ToppersNotes

IES/GATE

MECHANICAL ENGINEERING

I.C ENGINE & SOM/MOS/MOM/SM

VOLUME-III

Sierra Innovations Pvt. Ltd.

Contents

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I.C-Engine

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Books:-

- Automotive mechanics by Joseph Heitrus
  (For concept & Interview purpose)
- I.C-engines by V. Ganesan.
  (For Problem purpose)
- I.C-Engines by Mathur & Sharma
  (For IES Problem)

— 70/80 → marks

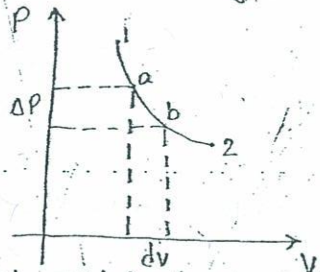
- The only difference in b/w reversible & irreversible process is Friction loss.
- In quasi-static process will not to be taken in irreversible process.
- Degree of randomness means measurment of out of order. (for entropy).

Quasistatic process :-

⇒ Quasi → partly (or) rest
or. differential calculus are same meaning.

$w = \int dw = \int_1^2 P\,dv$

$w = P(V_2 - V_1)$



Quasi-static process is not used for irreversible process.
- It should be taken when the value is constant & it change the value.

- Table showing the various expression for the different thermodynamic process undergone by a system :-

- only For ideal gas reversible process

SL NO	CONTENTS / process	constant volume Process	Constant Pressure Process	Constant Temprature Process	The Adiabatic process
1.	P, V & T relations	$\frac{P_2}{P_1} = \frac{T_2}{T_1}$	$\frac{V_2}{V_1} = \frac{T_2}{T_1}$	$P_1V_1 = P_2V_2$	① $P_1V_1^{\gamma} = P_2V_2^{\gamma}$ ② $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ ③ $\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = \frac{T_2}{T_1}$ ④ $\left(\frac{V_2}{V_1}\right)^{\gamma-1} = \frac{T_1}{T_2}$
2.	Change in Internal energy (du)	$mc_v(T_2 - T_1)$	$mc_v(T_2 - T_1)$	0	$mc_v(T_1 - T_2)$
3	work done	0	$P(V_2 - V_1)$	$P_1V_1 \log_e \frac{V_2}{V_1}$	$\frac{P_1V_1 - P_2V_2}{\gamma - 1}$
4.	Heat transfer (dQ)	$mc_v(T_2 - T_1)$	$mc_p(T_2 - T_1)$	$P_1V_1 \log_e \frac{V_2}{V_1}$	0
5	change in enthalpy (dH)	$mc_p(T_2 - T_1)$	$mc_p(T_2 - T_1)$	0	$mc_p(T_2 - T_1)$
6	change in entropy (ds)	$mc_v \log_e \frac{T_2}{T_1}$	$mc_p \log_e \frac{T_2}{T_1}$	$mR \log_e \frac{T_2}{T_1}$	$ds = 0$ (or) $(S_2 - S_1) = 0$ (or) $(S_2 = S_1)$

- Heat supplied, work done, heat rejection & compression then the cycle is completed.

The order of cycle is – HA → WD (expansion) → HR → compression

- No heat rejection in case of expanssion process then it should be adiabatic and also it is for compression process.

Cycle :-

- when a system after undergoing a number of process is called or is able to attain its original condition, it is then said to have completed a cycle.
- IF a cycle is not completed, then continous work will not be obtained.
- The following are the requirment for completing a cycle. i.e, HA, HR, Expansion (useful WD) + compression.

Ideal cycle :-

An ideal cycle is cycle in which both the expanssion and compression Process must take place reversily + Adiabatically.

I.C. Engines :-

An I.C. engine is the engine in which the combustion takes place inside the engine, besides all the operations required for a complete cycle take places inside the engine. thus the I.C. engine (his by itself a complete plant).

Only costly liquid and gaseous fuel can be used for I.C. engines.

