273
35
308

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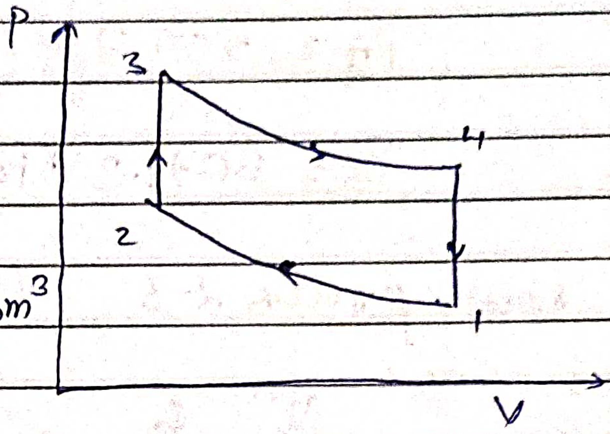
TUTORIAL-7

Otto cycle

1. $r_k = 9.5 = \frac{v_1}{v_2}$



@ State 1: $P_1 = 100 KPa$
$T_1 = 35°C$
$v_1 = 600 cm^3 = 0.0006 m^3$

$v_2 = \frac{v_1}{9.5}$

$T_4 = 800K$

$v_2 = 0.63 \times 10^{-4} m^3$

$m = \frac{P_1 V_1}{RT} = \frac{100 \times 6 \times 10^{-4}}{0.287 \times 308}$

$v_4 = v_1 \qquad v_2 = v_3$

$\boxed{m = 0.678 \times 10^{-3} kg}$

The highest temp & Pressure after heat addition i.e at state 3.

Process 3-4 isentropic

$TV^{\gamma-1} = K$
$T_3 V_3^{\gamma-1} = T_4 V_4^{\gamma-1}$
$T_3 = T_4 (r_k)^{\gamma-1}$

$T_3 = 800 (9.5)^{2/5} = 1968.6 K$
$\approx 1969 K$

Process 4-1 isochoric

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

$P_4 = 100 \frac{800}{308}$

$P_4 = 259.7 KPa$

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$$P_3V_3^{\gamma} = P_4V_1^{\gamma}$$

$$P_3 = 259.7 \times (9.5)^{7/5}$$

$$P_3 = 6071.3 \text{ KPa}$$

Now process 2-3 Isochoric $W = 0$

$$\Delta U = Q_{in}$$

$$mC_v(\Delta T) = Q_{in}$$

$$0.678 \times 10^{-3}(0.718)(T_3 - T_2) = Q_{in}$$

Now process 1-2 isentropic

$$T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$$

$$T_2 = 308 \times (9.5)^{2/5}$$

$$T_2 = 758 \text{ K}$$

$$Q_{in} = 0.678 \times 10^{-3}(0.718)(1964 - 758)$$

$$Q_{in} = 0.589 \text{ KJ}$$

$$\eta_{Thermal} = 1 - \frac{q_{out}}{q_{in}}$$

$$Q_{out} = mC_v(T_1 - T_4)$$

$$= 0.678 \times 10^{-3} \times 0.718 \times (308 - 800)$$

$$Q_{out} = -0.239 \text{ KJ}$$

$$\eta_{Therma} = 1 - \frac{0.239}{0.589}$$

$$= 0.594 \approx 59.4\%$$

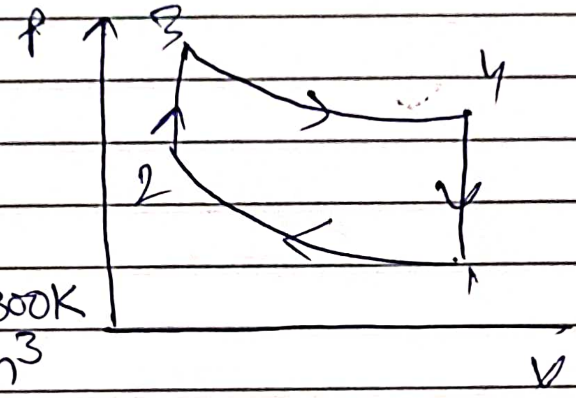
Mean effective pressure $= \dfrac{W_{net}}{v_1 - v_2}$

$$= \frac{|q_{in}| - |q_{out}|}{v_1 - v_2}$$

$$= \frac{0.589 - 0.239}{0.0006 - 0.000063} = \frac{0.35 \times 10^4}{5.37}$$

$$= 651.7 \text{ KPa}$$

2. $r_K = 7 \Rightarrow \dfrac{v_1}{v_2} = 7$



Otto cycle

State 1: $P_1 = 90 KPa$

$T_1 = 27^\circ C = 300K$

$V_1 = 0.004 m^3$

$T_3 = 1127^\circ c = 1400K$

$$m = \frac{P_1 V_1}{RT_1} = \frac{90 \text{ KPa} \times 0.004 m^3}{0.287 \text{ KJ/kg} \times 300K}$$

$$= 4.18 \times 10^{-3} \text{ kg}$$

~~Now Process~~ $v_2 = \dfrac{v_1}{7} = \dfrac{0.004}{7}$

$$= 0.00057 m^3$$

$v_2 = v_3 \qquad v_1 = v_4 \qquad \Rightarrow \dfrac{v_1}{v_2} = \dfrac{v_4}{v_3} = 7$

