Qn> A Carnot cycle works between the two temperatures 327°C and 27°C. Find out the thermal efficiency of the cycle. Also find the heat supplied during the heat addition process, if the net work done is 120 kJ.

Solution :

Given, $T_H = 327°C = 327 + 273$

$= \underline{600\,K}$

$T_L = 27°C = 27 + 273$

$= 300\,K.$

$W = 120\,kJ$

$$\eta_{Carnot} = 1 - \frac{T_L}{T_H}$$

$$= 1 - \frac{300}{600} = 1 - 0.5$$

$$= 0.5$$

$$= \underline{50\,\%}$$

$$\eta = \frac{W}{Q_{in}}$$

$$0.5 = \frac{120}{Q_{in}}$$

$$Q_{in} = \frac{120}{0.5} = \underline{\underline{240\ kJ}}$$

Qn) An engine working in Otto cycle has a compression ratio 6. Find the air standard efficiency of the engine. Take $\gamma = 1.4$. What is the percentage change in efficiency if the compression ratio is reduced to 5.

Solution :

Given : Compression ratio, $r = 6$

$\gamma = 1.4$

$$\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}}$$

$$= 1 - \frac{1}{6^{1.4-1}}$$

$$= 0.51164$$

$$= \underline{51.16\ \%}$$

Efficiency when $r = 5$

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$$\eta_{otto} = 1 - \frac{1}{5^{(1.4-1)}}$$

$$= 0.47469$$

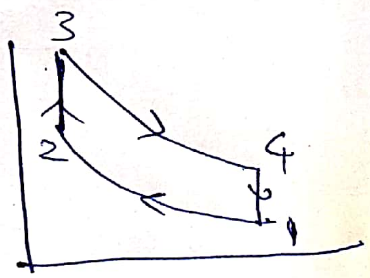
$$= \underline{47.47\%}$$

Percentage change in efficiecy

$$= \frac{51.16 - 47.47}{51.16} = 0.0721$$

$$= \underline{7.21\%}$$

Qn) The pressure ratio between the end & beginning of compression in an engine working on Otto Cycle is 14. Calculate the air standard efficiency of the engine. Take $\gamma = 1.4$.



__Solution:__

Given, $\frac{P_2}{P_1} = 14$

$\gamma = 1.4$

1-2 is an adiabatic process.

$$\therefore \quad P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$$\frac{V_1^{\gamma}}{V_2^{\gamma}} = \frac{P_2}{P_1}$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$\frac{V_1}{V_2} = \left(\frac{P_2}{P_1}\right)^{1/\gamma} = (14)^{1/1.4}$$

$$= \underline{\underline{6.5866}}$$

Compression ratio, $r = \frac{V_1}{V_2} = \underline{\underline{6.5866}}$

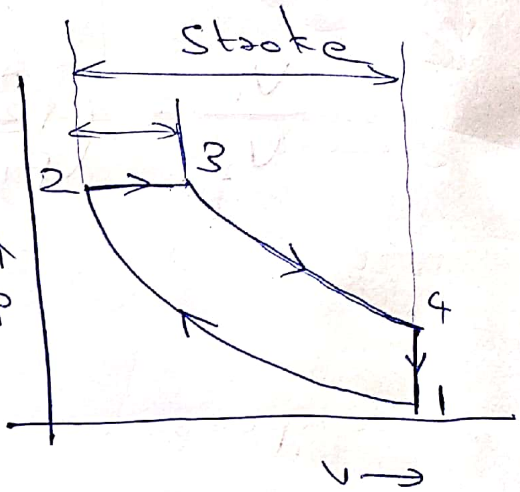
$$\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}}$$

$$= 1 - \frac{1}{6.5866^{(1.4-1)}}$$

$$= 0.5295$$

$$= \underline{\underline{52.95\,\%}}$$

Qn) The compression ratio of an engine working on Diesel cycle is 16. Cut off takes place at 6% of the stroke. Find the air standard efficiency of the cycle. Take $\gamma = 1.4$.