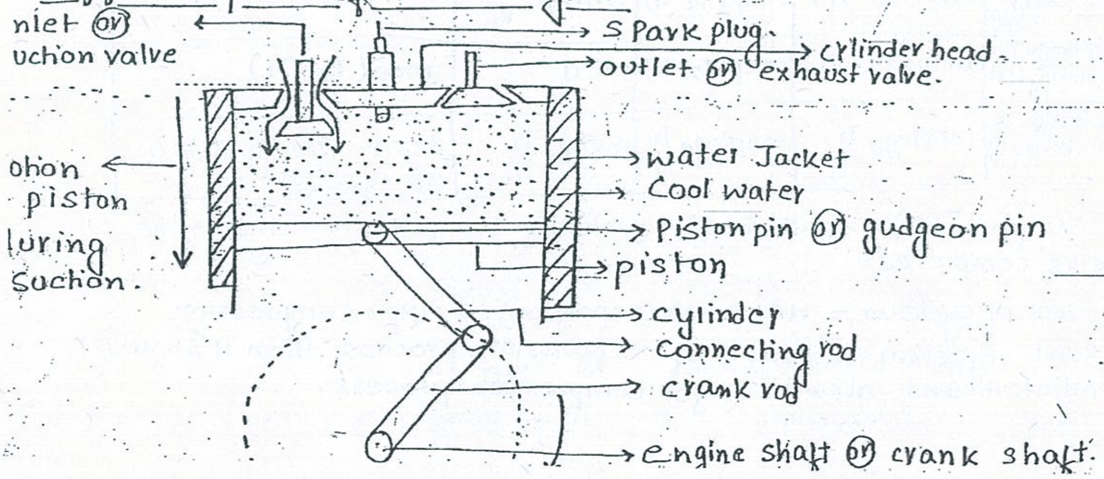
External combustion engine :-

An external combustion engine is the engine in which the combustion take place on the outside of the engine. exceptig the expanssion process, the rest of the operation are carried out outside the engine.

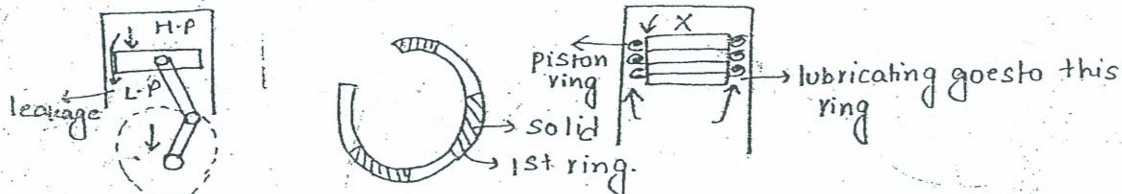
cheaper solid fuels can also be used for external combustion engines.

when a cycle is taken into account by considering only the expanssion process, then the efficiency of the external combustion engine is higher than that of the internal combustion engines.

Different parts of an I.C. engine :-

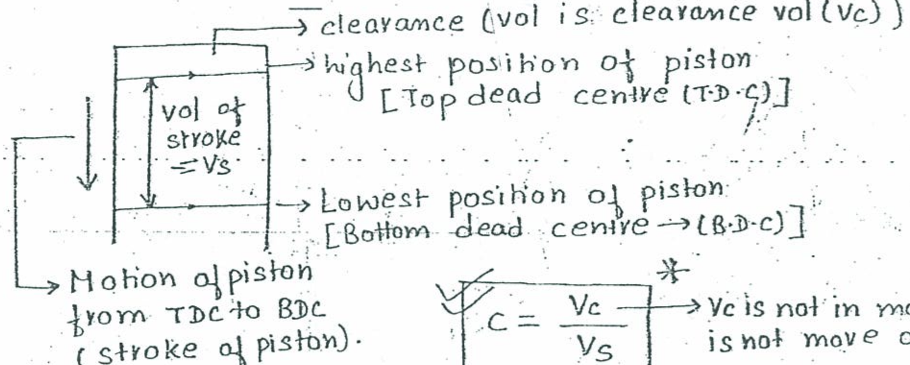


Leakage is more → engine starting create problem. (3)



· compression ratio is same for all cycle.

→ Thermodynamics of I.C. engine :-



$$C = \frac{V_c}{V_s}$$ * → V_c is not in motion piston is not move on the top.

· clearance is provide in the cylinder because the pressure is still inside the cylinder.

· In case of heat addition the diesel engine, the volume will change.

Clearance ratio :-

The ratio of the clearance volume to stroke volume is defined as the clearance ratio of the engine.

