

Unit - 3

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Air standard cycle -

- Definition - the efficiency of engine using air as the working medium is known as air standard efficiency & the cycle is known as air standard cycle.

Assumptions -

- i. The working medium is air (perfect gas)
- ii. There is no change in mass of air during cycle
- iii. Working medium has constant specific heat: C_p & C_v
- iv. The working medium homogeneous & no chemical rxn takes place
- v. Physical constants of working medium are same as that of Air. at standard atmospheric pressure.

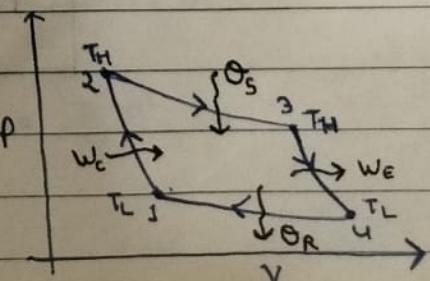
$$C_p = 1.005, C_v = 0.718 \text{ kJ/kg}, \gamma = \frac{C_p}{C_v} = 1.4$$

- vi. K.E & P.E of working fluid are neglected.
- vii. Operation of engine is frictionless.
- viii. Heat is supplied / rejected in a reversible manner
- ix. Source of heat supply & sink for heat rejection are external to air (working medium).
- x. compression & Expansion process are reversible adiabatic i.e. no loss or gain of entropy.

Carnot cycle :-

contains four processes.

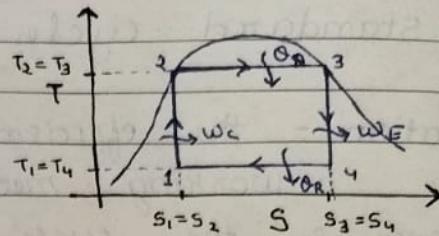
- i. $1 \rightarrow 2$ Reversible adiabatic compression
- ii. $2 \rightarrow 3$ Reversible isothermal heat addition
- iii. $3 \rightarrow 4$ Reversible adiabatic / isentropic expansion
- iv. $4 \rightarrow 1$ Reversible isothermal heat rejection



We know, that

$$\int ds = \int \frac{d\theta}{T}$$

now, $\int_2^3 ds = \int_2^3 \frac{d\theta}{T_H}$



$$\Theta_B = m \cdot T_H (S_3 - S_2)$$

and $\int_4^1 ds = \int_4^1 \frac{d\theta}{T_L}$

$$\Theta_A = m \cdot T_L (S_4 - S_1)$$

$$\eta = \frac{\text{output}}{\text{input}} = \frac{W_{net}}{\Theta_B}$$

acc to 1st law, $W_{net} = \Theta_{net}$

$$W_{net} = \Theta_B - \Theta_A$$

$$\eta = \frac{\Theta_B - \Theta_A}{\Theta_B}$$

$$= \frac{m \cdot T_H (S_3 - S_2)}{m \cdot T_H (S_4 - S_1)} - \frac{m \cdot T_L (S_4 - S_1)}{m \cdot T_H (S_4 - S_1)}$$

in Carnot cycle, $S_1 = S_2$ & $S_3 = S_4$, then

$$= \frac{m \cdot T_H (S_4 - S_1)}{m \cdot T_H (S_4 - S_1)} - \frac{m \cdot T_L (S_4 - S_1)}{m \cdot T_H (S_4 - S_1)}$$

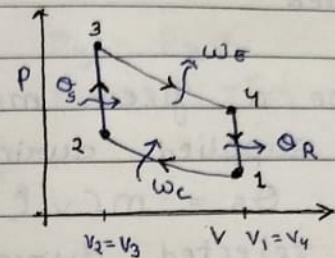
$$= \frac{T_H - T_L}{T_H}$$

$$\boxed{n = 1 - \frac{T_L}{T_H}}$$

Air standard otto cycle :-

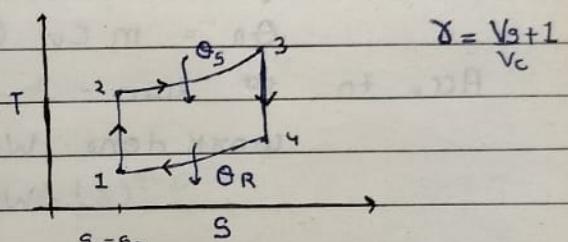
i. Also known as const. volume cycle, by using those cycle petrol, gas or any spark ignited engines are designed.