Process 1-2 : isentropic

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

$$T_2 = 300 (7)^{2/5}$$

$$T_2 = 653.3K$$

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$$P_2 = 90 \times (7)^{1.4}$$

$$P_2 = \cancel{196\,kPa}\ 1372.08\,kPa$$

Process 2-3 Isochoric

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

$$P_3 = \frac{1400}{653.3} \times \cancel{196}\ 1372$$

$$= \cancel{420\,kPa}\ 2940.1\,kPa$$

Process 3-4 isentropic

$$T_3 V_3^{\gamma-1} = T_4 V_4^{\gamma-1}$$

$$T_4 = 1400\left(\frac{1}{r_K}\right)^{0.4}$$

$$T_4 = 1400\left(\frac{1}{7}\right)^{0.4}$$

$$T_4 = 642.8\,K$$

~~Proc~~ Apply first law in process 2-3

Q_{in}

$$\Delta U = Q_{in} - \cancel{W} \xrightarrow{} 0 \rightarrow \text{isochoric process}$$

$$m C_v(\Delta T) = Q_{in}$$

$$Q_{in} = 4.18\times10^{-3}(0.718)(1400-653.3)$$

$$Q_{in} = 2.24\ kJ$$

First law in process ~~T4T1~~ 4-1

$$Q_{out} = m c_v(\Delta T) \qquad \text{isochoric} \Rightarrow W = 0$$

$$Q_{out} = 4.18\times10^{-3}(0.718)(300-642.8)$$

$$= -1.028\,kJ \Rightarrow \text{Heat rejected in process}$$

$W_{net} = |Q_{in}| - |Q_{out}|$

$= 2.24 - 1.028$

$W_{net} = 1.211 \text{ kJ}$

$\eta_{Thermal} = 1 - \dfrac{Q_{out}}{Q_{in}}$

$= 1 - \dfrac{1.028}{2.24}$

$= 0.541 \approx 54.1\%$

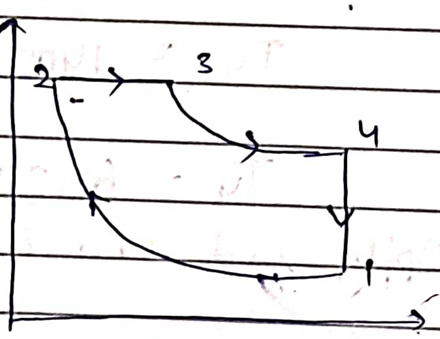
Mean effective pressure $= \dfrac{W_{net}}{V_1 - V_2}$

$= \dfrac{1.211}{0.004 - 0.00057} = \dfrac{1.211}{3.43}$

$= 353$

3. $r_k = 20$

$\Rightarrow \dfrac{v_1}{v_2} = 20$



@ State 1 : $P_1 = 95 \text{ kPa}$

$T_1 = 20°C = 293K$

$T_3 = 2200 K$

$v_1 = 20 v_2$

$v_4 = v_1 \quad P_2 = P_3$

Process 1-2 Isentropic

$T_1 V_1^{r-1} = T_2 V_2^{r-1}$

$T_2 = 293 (20)^{2/5}$

$T_2 = 971.1 K$

Process 2-3 $\dfrac{v_2}{T_2} = \dfrac{v_3}{T_3}$ $\quad v_3 = \dfrac{2200}{971.1} v_2 \Rightarrow$

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$v_3 = 2.26 v_2$

Process 3-4 : isentropic

$T_3 V_3^{\gamma-1} = T_4 v_4^{\gamma-1}$

$T_4 = T_3 \; (2.26)^{2/5} \cdot \left(\frac{1}{20}\right)^{2/5}$

$T_4 = 919.7\,K$

Now first law in process 4-1

$C_v(\Delta T) = q_{out}$

$0.718\,(~~919.7~~\ 293 - 919.7) = q_{out}$

$q_{out} = -480\,kJ/kg$

In process 2-3 $\qquad$ In open

$C_p(\Delta T) = q_{in}$

$q_{in} = 1.005\,(2200 - 971.1)$

$q_{in} = 1235\ kJ/kg$

$\eta_{Thermal} = 1 - \frac{q_{out}}{q_{in}}$

$= 1 - \frac{480}{1235} = 0.635 = 63.5\%$

~~Mean effective pressure =~~

$v_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 293}{95\,kPa} = 0.885\ m^3/kg$