It is given by,

$$C = \frac{V_c}{V_s}$$ *

Volume ratio :-

The ratio of longer volume to lesser volume during any process inside an I.C engine is defined as the volume ratio of that Process. the volume ratio during compression is known as compression ratio. compression ratio remains same for all the cycles of I.C engines.

The volume ratio during the expanssion Process is known as expanssion ratio & is different for different cycle of I.C engine.

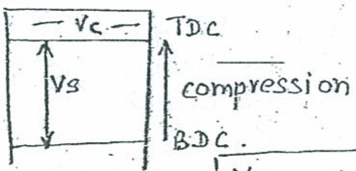
⇒ The compression ratio is :-

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

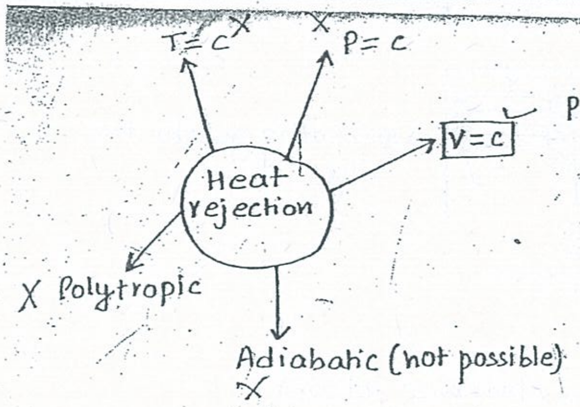
$V_2 = V_c$ — 2.

$$r = \frac{V_c + V_s}{V_c}$$

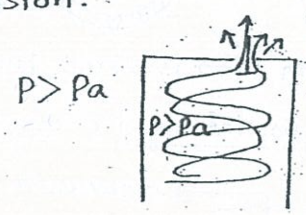
$V_1 = (V_c + V_s)$ — 1.

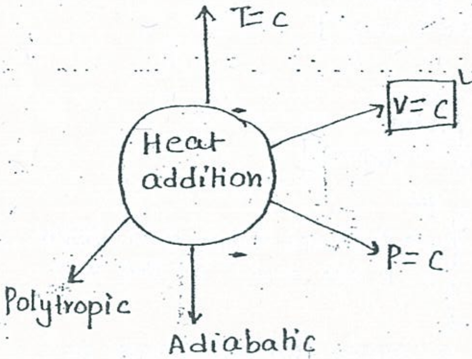


(or), $r = 1 + \frac{V_s}{V_c} \Rightarrow \frac{V_s}{V_c} = (r-1)$ **

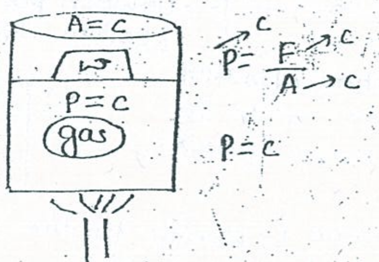


Piston is change its direction inside the cylinder during expanssion is over, then piston is at BDC piston.

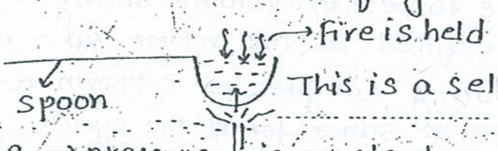




Same as for heat rejection.



- For any fuel is to be burn then it is should be at Flash point temp.
- Fire point temp – minimum temp so fuel to be burn at the burner.
- spark plug is behaves like a burner.
- Fire point temp to Flash point temp then spark plug is takes place continously.
- Compression ratio in petrol engine is less (6 to 8). in comparision to that of diesel engine (and it is 15 to 16).
- No need of Burner in diesel engine so it is not have any spark plug required.
- Temp is very high in diesel engine so that the fuel is automatically burned & this process is called a self ignition temp.



— Diesel cycle → pressure is constant
— Nicolus August otto → Gives at a constant volume

Due to engine limitations, heat rejection will take place at constant volume only for all the cycle of I-C engine.

Hence, the following operation are the same for all the ideal cycle of I-C engine.

— Isentropic exapansion.
— Isentropic compression.
— Heat rejection at const volume.