- i. 1→2 reversible adiabatic compression
- ii. 2→3 const. volume heat addition
- iii. 3→4 reversible adiabatic Expansion
- iv. 4→1 isochoric heat rejection.

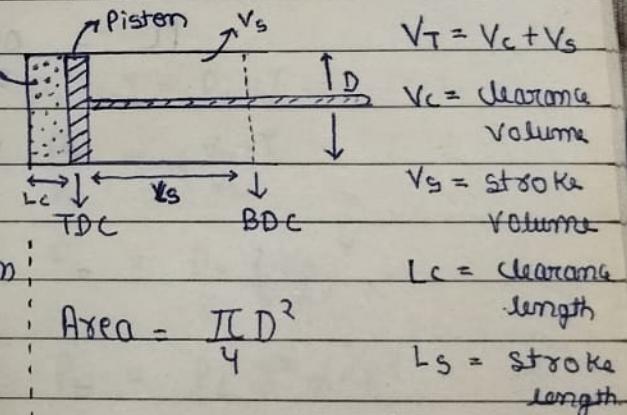


- 1→2 Air compressed adiabatically from v_1 to v_2 , then

$$\text{compression ratio } \gamma = \frac{v_1}{v_2} = \frac{v_t}{v_c}$$



- 2→3 Piston momentarily at rest, at TDC and heat is added to working fluid at const. volume from an external ^{heat} source which is brought into contact with cylinder head, due to heat addition pressure increases via an explosion ratio $\alpha = \frac{P_3}{P_2}$



- 3→4 due to increased high pressure great force is exerted to piston hence it expands from TDC to BDC Expansion of WF take place & adiabatically work is done by system., then

$$\text{Expansion ratio} = \frac{V_4}{V_3}$$

$$\text{Volume} = \frac{\pi}{4} D^2 \cdot L$$

$$V_c = \frac{\pi}{4} D^2 \cdot L_c$$

$$V_s = \frac{\pi}{4} D^2 \cdot L_s$$

- 4-1 Piston is momentarily at rest at BDC Heat is rejected to External sink by bringing this in contact with cylinder head. The process come to initial state and cycle is completed.

Let m be a fixed mass of a working fluid (Air), then Heat supplied during process 2-3

$$\Theta_s = m C_v (T_3 - T_2)$$

Heat rejected during process 4-1

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

Acc. to 1st law -

$$\text{work done } W_{\text{net}} = \Theta_{\text{net}}$$

$$W_{\text{net}} = \Theta_s - \Theta_R$$

η = output
input

$$= \frac{W_{\text{out}}}{\Theta_s} = \frac{\Theta_s - \Theta_R}{\Theta_s}$$

$$= \frac{m C_v (T_3 - T_2)}{m C_v (T_4 - T_1)} = \frac{m C_v (T_3 - T_2)}{m C_v (T_3 - T_2)}$$

$$= \frac{T_3 - T_2 - T_4 + T_1}{T_3 - T_2}$$

$$= 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

for Ideal gas $PV = nRT$

$$PV^Y = \text{const (adiabatic)}$$

at point 1 : $V_1 = V_2 \gamma$

b/w 1-2 process :- (adiabatic compression)

$$P_1 V_1^Y = P_2 V_2^Y$$

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

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

$$\text{at point 3 : } V_3 = V_2 = \frac{V_1}{\alpha}$$

$$\text{Explosion ratio : } \alpha = \frac{P_3}{P_2} \Rightarrow P_3 = P_2 \alpha$$

$$P_3 = P_1 \gamma^x \alpha$$

$$\text{(constant volume process) : } \frac{P_2}{T_2} = \frac{P_3}{T_3}$$

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

$$\Rightarrow \frac{T_3}{\alpha} = T_2 \alpha$$

$$\Rightarrow T_3 = T_1 \alpha (\gamma)^{\gamma-1}$$

$$\text{at point 4 : } V_4 = V_1$$

$$\text{adiabatic expansion : } P_3 V_3^\gamma = P_4 V_4^\gamma$$

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

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

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

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

$$P_4 = P_1 \gamma^x \alpha^{\frac{1}{\gamma}} \gamma^x$$

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

$$P_4 = P_1 \alpha$$

$$T_4 = T_1 \alpha$$

Substituting all value, then.