$v_2 = \frac{v_1}{20} \Rightarrow v_2 = 0.04425\ m^3/kg$

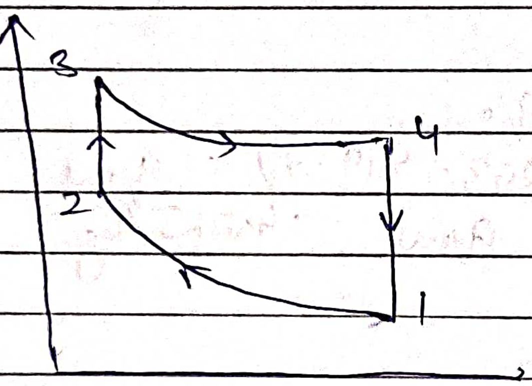
Mean effective pressure $= \dfrac{\cancel{W_{net}}\ w_{net}}{v_1 - v_2}$

$$= \frac{q_{in} - q_{out}}{v_1 - v_2}$$

$$= \frac{1235 - 450}{0.885 - 0.04425}$$

$$= \frac{785}{0.84075} = 933.6 \text{ kPa}$$

4. i) Otto cycle



Given $T_3 = 1400K$.
$T_4 = 700K$

State 1: $P_1 = 0.1 MPa$
$= 100 kPa$
$T_1 = 300K$.

~~Process 1-2 : isentropic~~

$\cancel{PV^{\gamma} = K}$
$\cancel{P^{1-\gamma} T^{\gamma} = K}$
$\cancel{P_1^{1-\gamma} T_1^{\gamma} = P_2^{1-\gamma} T_2^{\gamma}}$

$v_3 = v_2$
$v_4 = v_1$

$r_K = \dfrac{v_1}{v_2}$ = Compression ratio

Process 3-4: Isentropic

$$T_3 V_3^{\gamma-1} = T_4 V_4^{\gamma-1}$$

$$\frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{\gamma-1}$$

$$\frac{T_3}{T_4} = (r_K)^{2/5}$$

$$(2)^{5/2} = r_K \Rightarrow r_K = 5.65$$

Maximum pressure @ state 3.

$\frac{v_1}{v_2} = 5.65$

Process 1-2 : isentropic

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

$P_2 = P_1 (r_k)^{\gamma}$

$= 100 (5.65)^{7/5}$

$P_2 = 1129.45 \text{ KPa}$

$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

$T_2 = 300 (r_k)^{2/5}$

$T_2 = 300 (5.65)^{2/5}$

$T_2 = 599.7 \text{ K}$

Process 2-3 : isochoric

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

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

$= \frac{1400}{599.7} \times 1129.45$

$P_3 = 2636.7 \text{ KPa} = 2.63 \text{ MPa}$

First law in 2-3:

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

$0.718 (1400 - 599.7) = q_{in}$

$q_{in} = 574.6 \text{ KJ/Kg}$

First law in 4-1 :

$c_v (T_1 - T_4) = q_{out}$

$0.718 (300 - 700) = q_{out}$

$q_{out} = -287.2 \text{ KJ/Kg}$

$\eta_{Thermal} = 1 - \frac{q_{out}}{q_{in}}$

$= 1 - \frac{287.8}{574.6}$

$= 0.499 \approx 49.9\% \approx 50\%$

$W_{net} = q_{in} - q_{out}$

$w_{net} = 574.6 - 287.8 \text{ KJ/kg}$

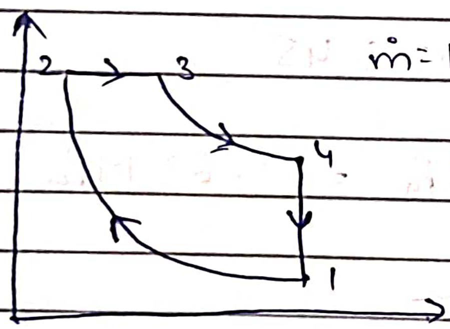
$w_{net} = 287.1 \text{ KJ/kg}$

$\dot{W}_{net} = \dot{m} w_{net}$

$= 1 \times 287.4$

$= 287.4 \frac{KJ}{min}$

ii) Diesel cycle



$T_3 = 1400K \qquad T_4 = 700K.$

$\dot{m} = 1 kg/min$

@ State 1: $P_1 = \cancel{95}\ 100 kPa$

$T_1 = 300K.$

Process 3-4 : isentropic

Process 2-3 : isobaric

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

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

$T_3 V_3^{\gamma-1} = T_4 V_4^{\gamma-1}$

$2 = \left(\frac{V_4}{V_3}\right)^{2/5}$

$5.65 = \frac{V_4}{V_3}$

$5.65 = \frac{V_1}{V_3}$

$\Rightarrow \frac{V_1 T_2}{T_3 V_2} = 5.65$

Process 1-2 : $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

$$T_2 = 300 \left(\frac{V_1}{V_2}\right)^{2/5}$$

$$\therefore V_3 = \frac{1400}{300} \left(\frac{V_2}{V_1}\right)^{2/5} \cdot V_2 = 4.67 \frac{V_2^{7/5}}{V_1^{2/5}}$$