~~It is thus clear that~~ different cycle exist for I-C engines only due to different type of heat addition.

when heat addition takes place at const volume, the cycle is known as the constant volume cycle or the otto cycle.

when heat addition takes place at const pr. the cycle is known as the "const pr" cycle (or) the "diesel cycle"

In other cycle the heat addition takes place first at const volume & then at const pressure, such a cycle is known as Dual combustion cycle (or) semi-diesel cycle.

For IC engines heat rejection can take place at constant volume only for all the cycle.

Hence, the following operations are common for all the ideal cycles for IC engines:-

I. Isentropic expansion

II. Heat rejection at const volume.

III. Isentropic compression

It is thus clear that it is only the heat addition that will be different for different ideal cycle for IC engines.

- when heat addition takes place at constant volume the cycle is known as the constant volume cycle (or) otto cycle.
- when heat addition takes place at constant pressure the cycle is known as a constant pressure cycle (or) Diesel cycle.
- In another cycle heat addition takes place 1st at const volume & then at constant pressure such a cycle is known as the dual combustion cycle or the semi diesel cycle.

The const volume cycle or the otto cycle :-

1. The adiabatic compression process (1-2) →
   - volume ↓, Pressure ↑, S = const, Tempt ↑
2. The constant volume heat addition (2-3) →
   - volume = const, Pressure ↑, temp ↑, S ↑

   charles law,

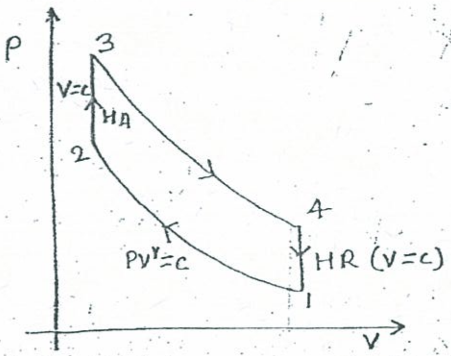
   $$\frac{P_2}{P_1} = \frac{T_2}{T_1} \quad \left\{ \begin{array}{l} \text{when} \\ \text{volume is const} \end{array} \right.$$

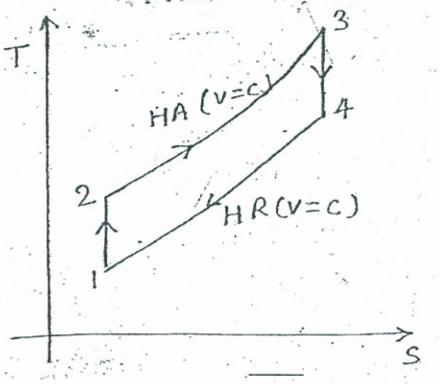
   entropy :-

   $$ds = c_v m dT$$

   $$ds = mc_v \log_e \frac{T_2}{T_1}$$

   $$+(S_2 - S_1) = mc_v \log_e \frac{T_2}{T_1}$$
3. The adiabatic expansion process (3-4) →
   - volume ↑, Pressure ↓, Tempt ↓, S = const
4. The heat rejection at constant volume (4-1) →
   - volume = const, Pressure ↓, Temp ↓, S ↓





Efficiency of the cycle :-

$$\eta_v = \frac{WD}{HA} = \frac{HA - HR}{HA} = 1 - \frac{HR}{HA}$$

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

$$HR = -dQ = -(T_1 - T_4) = (T_4 - T_1)$$

$\frac{V_1}{V_2} = r$, the compression ratio.

The expansion ratio $\frac{V_4}{V_3} = \frac{V_1}{V_2} = r$, only for this cycle.

$$\Rightarrow \frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1} \quad \text{—(b)}$$

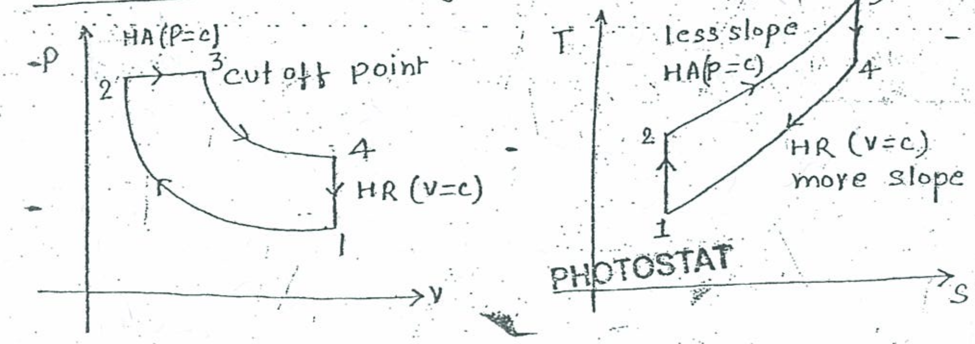
$$\Rightarrow \frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1} \quad \text{— (c)}$$

