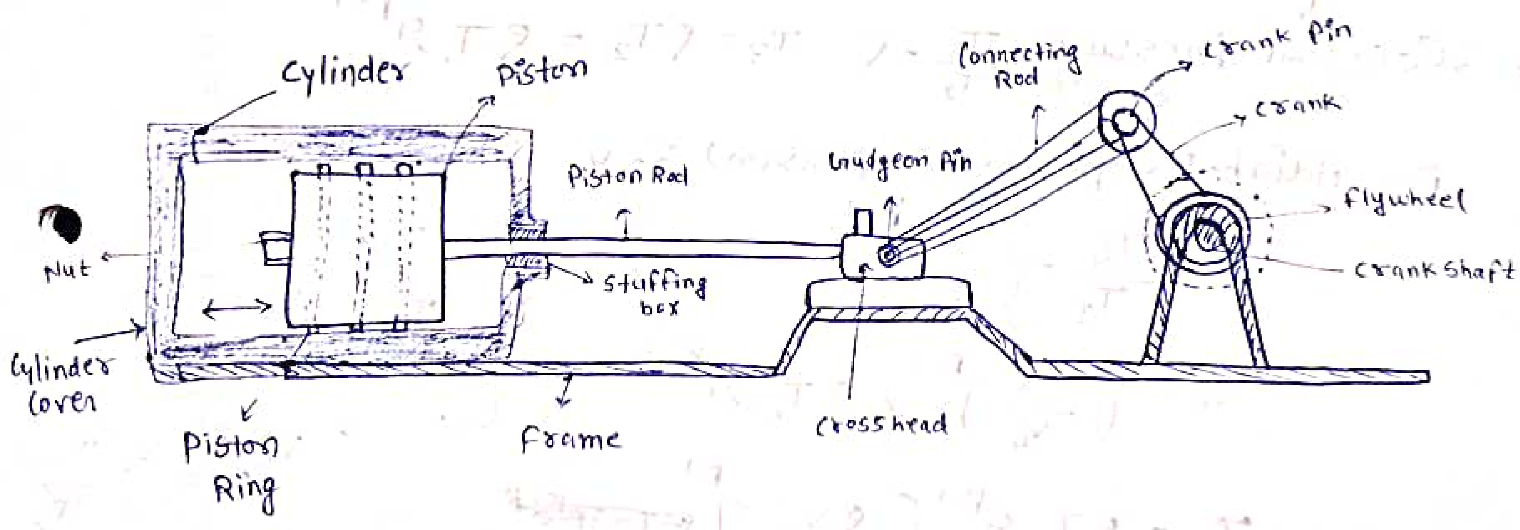
UNIT - 5

RECIPROCATING MACHINES

Reciprocating M/C like heat engine are used for converting heat energy into mechanical energy. Heat obtain from combustion of fuels is used to heat the working substance. In case of internal combustion engine, fuel is burned directly inside the engine. The combustion gases reach high temp & pressure. The heat energy of the combustion gases is utilized in moving the reciprocating parts of the engine like the piston.