And $\frac{V_1}{V_3} = 5.65$

$$\frac{V_1 \cdot V_1^{2/5}}{4.67 V_2^{7/5}} = 5.65$$

$$\left(\frac{V_1}{V_2}\right)^{7/5} = 5.65 \times 4.67$$

Process 1-2 : isentropic

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

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

$$\Rightarrow \frac{V_1}{T_3 V_2} \cdot T_1 \left(\frac{V_1}{V_2}\right)^{\gamma-1} = 5.65$$

$$\frac{300}{1400} \left(\frac{V_1}{V_2}\right)^{7/5} = 5.65$$

$$r_k = 10.354$$

$$\therefore T_2 = 300 (r_k)^{2/5}$$

$$T_2 = 300 (10.35)^{2/5}$$

$$T_2 = 764 \text{ K}$$

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Process 1-2 : $P_1^{1-\gamma} T_1^{\gamma} = P_2^{1-\gamma} T_2^{\gamma}$

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

$$\left(\frac{P_2}{P_1}\right)^{-2/5} = \left(\frac{300}{764}\right)^{7/5}$$

$$\frac{P_2}{100} = \left(\frac{300}{764}\right)^{-7/2}$$

$$P_2 = 100 \times 26.357$$

$$P_2 = 2635.7 \text{ KPa}$$

Highest pressu

First law 2-3: $q_{in} = C_p(T_3 - T_2)$

$$q_{in} = \cancel{0.718}\ 1.005(1400 - 764)$$

$$q_{in} = 639.18 \text{ KJ/kg}$$

First law 4-1 $q_{out} = C_v(T_1 - T_4)$

$$q_{out} = 0.718(300 - 700)$$

$$q_{out} = -287.2 \text{ KJ/kg}$$

$$\eta_{Thermal} = 1 - \frac{q_{out}}{q_{in}}$$

$$= 1 - 0.449 = 0.8509 \approx 55.09\%$$

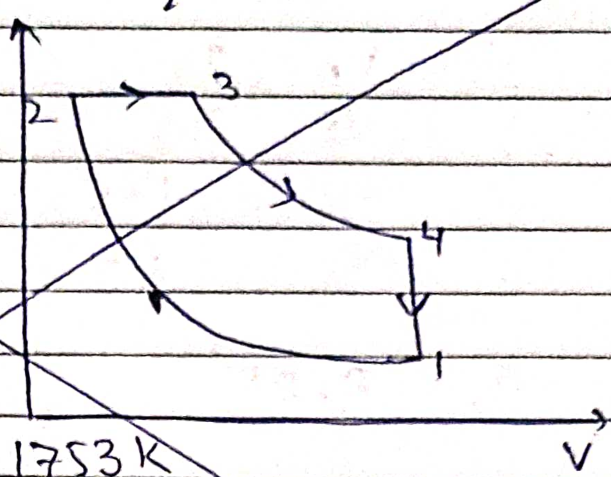
$$w_{net} = |q_{in}| - |q_{out}| = 639.18 - 287.2 = 351.98$$