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

$$\left(\frac{1}{r}\right)^{\gamma-1} = \frac{T_4}{T_3} = \frac{T_1}{T_2} = \frac{T_4 - T_1}{T_3 - T_2} \quad \text{— (d)}$$

$$\therefore \eta_v = 1 - \left(\frac{1}{r}\right)^{\gamma-1} \quad \text{— *}$$

The constant Pressure cycle or the diesel cycle :-



Let $\frac{V_1}{V_2} = r$, the compression ratio

$\frac{V_3}{V_2} = \rho$ (the cut off ratio)

The expansion ratio is $\frac{V_4}{V_3} = \frac{V_1}{V_2} \times \frac{V_2}{V_3} = \frac{r}{\rho}$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \quad \left\{ T_2 = T_1 \times r^{\gamma-1} \quad \text{— (1)} \right.$$

$$\frac{T_3}{T_2} = \frac{V_3}{V_2} \quad \left\{ T_3 = T_1 \times r^{\gamma-1} \rho \quad \text{— (2)} \right.$$

$(\because P = c)$

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

$$\therefore T_4 = T_1 \times r^{\gamma-1} \rho \times \left(\frac{\rho}{r}\right)^{\gamma-1}$$

$$\therefore T_4 = T_1 \rho^{\gamma} \quad \text{— (3)}$$

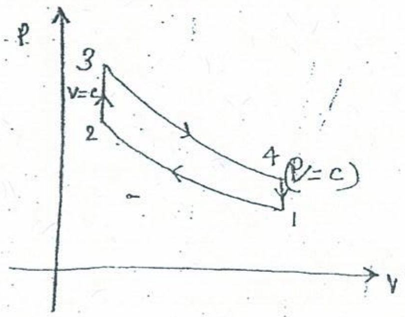
$$\eta_p = 1 - \frac{HR}{HA} = \frac{1 - c_v m(T_4 - T_1)}{m c_p (T_3 - T_2)}$$

or, $\eta_p = 1 - \frac{1}{\gamma}\left[\frac{T_1\rho^{\gamma} - T_1}{T_1 r^{\gamma-1}\rho - T_1 r^{\gamma-1}}\right]$

$$\boxed{\eta_p = 1 - \left(\frac{1}{r}\right)^{\gamma-1} \frac{\rho^{\gamma}-1}{\gamma(\rho-1)}}$$ effective efficiency.

$$\boxed{\eta_p = 1 - \left(\frac{1}{r}\right)^{\gamma-1} \frac{\rho^{\gamma}-1}{\gamma(\rho-1)}}$$

Q1. the η_{otto} is 54% the pressure at the start of compression is 1bar & the temp is 15°c. the maximum pressure of the cycle is 75 bar. determine the heat added, heat rejected, & the W.D per kg of air. also find the mean effective pressure of the cycle. take cv = .71 & R = 0.29 KJ/kg K.



given :-

$\eta_{otto} = 54\%$

$P_1 = 1bar$

$T_1 = 15°c$

$P_3 = 75 bar$

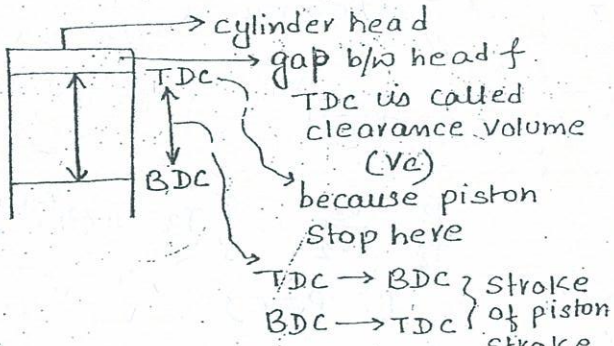
HA = ?