Given:

* Compression ratio, r

$$= \frac{V_1}{V_2} = 16$$

* $V_3 - V_2 = 6\% \,(V_1 - V_2)$

$$= \frac{6}{100}(V_1 - V_2)$$

$$= 0.06\,(V_1 - V_2)$$

Stroke = Swept Volume

$$= V_1 - V_2$$

we need to find $r_c = \frac{V_3}{V_2}$

$$V_3 - V_2 = 0.06\,(V_1 - V_2)$$

$$\frac{V_3 - V_2}{V_2} = 0.06\,\frac{(V_1 - V_2)}{V_2}$$

$$\frac{V_3}{V_2} - 1 = 0.06\left[\frac{V_1}{V_2} - 1\right]$$

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$$\frac{V_3}{V_2} = 1 + \left\{0.06\left[\frac{V_1}{V_2} - 1\right]\right\}$$

$$= 1 + \left\{0.06\left[16-1\right]\right\}$$

$$= \underline{\underline{1.9}}$$

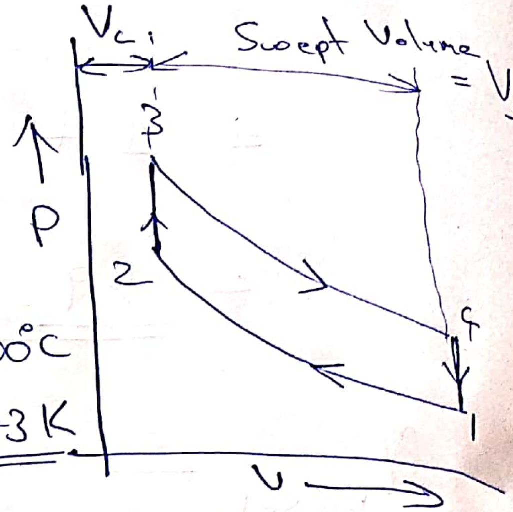
$$\eta_{Diesel} = 1 - \frac{1}{r^{\gamma-1}} \frac{r_c^{\gamma}-1}{\gamma(r_c-1)}$$

$$= 1 - \left[\frac{1}{16^{(1.4-1)}} \frac{(1.9^{1.4}-1)}{1.4\,(1.9-1)}\right]$$

$$= 0.6188$$

$$= \underline{\underline{61.88\%}}$$

Qn → An engine working on Otto cycle takes in air at a pressure & temperature of 100 kPa & 300 K. Find out the air standard efficiency of the engine if the clearance volume of the engine is 16% of the cylinder volume. Also, find the maximum pressure of the cycle, if the maximum temperature is limited to 600°C



Solution:

Given: $P_1 = 100\ kPa$, $T_3 = 600°C = \underline{873\ K}$

$T_1 = 300\ K$

$$V_c = V_2 = V_3 = 16\%(V_{cylinder})$$

$$= \frac{16}{100}(V_1)$$

V_c = Clearance Volume

V_s = Swept Volume

$V_c + V_s$ = Total cylinder volume $= V_1$

$$V_2 = \frac{16}{100} V_1$$

$$r = \frac{V_1}{V_2} = \frac{100}{16} = \underline{\underline{6.25}}$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

$$= 1 - \frac{1}{6.25^{(1.4-1)}}$$

$$= 0.51955$$

$$= \underline{\underline{51.96\%}}$$

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In the adiabatic process 1-2

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$P_2 = P_1 \times \left(\frac{V_1}{V_2}\right)^{\gamma} = 100 \times (6.25)^{1.4}$$

$$= \underline{\underline{1300.86 \text{ kPa}}}$$

Also

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

$$T_2 = T_1 \times \left(\frac{V_1}{V_2}\right)^{\gamma-1} = 300 \times (6.25)^{(1.4-1)}$$

$$= \underline{\underline{624.4 \text{ K}}}$$

Process 2-3 is constant volume

$\therefore$ $p \propto T$

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

$$P_3 = P_2 \times \frac{T_3}{T_2} = 1300.86 \times \frac{873}{624.4}$$

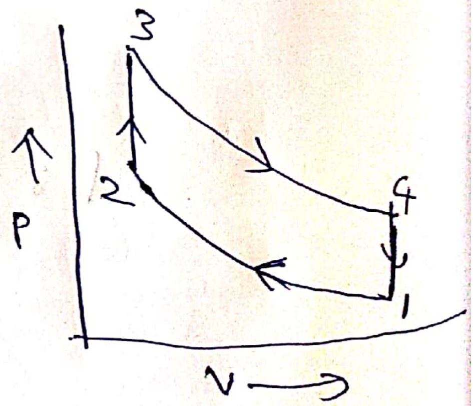
$$= \underline{\underline{1818.79 \text{ kPa}}}$$

Q) An engine having a swept volume of $0.065\ m^3$ operates on Otto Cycle. The conditions of air at beginning of compression are 100 kPa and ~~87~~ 57°C. The compression ratio of engine is 6. & the heat supplied /cycle is 75 kJ. Find out the values of pressure, Volume & temperature at salient points. Also calculate the work done, thermal efficiency & mean effective pressure of the cycle. Take $C_v = 0.718\ kJ/kgK$