$$\dot{W} = \dot{m}\, w_{net}$$

$$= 1 \times 351.98 \text{ KJ/min}$$

$$= 351.98 \text{ KJ/min}$$

5. Diesel cycle $r_K = 16 \Rightarrow \frac{v_1}{v_2} = 16$



...en beginning of
isentropic ~~general~~ compression
∴ State 2

Given

@ State 2: $T_2 = 15°C = 288 K$

$P_2 = 100 kPa$

@ State 3: $T_3 = 1480°C = 1753 K$

Process 2-3 : isobaric

$$\frac{v_2}{T_2} = \frac{v_3}{T_3}$$

$$\frac{T_3}{T_2} = \frac{v_3}{v_2} \Rightarrow r_c = \frac{1753}{288}$$

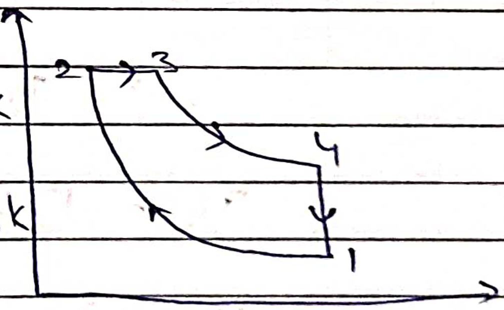
$$r_c = 6.086$$

5. diesel engin $r_K = 16 \Rightarrow \frac{v_1}{v_2} = 16$

Given @ State 1: $P_1 = 100 kPa$

$T_1 = 15°C = 288 K$

@ State 3 : $T_3 = 1480°C = 1753 K$



Process 1-2 : Isentropic

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

$$T_2 = 288 (16)^{2/5}$$

$$T_2 = 873 K$$

Process 2-3: Isobaric

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

$$\frac{v_3}{v_2} = \frac{1753}{873} \approx 2.01$$

$r_c = 2.01$

Heat is supplied in process 2-3: per kg

$$q_{in} = C_p(T_3 - T_2)$$
$$= 1.005(1753 - 873)$$
$$= 884.8 \text{ KJ/kg}$$

Process 3-4: Isentropic

$$T_3 v_3^{\gamma-1} = T_4 v_4^{\gamma-1}$$

$$T_4 = T_3 \left(\frac{v_3}{v_1}\right)^{\gamma-1}$$

$$= T_3 \left(\frac{v_3}{16 v_2}\right)^{\gamma-1}$$

$$T_4 = 1753 \left(\frac{2.01}{16}\right)^{2/5}$$

$$T_4 = 764.5 \text{ K}$$

Now heat rejected in process 4-1:

$$q_{out} = C_v(T_1 - T_4)$$
$$q_{out} = 0.718(288 - 764.5)$$
$$q_{out} = -342.12 \text{ KJ/kg}$$

$$\eta_{thermal} = 1 - \frac{q_{out}}{q_{in}}$$

$$= 1 - \frac{342.12}{884.8}$$

$$= 0.613$$

$$\eta_{thermal} = 61.3\ \%$$

Process 1-2 : isentropic

$$P_1^{1-\gamma} T_1^{\gamma} = P_2^{1-\gamma} T_2^{\gamma}$$

$$\left(\frac{P_1}{P_2}\right)^{-2/5} = \left(\frac{873}{288}\right)^{7/5}$$

$$\frac{P_1}{P_2} = 0.0206$$

$$P_2 = \frac{100}{0.0206}$$

$$P_2 = 4854.3\ kPa$$

$$w_{net} = |q_{in}| - |q_{out}|$$

$$= 884.8 - 342.12$$

$$= 542.68\ kJ/kg$$

$$v_1 = \frac{RT_1}{P_1}$$

$$= \frac{0.287 \times 288}{100}$$

$$= 0.826\ m^3$$

$$v_2 = \frac{RT_2}{P_2}$$

$$= \frac{0.287 \times 873}{4854.3}$$

$$= 0.05\ m^3$$

$$\text{Mean effective pressure} = \frac{w_{net}}{v_1 - v_2}$$

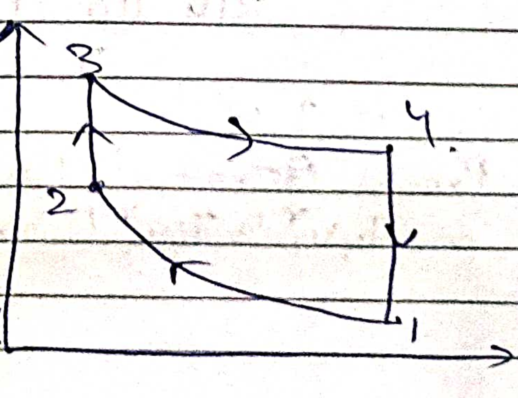
$$= \cancel{542.68\ kPa}$$

$$\frac{542.68}{0.826 - 0.05}$$

$$= 699.3\ kPa$$

6. Lets calulate for 1 cylinder first

otto cycle



@ State 1: $P_1 = 96.5\ kPa$

$T_1 = 41°C = 314\ K$

@ State 3 : $T_3 = 1315°C = 1588\ K$

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Given $V_2 = 9.8\%$ of v_1

$$\Rightarrow V_2 = 0.098\, v_1$$

$$\frac{V_1}{V_2} = \frac{1000}{98}$$

$$\frac{V_1}{V_2} = 10.2$$

Also $v_1 - v_2$ = stroke × Area of cylinder

$$= L \times \frac{\pi D^2}{4} \qquad D \rightarrow \text{bore}$$

Given stroke = 9.91 cm

bore = 8.89 cm

$$V_1 - V_2 = \frac{9.91 \times 3.14 \times 8.89 \times 8.89}{4}$$

$$V_1 - V_2 = 607.9 \text{ cm}^3$$

$$10.2 V_2 - V_2 = 607.9 \text{ cm}^3$$

$$9.2 V_2 = 607.9 \text{ cm}^3$$

$$V_2 = 66.07 \text{ cm}^3$$

$$V_1 = 10.2 V_2$$

$$V_1 = 673.9 \text{ cm}^3$$

Process 1-2 : Isentropic

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

$$314\,(10.2)^{2/5} = T_2$$

$$T_2 = 795 \text{ K}$$

Process 3-4 : Isentropic

$$T_4 V_4^{\gamma-1} = T_3 V_3^{\gamma-1} \Rightarrow T_4 = 1588 \times \left(\frac{1}{10.2}\right)^{2/5}$$