$$n = 1 - \frac{(T_1 \alpha - T_1)}{(T_1 \alpha (\gamma)^{\gamma-1} - T_1 (\gamma)^{\gamma-1})} = 1 - \frac{T_1 (\alpha - 1)}{T_1 \gamma^{\gamma-1} (\alpha - 1)}$$

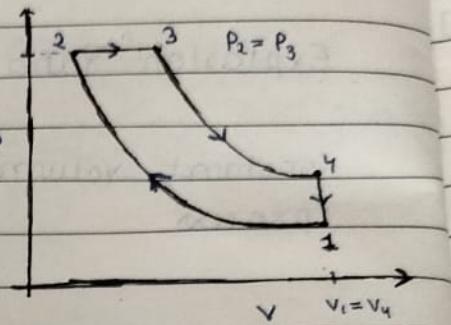
$$n_{ASE} = 1 - \frac{1}{\gamma^{\gamma-1}}$$

- Air Standard Diesel cycle

Also Known as const. pressure heat addition cycle.

Process 1→2 Reversible adiabatic or isentropic compression process.

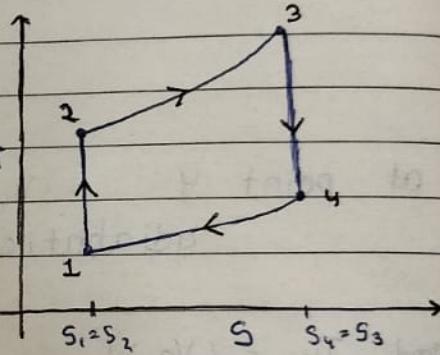
Working fluid (air) is compressed adiabatically from state point 1 to 2 via compression ratio $\gamma = \frac{V_1}{V_2}$
 $P \uparrow, V \downarrow, T \uparrow$



Process 2→3 Constant pressure heat addition.

During these process heat is added to w.f (air) at const. pressure due to this volume & temp. increases.

Point 3 is called "cut-off point" with a cut-off ratio $\gamma_c = \frac{V_3}{V_2}$
 $\theta_s = m C_p (T_3 - T_2)$



Process 3→4 Reversible adiabatic Expansion process

~~Due to~~ ~~is~~ these increased ^{high} pressure Exerts a greater amount of force on the piston toward BDC. Expansion of Air take place isentropically & work is done by the sys via Expansion ratio $\gamma_e = \frac{V_4}{V_3} = \frac{\gamma}{\gamma_c}$

Process 4→1 Constant volume heat rejection

The piston is momentarily addressed at BDC heat is

n cycle. rejected at const. volume to external sink & air comes to initial state 1 & cycle is completed.
 $P \downarrow, T \downarrow \quad \Theta_R = mC_V(T_4 - T_1)$

Let m be the fixed mass of working fluid (Air), then

$$\Theta_S = mC_P(T_3 - T_2)$$

$$\Theta_R = mC_V(T_4 - T_1)$$

$$W_{net} = \Theta_S - \Theta_R$$

now,

$$\frac{n}{\text{input}} = \frac{W_{net}}{\Theta_S} = \frac{\Theta_S - \Theta_R}{\Theta_S}$$

$$= \frac{mC_P(T_3 - T_2) - mC_V(T_4 - T_1)}{mC_P(T_3 - T_2)}$$

$$= 1 - \frac{C_V(T_4 - T_1)}{C_P(T_3 - T_2)}$$

$$\left[\gamma = \frac{C_P}{C_V} \right]$$

$$= 1 - \frac{1}{\gamma} \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

Efficiency in terms of γ , γ_c & γ , then.