Solution

Given → Swept Volume, $V_s = 0.065\ m^3$

Otto Cycle



$P_1 = 100\ kPa$

$T_1 = 57°C =$

$57 + 273 = \underline{330\ K}$

$r = 6 \left\{ \frac{V_1}{V_2} \right\}$

$Q_{in} = 75$ kJ

Swept volume, $V_s = V_1 - V_2$

$V_1 - V_2 = 0.065$ — (1)

$\frac{V_1}{V_2} = 6$

$V_1 = 6V_2$ — (2)

Sub in (1)

$6V_2 - V_2 = 0.065$

$\cancel{V_2(6-1) = 0}$ $5V_2 = 0.065$

$\underline{\underline{V_2 = 0.013 \text{ m}^3}}$

From (1) $\underline{\underline{= V_3}}$

$V_1 = 0.065 + V_2$

$= 0.065 + 0.013$

$= \underline{\underline{0.078 \text{ m}^3}}$ $\underline{\underline{= V_4}}$

From process 1-2 (adiabatic)

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$P_2 = P_1 \times \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$= 100 \times 6^{1.4}$$

$$= \underline{\underline{1228.6 \text{ kPa}}}$$

Also

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

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

$$= 330 \times 6^{(1.4-1)}$$

$$= \underline{\underline{675.73}}$$

From ideal gas relation,

$$pV = mRT$$

$$m = \frac{pV}{RT}$$

$$m = \frac{p_1 V_1}{RT_1} = \frac{(100 \times 10^3)_{Pa} \times (0.078)_{m^3}}{(287)_{J/kg\,K} \times (330)_{K}}$$

$$= 0.082357 \text{ kg}$$

In process 2-3

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

$$75000 = 0.082357 \times 718 (T_3 - 675.73)$$

$$T_3 = 675.73 + \left(\frac{75000}{718 \times 0.082357}\right)$$

$$T_3 = 1944.08 \text{ K}$$

Process 2-3 is Constant Volume

$$\therefore p \propto T$$

$$\frac{p_3}{p_2} = \frac{T_3}{T_2}$$

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

$$= \frac{1228.6 \times 1944.08}{675.75}$$

$$= \underline{\underline{3534.64 \text{ kPa}}}$$

For process 3-4 (adiabatic)

$$\frac{P_4}{P_3} = \left(\frac{V_3}{V_4}\right)^{\gamma} = \left(\frac{V_2}{V_1}\right)^{\gamma} = \left(\frac{1}{6}\right)^{\gamma}$$

$$= 0.08139$$

$$P_4 = P_3 \times 0.08139 = \underline{\underline{287.68 \text{ kPa}}}$$

Similarly

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

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

$$= 1944.08 \times \left(\frac{1}{6}\right)^{(1.4-1)}$$

$$= \underline{\underline{949.41 \text{ K}}}$$

Heat Rejected

$$Q_R = m C_v (T_1 - T_4)$$

$$= m C_v (T_4 - T_1)$$

$$= 0.082357 \times 0.718 \times (949.41 - 330)$$

$$= \underline{\underline{36.627 \text{ kJ}}}$$

Work Done/cycle

$$W = Q_{in} - Q_R$$

$$= 75 - 36.627$$

$$= \underline{\underline{38.373 \text{ kJ}}}$$

Thermal efficiency, $\eta = \frac{W}{Q_{in}}$

$$= \frac{38.373}{75} = 0.5116$$

$$= \underline{\underline{51.16\%}}$$

Mean effective pressure

$$P_m = \frac{W}{V_s} = \frac{38.373}{0.065}$$

$$= \underline{\underline{590.35 \text{ kPa}}}$$

Qn) The bore & stroke of an engine working on Diesel cycle is 200 mm and 300 mm respectively. The clearance volume of the engine is 0.8 litres & cut off takes place at 50% of the stroke. Assuming $\gamma = 1.4$, find the air standard efficiency of the cycle.

Solution:

Given: Bore = Cyl dia = 200 mm

= 0.2 m

Stroke = Cyl length = 300 mm

= 0.3 m

Clearance Volume, $V_c = 0.8$ litres

$V_c = V_2$ ie $V_2 = \frac{0.8}{1000} m^3$

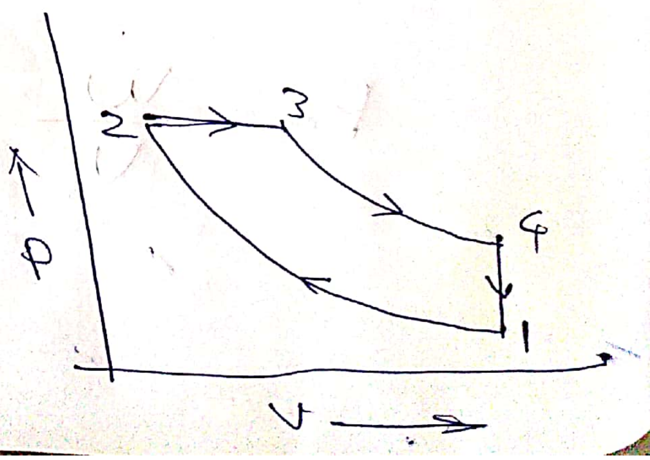
~~1 litre = 1000~~

1000 litre = $1 m^3$

Cut off ⇒ 5 % (Stroke)