$$T_4 = 627.2 \text{ K}$$

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$$m = \frac{P_1 V_1}{R T_1} = \frac{96.5 \times 0.673 \times 10^{-3}}{0.287 \times 314}$$

$$m = 0.72 \times 10^{-3}\ Kg$$

Now $Q_{in} = m c_v (T_3 - T_2)$ first law in 2-3

$Q_{in} = 0.72 \times 10^{-3} \times 0.718 (1588 - 795)$

$Q_{in} = \cancel{0.410}\ 409.9\ J$

$Q_{out} = m c_v (T_1 - T_4)$ first law in 4-1

$= 0.72 \times 10^{-3} \times 0.718 (314 - 627.2)$

$= -161.9\ J$

$W_{net} = \cancel{409}\ |Q_{in}| - |Q_{out}|$

$= 409.9 - 161.9$

$W_{net} = 248\ J \rightarrow$ Work produced by one device

$W_{Total} = 6 \times W_{net} = 1488\ J$

$= 1.488\ KJ/cycle$

Given $2500 \frac{rev}{min} = \frac{2500}{60} \frac{rev}{s}$

$= 41.67 \frac{rev}{s}$

In a four stroke engine 2 rev = 1 cycle

$= \frac{41.67}{2} \frac{cycles}{s}$

$= 20.835 \frac{cycles}{s}$

Power produced = $W_{Total} \times$ speed

$= 1.48 \frac{KJ}{cycle} \times 20.835 \frac{cycle}{s}$

$= 30.83\ KW$

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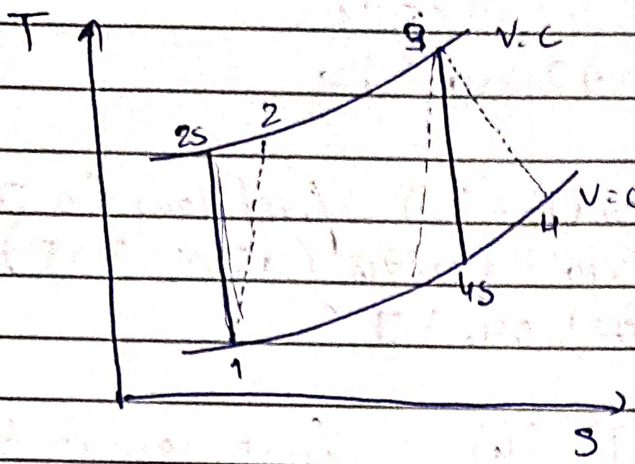
Q. Otto ~~cy~~ cycle $r_k = 8 \Rightarrow \frac{v_1}{v_{2s}} = 8$



$\eta_{isentropic, 1-2} = 0.85$

$\eta_{isen, 3-4} = 0.95$

Now processes 1-2s & 3-4s are reversible pro[cesses] giving reversible

Process 1-2 & 3-4 are actual processes give actual

$-W_{1-2s} = \Delta U \qquad Q = 0$ (adiabatic)

$W_{1-2s} = c_v(T_1 - T_{2s})$

Similarly

$W_{3-4s} = c_v(T_3 - T_{4s}) \qquad W_{12} = c_v(T_1 - T_2)$

$W_{34} = c_v(T_3 - T_4)$

Compression

$$\eta_{isen, 1-2} = \frac{W_{rev}}{W_{act}} = \frac{\cancel{c_v}(T_1 - T_{2s})}{\cancel{c_v}(T_1 - T_2)}$$

$$0.85 = \frac{T_1 - T_{2s}}{T_1 - T_2} \longrightarrow (1)$$

expansion

Similarly

$$\eta_{isen, 3-4} = \frac{W_{act}}{W_{rev}} \Rightarrow 0.95 = \frac{T_3 - T_4}{T_3 - T_{4s}} \longrightarrow (2)$$

Let us assume an ideal ~~Otto~~ Otto cycle to fi[nd] T_{4s} & T_{2s}

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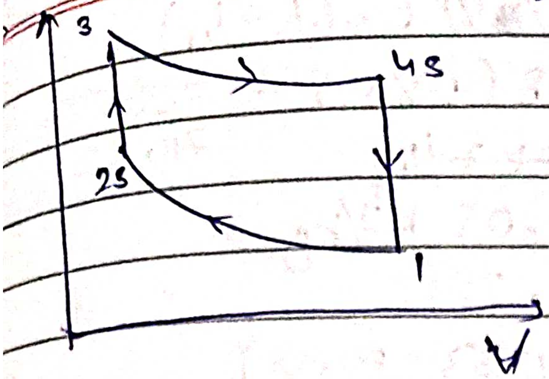
w.k.t $\frac{V_1}{V_{2s}} = 8.$