HR = ?

WD per kg of air = ?

$C_v = .71$

$R = 0.29 KJ/kg K$



The volume travel by stroke length is called stroke volume (spewt volume)

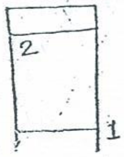
$c_p - c_v = 0.29$

$c_p - .71 = 0.29$

$c_p = 1 KJ/kgK$

$\gamma = \frac{c_p}{c_v}$

$= 1/.71 = 1.408$



$V_1 = (V_c + V_s)$

$V_2 = V_c$

$\eta_{otto} = 0.54$

$\Rightarrow 1 - \left(\frac{1}{r}\right)^{\gamma - 1} = 0.54$

$\therefore \frac{1}{r} = (1 - 0.54)^{\frac{1}{1.408 - 1}}$

$\therefore r = 6.707 = \frac{V_1}{V_2}$

$\frac{V_c + V_s}{V_c} = 6.707$

$V_c + V_s = 6.707 V_c$

$V_s = 6.707 V_c - V_c$

$V_s = 5.707 V_c = 5.7 V_2$

$V_1 = V_c + V_s = \frac{V_s}{5.707} + V_s$

$\therefore V_1 = \frac{6.7}{5.7} V_s$

$P_1 = 1$ bar

$T_1 = 15°C = 288K$

$P_3 = P_{max} = 75$ bar

process (2-3) const volume :-

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

$\therefore T_3 = T_2 \left(\frac{P_3}{P_2}\right)$

$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$ (Adiabatic process)

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

$P_2 = 1 \times (6.7)^{1.408}$ bar

$P_2 = 14.58$ bar.

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

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

$= 288 (6.7)^{.408}$

$T_2 = 626.76K$

$T_3 = T_2 \left(\frac{P_3}{P_2}\right)$

$= 626.76 \times \left(\frac{75}{14.55}\right)$

$T_3 = 3225.25K$

$\approx 3230.9K$

$HA = mc_v(T_3 - T_2)$

$= \cdot 71(3230.9 - 626.8)$

$HA = 1848.911 \text{ kJ/kg}$

$WD = \eta \times HA$

$= 0.54 \times 184.911$

$= 998.41 \text{ kJ/kg}$

$WD = HA - HR$

$HR = HA - WD$

$= 1848.911 - 998.41 \text{ kJ/kg}$

$= 850.501 \text{ kJ/kg}$

$W = P(V_2 - V_1)$ - diesel cycle

$W = P_m \times V_s$

$\therefore P_m = \frac{W}{V_s}$

$V_1 = \frac{RT_1}{P_1} = \frac{290 \times 288}{1 \times 10^5} \text{ m}^3/\text{kg} = 0.835 \text{ m}^3/\text{kg}$

$V_s = \frac{5.7}{6.7} V_1 = \frac{5.7}{6.7} \times 0.835 \text{ m}^3 = 0.71 \text{ m}^3$

$P_m = \frac{WD/\text{kg}}{V_s/\text{kg}} = \frac{998.4 \times 1000 \text{ N/m}^2}{0.71}$

$= 1406197.18$

$= 14.06 \times 10^5 \text{ N/m}^2$

$P_m = 14 \text{ bar}$

Q. when a workdone of a diesel cycle is increased the efficiency of the cycle will

a) increases b) remain same c) decreases d) any thing is possible

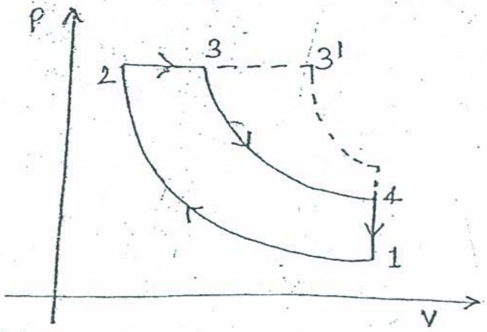
$\eta_{diesel} = 1 - \left(\frac{1}{r}\right)^{\gamma-1} \frac{(\rho^\gamma - 1)}{\gamma(\rho - 1)}$

$\eta_p = \frac{WD}{HA} = \frac{r^{\gamma-1}(\rho-1) - (\rho^\gamma - 1)}{r^{\gamma-1} \times \gamma(\rho-1)} = \frac{5-3}{5}$ if ↑

then denominator increases more ↑↑↑

If the work done is increased, (numerator), then denominator even increased more as there is no -ve term in the denominator. hence the η will only decreases.