Process 1-2 adiabatic compression, then

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

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

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

$$P_2 = P_1 \gamma^\gamma$$

$$T_2 = T_1 (\gamma)^{\gamma-1}$$

Process 2-3 constant pressure, then ($V \propto T$)

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

$$T_3 = T_2 \gamma_c \Rightarrow T_3 = T_1 \cdot \gamma^{\gamma-1} \gamma_c$$

Process 3 → 4 adiabatic Expansion, then $(PV^\gamma = \text{const})$

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

$$T_4 = T_3 \left(\frac{V_3/V_2}{V_4/V_2}\right)^{\gamma-1} = T_3 \left(\frac{\gamma_c}{\gamma}\right)^{\gamma-1} \quad [\because V_4 = V_1]$$

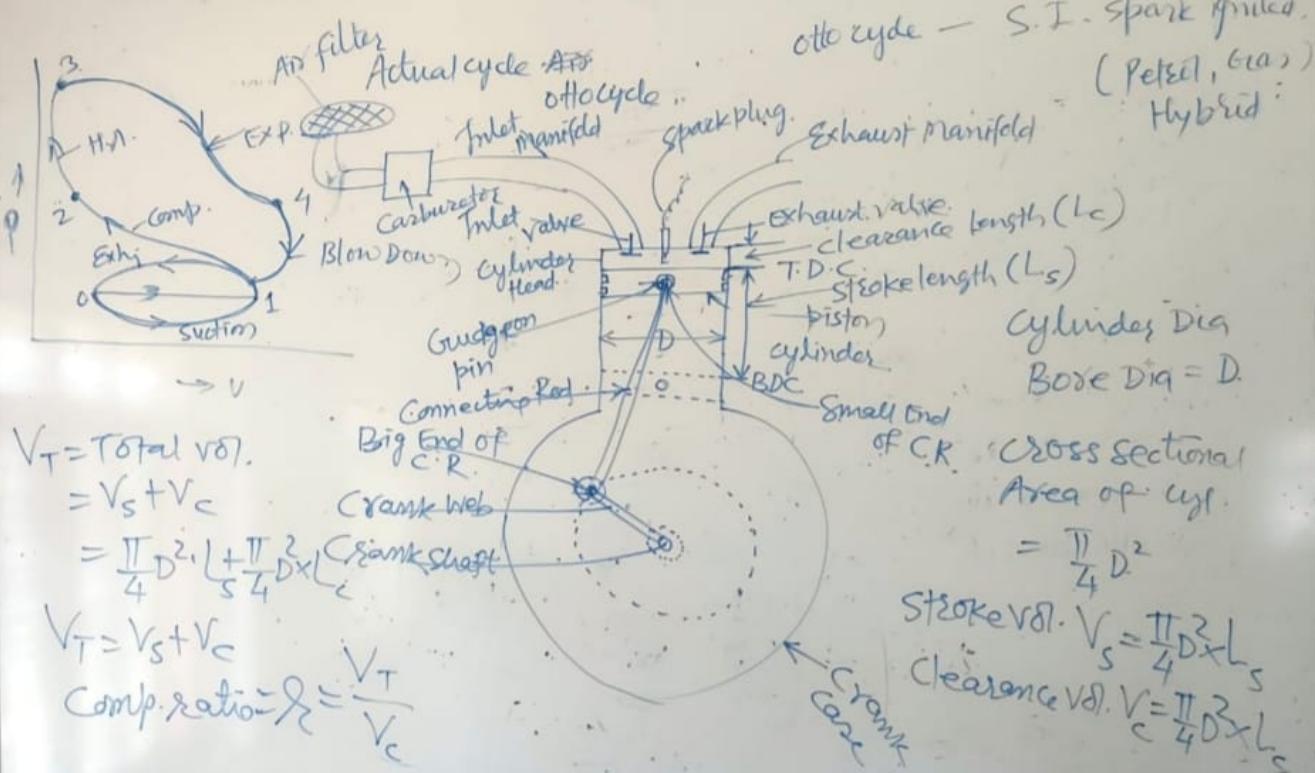
$$T_4 = T_1 \cdot \gamma^{\gamma-1} \cdot \gamma_c \cdot \frac{\gamma_c^{\gamma-1}}{\gamma^{\gamma-1}}$$

$$T_4 = T_1 \cdot \gamma_c^\gamma$$

put the value of $T_2, T_3 \& T_4$ in eq i,

$$n = 1 - \frac{1}{\gamma} \frac{(T_1 \cdot \gamma_c^\gamma - T_1)}{(T_1 \cdot \gamma^{\gamma-1} \cdot \gamma_c - T_1 \cdot \gamma^{\gamma-1})}$$

$$n_{\text{diesel}} = 1 - \frac{1}{\gamma \cdot \gamma^{\gamma-1}} \left(\frac{\gamma_c^\gamma - 1}{\gamma_c - 1} \right)$$