Given

@ State 1 : $P_1 = 89.6 kPa$

$T_1 = 15.5°C = 288.5 K$

& @ State 3 : $T_3 = 1260°C$

$T_3 = 1533 K$

Process 1-2s : Isentropic

$T_1 V_1^{\gamma-1} = T_{2s} V_{2s}^{\gamma-1}$

$T_{2s} = 288.5 \, (8)^{2/5}$

$T_{2s} = 662.8 K.$

Process 3-4s : Isentropic

$V_1 = V_{4s}$

$V_3 = V_{2s}$

$T_3 V_3^{\gamma-1} = T_{4s} V_{4s}^{\gamma-1}$

$T_{4s} = 1533 \left(\frac{1}{8}\right)^{2/5}$

$T_{4s} = 667.3 K$

Now Eqn (1)

$0.85 = \frac{T_1 - T_{2s}}{T_1 - T_2}$

$0.85(288.5 - T_2) = 288.5 - 662.8$

$T_2 = 728.8 K$

Eqn (2)

$0.95 = \frac{T_3 - T_4}{T_3 - T_{4s}}$ 0.95

$0.95(1533 - 667.3) = (1533 - T_4)$

$T_4 = 1533 - 822.2$

~~= 621.93 K~~

$T_4 = 710.585 K$

~~Heat supplied per unit mass = $c_v(t_2 - T_1)$~~

~~$= 0.718(728.8 - 288.5)$~~

~~$= 316.1 kJ$~~

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q_{out} = Heat rejected = ~~[illegible]~~ $C_v(T_1 - T_4)$

$= 0.718(288.5 - \cancel{621.73}\ 710.58)$

$= \cancel{239.25\ kJ/kg}$

$= -303.05\ kJ/kg$

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

$= 0.718(1533 - 728.8)$

$= 577.41\ kJ/kg$

$$\eta_{Therm} = 1 - \frac{q_{out}}{q_{in}}$$

$$= 1 - \frac{\cancel{239.25}\ 303.05}{577.41}$$

$= \cancel{0.585} \approx \cancel{58.5\%}$

$= 0.475 \approx 47.5\%$

Now $v_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 288.5}{89.6}$

$v_1 = 0.924\ m^3/kg$

$v_2 = v_{2s} = \frac{v_1}{8} = 0.115\ m^3/kg$

Mean effective pressure $= \frac{|q_{in}| - |q_{out}|}{v_1 - v_2}$

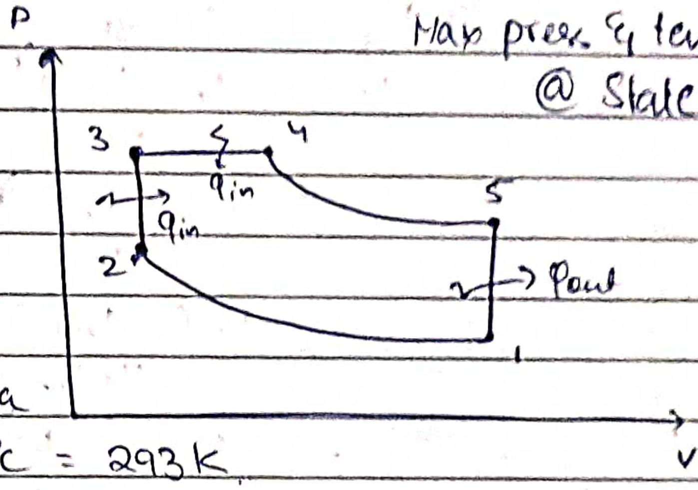
$$= \frac{577.41 - 303.05}{0.924 - 0.115}$$

$$= \frac{274.36}{0.809} = 339.1\ kPa$$

Q. Dual cycle $r_K = 14$ $r_c = 1.2$
$r_p = 1.5$

$\frac{V_1}{V_2} = 14$ $\frac{V_4}{V_2} = 1.2$

$\frac{P_3}{P_2} = 1.5$



Max pres. & temp @ State 4.

Given @ State 1: $P_1 = 80\,kPa$
$T_1 = 20°C = 293\,K$

Process 1-2 : isentropic

$$T_2 V_2^{\gamma-1} = T_1 V_1^{\gamma-1}$$
$$T_2 = 293\,(14)^{2/5}$$
$$T_2 = 842.01\,K$$

Process ~~3-4~~ 2-3: isochoric

$$\frac{T_3}{T_2} = \frac{P_3}{P_2}$$
$$T_3 = 1.5 \times 842.01$$
$$T_3 = 1263.01\,K$$

Process 3-4 : isobaric

$$\frac{T_4}{T_3} = \frac{V_4}{V_3}$$
$$T_4 = 1263.01 \times 1.2$$
$$T_4 = 1515.6\,K \longrightarrow \text{Maximum temp}$$

~~Process~~

Process 5-4 : isentropic

$$T_5 V_5^{\gamma-1} = T_4 V_4^{\gamma-1}$$

$$T_5 = T_4 \left(\frac{V_4}{V_5}\right)^{\gamma-1}$$

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

$$= T_4 \left(\frac{V_4}{14 V_3}\right)^{\gamma-1}$$

$$T_5 = 1515.6 \left(\frac{1.2}{14}\right)^{2/5}$$

$$T_5 = 567.2 \text{ K}$$

~~Now q_{in}~~ Process 1-2:

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

$$P_2 = 80 (14)^{7/5}$$

$$P_2 = 3218.6 \text{ KPa}$$

~~Process 2-3~~: W.K $\frac{P_3}{P_2} = 1.5$

$$P_3 = 1.5 P_2$$

$$P_3 = 4827.9 \text{ KPa}$$

$P_4 = P_3 = 4827.9$ KPa $\longrightarrow$ Maximum pressure

By first law in 2-3-4

$$q_{in,total} = q_{in,\ isochoric} + q_{in,\ isobaric}$$

$$= C_v (T_3 - T_2) + C_p (T_4 - T_3)$$

$$q_{in,total} = 0.718 (1263.01 - 842.01) + 1.005 (1515.6 - 1263.01)$$

$$= 302.3 + 253.8$$

$$q_{in,total} = 556.15 \text{ KJ/kg}$$

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First law in 5-1

$q_{out} = C_v (T_1 - T_5)$

$q_{out} = 0.718 (293 - 567.3)$

$q_{out} = -196.9 \text{ kJ/kg}$

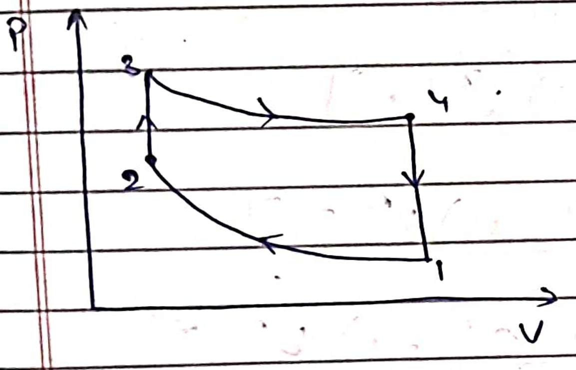
$\eta_{Therm} = 1 - \frac{q_{out}}{q_{in}}$

$= 1 - \frac{196.9}{556.15}$

$= 0.646 \approx 64.6\%$ efficiency.

9. Given: i) Otto cycle
ii) q_{in} remains same
iii) State 1 remains same

Let $\left(\frac{v_1}{v_2}\right)_i = K$



The compression ratio is doubled

$\Rightarrow \left(\frac{v_1}{v_2}\right)_f = 2K$

Process 1-2 : initially

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

$P_{2i} = P_1 (K)^{\gamma}$

finally $P_{2f} = 2^{\gamma} \cdot P_1 (K)^{\gamma} \Rightarrow P_{2f} = 2^{\gamma} P_{2i}$

Now, initially $T_1 V_1^{\gamma-1} = T_{2i} V_{2i}^{\gamma-1}$

$T_{2i} = \cancel{2^{\gamma-1}} T_1 (K)^{\gamma-1}$

finally $T_{2f} = 2^{\gamma-1} T_1 (K)^{\gamma-1}$

$T_{2f} = 2^{\gamma-1} T_{2i}$

Heat addition remain same

$\Rightarrow \cancel{C_v}(T_{3i} - T_{2i}) = \cancel{C_v}(T_{3f} - T_{2f})$

$T_{3i} - T_{2i} = T_{3f} - T_{2f}$

$T_{3i} + (2^{\gamma-1}+1)T_{2i} = T_{3f}$

Maximum temperature finally

$\boxed{T_{3f} = T_{3i} + (2^{\gamma-1}+1)K^{\gamma-1} \cdot T_1}$

T_{3i} → Max temperature initially.

Process 2-3: isochoric

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

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

Final state:

$P_{3f} = P_{2f} \frac{T_{3f}}{T_{2f}}$

Initial state

$P_{3i} = P_{2i} \frac{T_{3i}}{T_{2i}}$

$= \cancel{2^{\gamma}} P_{2i} 2 \frac{[T_{3i} + (2^{\gamma-1}+1)K^{\gamma-1} \cdot T_1]}{\cancel{2^{\gamma}} T_{2i}}$

$P_{3f} = 2P_{2i} \frac{[T_{3i} + (2^{\gamma-1}+1)K^{\gamma-1} T_1]}{T_{2i}}$

$= \frac{2P_{2i}T_{3i}}{T_{2i}} + \frac{2P_{2i}(2^{\gamma-1}+1)\cancel{K^{\gamma-1}}T_1}{\cancel{T_{2i}}}$

$P_{3f} = 2P_{3i} + 2P_1 K^{\gamma}(2^{\gamma-1}+1)$

$\boxed{P_{3f} = 2[P_{3i} + P_1 K^{\gamma}(2^{\gamma-1}+1)]}$

Maximum pressure @ finally ~~state~~

Maximum temp. @ ~~fina~~ initially.