The compression ratio of a diesel engine is 14 determine the % change in the η of the cycle when the cut off changes from 5% to 15% of the stroke.



given :-

$r = 14 = \frac{V_1}{V_2}$

$\frac{V_1}{V_2} = \frac{V_c + V_s}{V_c} = 14$

$V_s = 13V_c$

$V_s = 13V_2$

$\frac{5}{100} V_s = V_3 - V_2$

or,

$V_3 = 0.05(13V_2) + V_2 = 1.65V_2$

$\rho = \frac{V_3}{V_2} = 1.65$

$\eta_1 = 1 - \left(\frac{1}{14}\right)^{1.4-1} \frac{(1.65-1)^{1.4}}{1.4(1.65-1)} = 0.6115$

when cutt off takes place at 15% of stroke

$\frac{15}{100} V_s = V_3' - V_2$

$V_3' = .15(13V_2) + V_2$

$V_3' = 2.95V_2$

$\rho' = \frac{V_3'}{2} = 2.95$

$\eta_2 = 1 - \left(\frac{1}{14}\right)^{1.4-1} \times \frac{(2.95^{1.4} - 1)}{1.4(2.95-1)} = 0.5478$

$\% \text{ diff} = \frac{0.6115 - 0.5478}{0.6115} \times 100$

$= 10.3\%$

↑W = ↑F × S load increases WD increases η↓.

Diesel → load ince, WD↑ → cut off ↑.

Q. the WD of a diesel cycle is 1500 Joules the pressure at the start of compression is 1 bar. the clearance ratio is 10% & the cut off take place at 5% of the stroke determine the P_{mean}, the P_{max} & the efficiency of the cycle. also determine the cylinder dimensions if the stroke length is 1.5 times the cylinder bore.

→ Given:-

WD = 1500 Joules

$P_1 = 1$ bar

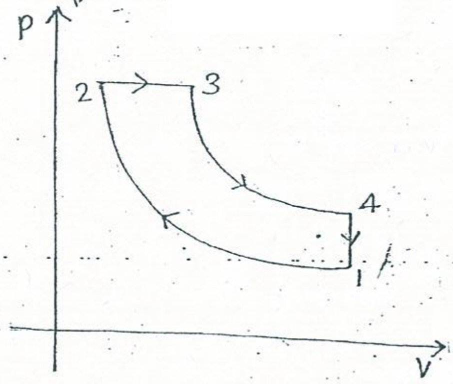
$R_c = 10\%$

$f = 5\%$

$P_{mean} = ?$

$P_{max} = ?$

$\eta = ?$



$P_1 = 1$ bar

$$c = \frac{V_c}{V_s} = 0.1$$

$\therefore V_c = 0.1 V_s = V_2$

$V_1 = V_c + V_s = 0.1V_s + V_s = 1.1 V_s = V_4$

$$r = \frac{V_1}{V_2} = \frac{1.1 V_s}{0.1 V_s} = 11$$

$$\frac{5}{100} V_s = V_3 - V_2$$

or,

$0.05 V_s + 0.1 V_s = V_3$

$\therefore V_3 = 0.15 V_s$

$$f = \frac{V_3}{V_2} = \frac{0.15 V_s}{0.1 V_s} = 1.5$$

WD/cycle = 1500 J

or, $W_1 + W_2 + W_3 = 1500 J$ — (1)

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

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

$= 1 \times 11^{1.4}$ bar

$= 28.7$ bar $= P_2 = P_3$

$P_3 V_3^{\gamma} = P_4 V_4^{\gamma}$

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

$= 28.7 \left(\frac{0.15 V_s}{1.10 V_s}\right)^{1.4}$ bar

$P_4 = 1.76$ bar.

$W_1 = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$

$= \left(\frac{1 \times 1.1 V_s - 28.7 \times 0.1 V_s}{1.4 - 1}\right) \times 10^5$ J

$= -4.425 \times 10^5 V_s$ J

$W_2 = P(V_3 - V_2)$

$= 28.7 \times 10^5 (0.15 V_s - 0.1 V_s)$

$= 1.43 \times 10^5 V_s$ J

$W_3 = \frac{P_3 V_3 - P_4 V_4}{\gamma - 1} = \left(\frac{28.7 \times 0.15 V_s - 1.76 \times 1.1 V_s}{1.4 - 1}\right) \times 10^5$ J

$= 5.92 \times 10^5 V_s$ J.