Fuel air cycle

→ specific heat varied with Temp - $C_p - C_v = R$
for monoatomic gases.

$$C_v = \frac{3R}{2}, C_p = \frac{5R}{2} \Rightarrow MC_v = \frac{3MR}{2}, MC_p = \frac{5MR}{2}$$

for diatomic gas

$$C_v = \frac{5R}{2}, C_p = \frac{7R}{2}, MC_v = \frac{5MR}{2}, MC_p = \frac{7MR}{2}$$

for polyatomic gas.

$$C_v = 3R, C_p = 4R, MC_v = 3MR, MC_p = 4MR$$

where, R is character gas constant

MR = mole weight \times character gas constant

= universal gas constant

= 8.314 KJ

- Effect of variable specific heat on efficiency of air standard cycle

(a) Otto cycle

we know that

$$n = \frac{1 - \frac{1}{\gamma^{y-1}}}{1 - \frac{1}{\gamma}} = 1 - \gamma^{-(y-1)} = \frac{\gamma}{\gamma - 1}$$

$$n = 1 - \gamma^{1-y}$$

$$\text{and } C_p - C_v = R$$

$$\text{or } \frac{C_p - C_v}{C_v} = \frac{R}{C_v} \Rightarrow \frac{C_p - 1}{C_v} = \frac{R}{C_v} \Rightarrow y - 1 = \frac{R}{C_v}$$

$$\text{then, } n = 1 - \gamma^{-R/C_v}$$

$$1 - n = \gamma^{-R/C_v}$$

taking log on both side

$$\log(1-n) = -\frac{R}{C_v} \log \gamma$$

Differentiating

$$\frac{1}{(1-n)} \cdot dn = -\frac{R}{C_v} \log \gamma \left[-\frac{1}{C_v^2} dC_v \right]$$

$$\text{or } dn = -\frac{(1-n)}{C_v^2} \cdot \frac{R}{C_v} \log \gamma \cdot dC_v$$

Dividing by n

$$\frac{dn}{n} = -\frac{(1-n)}{n} \cdot \frac{R}{C_v} \log \gamma \cdot \frac{dC_v}{C_v}$$

$$\frac{dn}{n} = -\frac{(1-n)}{n} \cdot (y-1) \cdot \log \gamma \cdot \frac{dC_v}{C_v}$$

Variation
in eff.

variation
in specific heat
at constant volume

(b) Diesel cycle

Efficiency of Air standard Diesel cycle is

$$\eta = 1 - \frac{1}{\gamma \cdot \gamma^{Y-1}} \cdot \left(\frac{\gamma_c^Y - 1}{\gamma_c - 1} \right)$$

$$1-\eta = \frac{1}{\gamma \cdot \gamma^{Y-1}} \cdot \left(\frac{\gamma_c^Y - 1}{\gamma_c - 1} \right)$$

taking log both side.

$$\log(1-\eta) = \log \left(\frac{1}{\gamma \cdot \gamma^{Y-1}} \cdot \left(\frac{\gamma_c^Y - 1}{\gamma_c - 1} \right) \right)$$

$$= \log \left(\frac{1}{\gamma \cdot \gamma^{Y-1}} \right) + \log \left(\frac{\gamma_c^Y - 1}{\gamma_c - 1} \right)$$

$$= -\log(\gamma \cdot \gamma^{Y-1}) + \log(\gamma_c^Y - 1) - \log(\gamma_c - 1)$$

$$= -(\log \gamma + \log(\gamma^{Y-1})) + \log(\gamma_c^Y - 1) - \log(\gamma_c - 1)$$

$$\log(1-\eta) = \log_e(\gamma_c^Y - 1) - \log_e(\gamma_c - 1) - \log_e \gamma - (Y-1) \log_e \gamma$$