$V_3 - V_2 = 5\% (V_1 - V_2)$

$V_3 - V_2 = \frac{5}{100}(V_1 - V_2)$



Swept Volume =

$$(V_1 - V_2) = \text{Piston area} \times \text{Stroke length}$$

$$= \pi r^2 \times L_s$$

$$= \pi (0.1)^2 \times 0.3$$

$$= \underline{\underline{0.009425 \ m^3}} \quad \text{—— (1)}$$

$$V_1 - \frac{0.8}{1000} = 0.009425$$

$$V_1 = 0.009425 + \frac{0.8}{1000}$$

$$= \underline{\underline{0.010225}} \ m^3$$

$$r = \frac{V_1}{V_2} = \frac{0.010225}{(0.8/1000)}$$

$$= \underline{\underline{12.78}}$$

$$V_3 - V_2 = \frac{5}{100}(V_1 - V_2)$$

$$V_3 = V_2 + 0.05(V_1 - V_2)$$

From (1)

$$V_3 = \frac{0.8}{1000} + 0.05(0.009425)$$

$$= \underline{\underline{0.00127125}}$$

$$r_c = \frac{V_3}{V_2} = \frac{0.00127125}{\left(0.8/1000\right)}$$

$$= \underline{\underline{1.589}}$$

$$\eta = 1 - \left[\frac{1}{r^{\gamma-1}}\left(\frac{r_c^{\gamma}-1}{\gamma(r_c-1)}\right)\right]$$

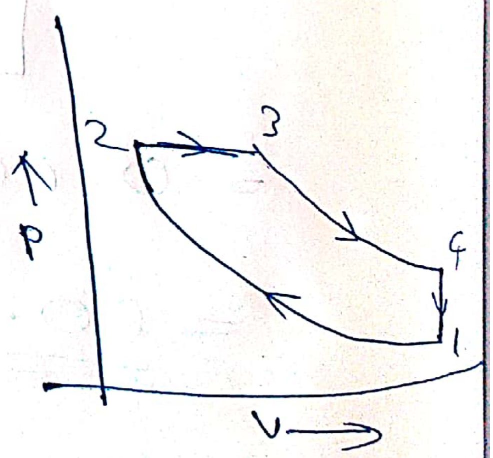
$$= 1 - \left[\frac{1}{12.78^{(1.4-1)}} \frac{(1.589^{1.4}-1)}{1.4(1.589-1)}\right]$$

$$= 0.6007$$

$$= \underline{\underline{60.07\ \%}}$$

Qn) The pressure & temperature of air at the beginning of compression stroke in a Diesel engine is 100 kPa & 17° C respectively. The compression ratio of the engine is 15. If the maximum temperature in the cycle is limited to 2300°C, find the required cut off ratio and the achievable air standard efficiency. Take $\gamma = 1.4$.

Solution



Given ⟹ $P_1 = 100$ kPa

$T_1 = 17°C$

$= 17 + 273$

$= \underline{\underline{290\ K}}$

Max temp occurs at 3

$\therefore T_3 = 2300°C$

$= 2300 + 273$

$= \underline{\underline{2573\ K}}$

$r = 15 = \frac{V_1}{V_2}$

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In the adiabatic process 1-2

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

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

$$= 290 \times (15)^{(1.4-1)}$$

$$= \underline{\underline{856.71\ K}}$$

In the process 3-2 (Constant Pressure)

$$V \propto T$$

$$\frac{V_3}{V_2} = \frac{T_3}{T_2}$$

$$\frac{v_3}{v_2} = r_c = \frac{2573}{856.71}$$

$$= \underline{\underline{3}}$$

$$\eta = 1 - \left[\frac{1}{r^{\gamma-1}}\left(\frac{r_c^{\gamma}-1}{\gamma(r_c-1)}\right)\right]$$

$$= 1 - \left[\frac{1}{15^{(1.4-1)}}\left(\frac{3^{1.4}-1}{1.4(3-1)}\right)\right]$$

$$= 0.5581$$

$$= \underline{\underline{55.81\,\%}}$$