From eq (1)

$W_1 + W_2 + W_3 = 1500$ J

$V_s(-4.425 \times 10^5 + 1.43 \times 10^5 + 5.92 \times 10^5) = 1500$ J

$V_s = 5.128205 \times 10^{-3}$ m^3

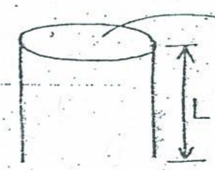
$W = P_m \times V_s$

$\frac{1500}{5.128205 \times 10^{-3}} = P_m$

$P_{mean} = 292511.7$

$= 2.92 \times 10^5$ bar

$A = \frac{\pi}{4} d^2$



$V_s = \frac{\pi}{4} d^2 \times L = 5.1 \times 10^{-3}$ m3

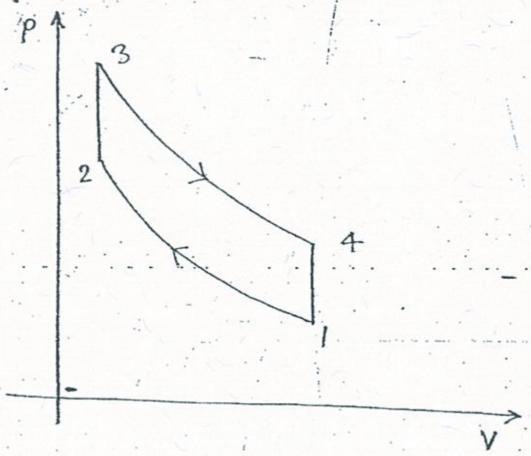
or, $\frac{\pi}{4} \times d^2 \times 1.5 d = 5.1 \times 10^{-3}$ m^3

$d = 0.163$ m

$= 16.3$ cm

$L = 1.5 d = 24.45$ cm

Q. In an otto cycle air at 17°c and 1 bar is compressed adiabatically untill the pressure is 15 bar. heat is added at constant volume untill the pressure rises to 40 bar. calculate the air-standard efficiency, the compression ratio and the mean effective pressure for the cycle. Assume $C_v = 0.717$ KJ/kg K & $R = 8.314$ KJ/kmol K.



$T_1 = 17°c = ~~287K~~\ 290K$

$P_1 = 1$ bar

$P_2 = 15$ bar

$P_3 = 40$ bar

$\eta = ?$

$C_v = 0.717$ KJ/kg K

$R = 8.314$ KJ/kmol K.

Process - 1-2

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

$$T_2 = 290\,(15)^{\frac{.4}{1.4}}$$

$$T_2 = 629.16\ K$$

or,

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

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

$$\frac{V_1}{V_2} = (15)^{\frac{1}{1.4}}$$

$$\frac{V_1}{V_2} = 6.91$$

$$\eta_{otto} = 1 - \left(\frac{1}{r}\right)^{\gamma-1}$$

$$= 1 - \left(\frac{1}{6.91}\right)^{1.4-1}$$

$$= 0.538$$

$$= 53.8\%$$

Considering Process 2-3

$$\frac{T_3}{T_2} = \frac{P_3}{P_2} \quad [V = C]$$

$$T_3 = T_2 \times \left(\frac{P_3}{P_2}\right)$$

$$= 629.5 \times \left(\frac{40}{15}\right)$$

$$T_3 = 1678.66\,K$$

Heat supplied $= C_v(T_3 - T_2)$

$$= 0.717 \times (1678.6 - 629.5)$$

$$= 752.20\ kJ/kg$$

work done $= \eta \times$ Heat supplied

$$= .538 \times 752.3$$

$$= 404.68\ kJ/kg$$

$WD = Pr_{mean} \times V_s$

V_s = Swept volume

$V_1 = V_c + V_s$

$V_1 = V_2 + V_s$

$6.91V_2 = V_2 + V_s$

$6.91V_2 - V_2 = V_s$

$5.91V_2 = V_s$