Differentiating

$$\frac{1}{(1-\eta)} \cdot -dn = \frac{1}{\gamma_c^Y - 1} \cdot \gamma_c^Y \ln \gamma_c \cdot d\gamma - \frac{1}{\gamma} \cdot dy - \ln \gamma (dy)$$

$$\therefore dn = -(1-\eta) \cdot \left[\frac{\gamma_c^Y \ln \gamma_c - \frac{1}{\gamma} - \ln \gamma}{\gamma_c^Y - 1} \right] dy$$

Dividing both side by n

$$\frac{dn}{n} = + \frac{(1-\eta)}{n} \cdot \left[\ln \gamma + \frac{1}{\gamma} - \left(\frac{\gamma_c^Y}{\gamma_c^Y - 1} \right) \ln \gamma_c \right] dy$$

$$\therefore C_p - C_v = R \Rightarrow \frac{C_p - C_v}{C_v} = R \Rightarrow \frac{Y - 1}{C_v} = \frac{R}{C_v}$$

$$\text{Diff. , then } \Rightarrow dy = -\frac{R}{C_v^2} \cdot dC_v \Rightarrow dy = -(Y-1) \cdot \frac{dC_v}{C_v}$$

$$\frac{dn}{n} = -\frac{(1-\eta)}{n} \cdot (Y-1) \cdot \left[\ln \gamma + \frac{1}{\gamma} - \left(\frac{\gamma_c^Y}{\gamma_c^Y - 1} \right) \ln \gamma_c \right] \cdot \frac{dC_v}{C_v}$$

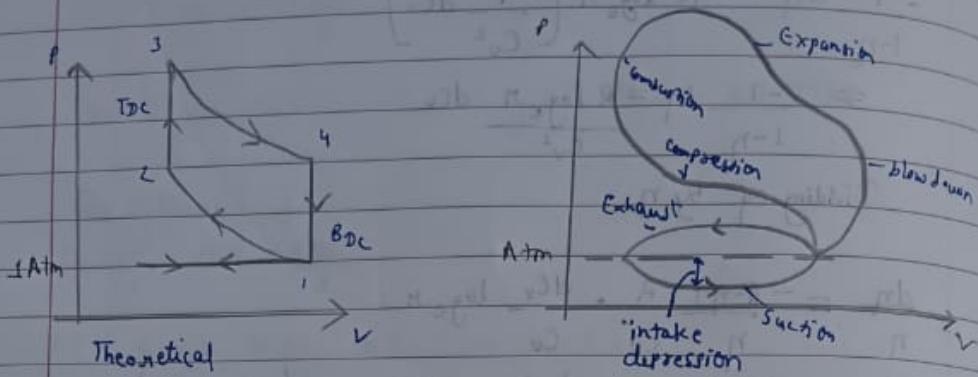
(Y-1) Q what is the effect of γ . Change in efficiency of otto cycle having compression ratio 7, if specific heat at cons vol. increase by 1% ?

Sol. $n = 1 - \frac{1}{\gamma^{k-1}} = 1 - \frac{1}{7^{1.4-1}} = 1 - \frac{1}{7^{0.4}} = 1 - 0.46 = 0.54$.

$$n = 54\%$$

$$\begin{aligned} \text{now, } \frac{dn}{n} &= -\frac{(1-n)}{n} \cdot (\gamma-1) \ln r \cdot \frac{\delta c_v}{c_v} \\ &= -\frac{(1-0.54)}{0.54} \cdot (1.4-1) \ln 7 \cdot 0.01 \\ &= -6.63 \times 10^{-3} \\ &= -\frac{6.63 \times 10^{-1}}{100} \times 100 \\ &= -0.663\% \end{aligned}$$

Theoretical & Actual P-V Diagrams for engines



For efficient suction, the pressure inside the cylinder at suction is less than atmospheric pressure. This pressure diff. is called intake depression. This is needed to overcome resistance of the flow of the charge through the restricted area of the inlet passage.

For proper exhaust of the burnt gases, there has to be net positive pressure from inside of the cylinder to outside. That is why exhaust line does not coincide with the atmospheric pressure line but it is slightly above it.

Compression & expansion are not isentropic and there is interchange of heat between the charge (fuel) & the cylinder walls. There is always time lag between the ignition of the charge & its actual combustion. And also combustion does not take place at constant volume and pressure rise is not along straight line.

Opening & closing of the valve are not instantaneous. It takes some time. That's why P-V will change & this is reflected by rounding of the corners on PV diagram.

Ignition of charge & opening of the walls is never at dead centre. This occurs at some degree on either side of the dead centre to get better charging, better ignition & pushing of burnt gases.

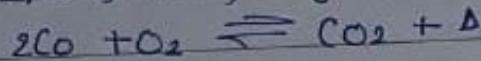
At high pressures and temperatures, there are chances of dissociation of products of combustion.

Dissociation or Chemical Equilibrium Loss

This is the disintegration of burnt gases at high temperatures. This is a endothermic, reversible process & increases with temperature. During dissociation, a considerable amount of heat is absorbed. This heat will be liberated when the elements recombine as the temperature falls. So general effect of dissociation is suppression of a part of heat during combustion period & liberation of heat during expansion process. So effect of dissociation is much lesser than that of change in specific heat.

This causes power & efficiency loss

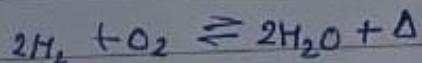
The dissociation is mainly of CO_2



at 1000°C \rightarrow dissociation starts

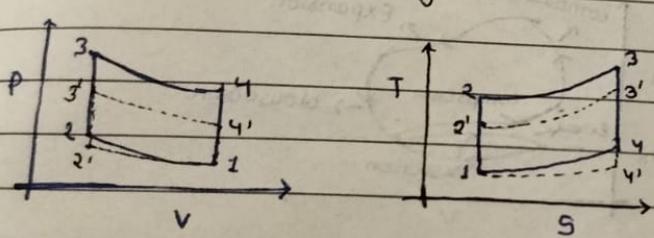
at 1500°C \rightarrow 1% dissociation

Temp in diesel engine during combustion $\approx 1800 - 1850^\circ\text{C}$



Dissociation is very severe in case of chemically correct mixture.

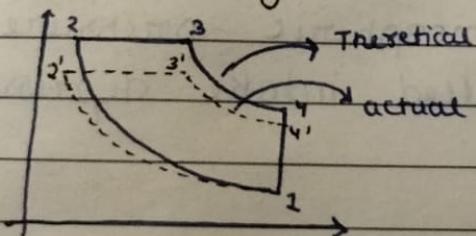
Effect of variable specific heat & dissociation on P-V & T-S diagram of Otto cycle



→ Loss in actual engine

- Loss is due to variation of sp. heat with temp
- Chemical equilibrium loss or dissociation loss

Diesel cycle



• Time loss

- Direct heat losses (from cylinder walls)
- Exhaust blow down loss
- Pumping losses
- Loss due to incomplete combustion.

Q. Engine working in otto cycle. The air is at 37°C at 1 bar. The press. at the end is 30 ~~at~~^{higher or equal} bar. at the end of combustion is 80 bar. Calc. compression ratio %, high temp of cycle and ASF.

Q. A Otto cycle operate under suction condⁿ at 1 bar at 326°C and C.R. is 8. Calc. p & T at the end of comp. and ASF.

Q. An engine working on diesel cycle operate suction 1 bar 34°C at the end of comp. the press. is 3.5 bar the cutoff is take place at 6% of the stroke. Calc. C.R., the % clearance heat supplied, heat rejected, thermal efficiency.

Q. In an engine cylinder bore 13.7 cm stroke length 13 cm clearance volume is 800 cm^3 express the clearance as p% of clearance volume also calc. ASF

Q. An engine working on otto cycle energy generated per cycle is twice higher than the rejected heat. Calc. ASF and C.R.

Q. In otto cycle air at 1 bar 15°C the comp. ratio is 8 200 kJ is released to a each cycle. Calc. C.R. so that net work done inc. by 20% is

Q. In an air stand. otto cycle max cycle p & T 5 mpa. and 2250°K min. p & T of cyl. 0.1 mpa and 300 K Calc. net work output and thermal efficiency.