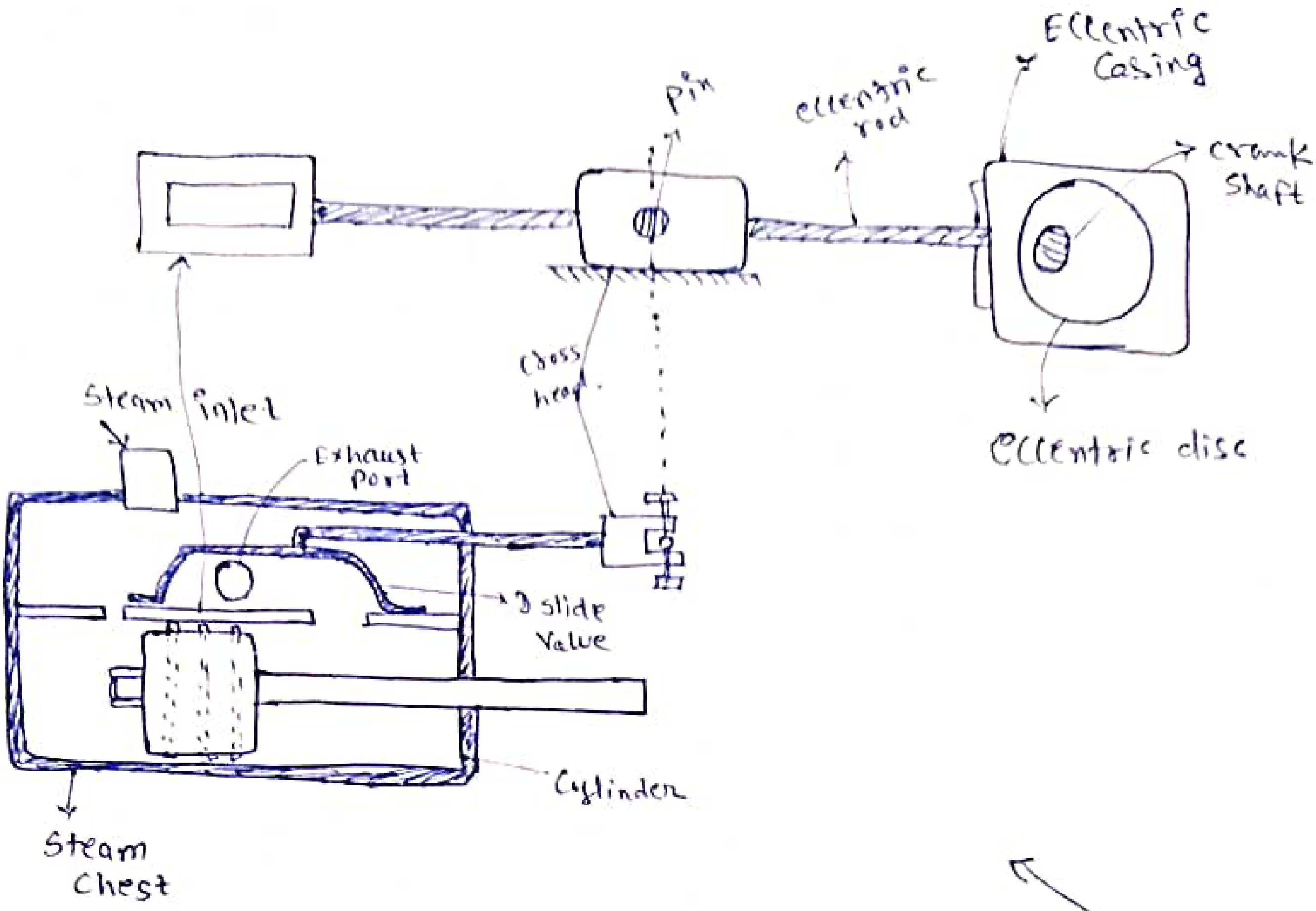
* Steam Engine :-

A steam engine uses steam as a working substance. In steam engine at high pressure and temp is expanded to move the piston. The reciprocating motion of the piston is converted into rotary motion by a slider crank mechanism. Steam engine was invented in 1712. James Watt developed it in is present form in 1770.



* Frame made with cast Iron
* cylinder made with cast Iron
* Piston & Piston Ring also cast Iron.
* Piston Ring prevent leakage of steam.
* Piston Rod mild steel
* Stuffing box contain tightly packing which prevent leakage

* Lowest temp in steam engine 40°C



Valve Gear Mechanism For Steam Engine

Classification of steam Engine :→

① Axis of Cylinder :→ ⓐ Vertical ⓑ Horizontal ⓒ Inclined

② Direction of steam :→ ⓐ Single acting ⓑ Double acting

③ Number of Cylinder :- ⓐ Single ⓑ Compound.

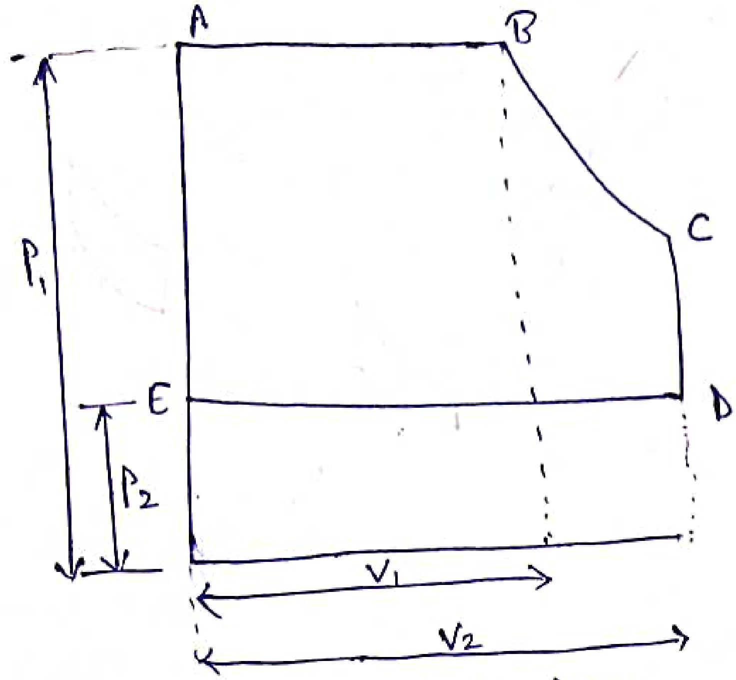
④ Exhaust of steam :- ⓐ Condensing ⓑ Non Condensing

⑤ Application :- ⓐ Stationary | ⓑ Locomotive | ⓒ Marine

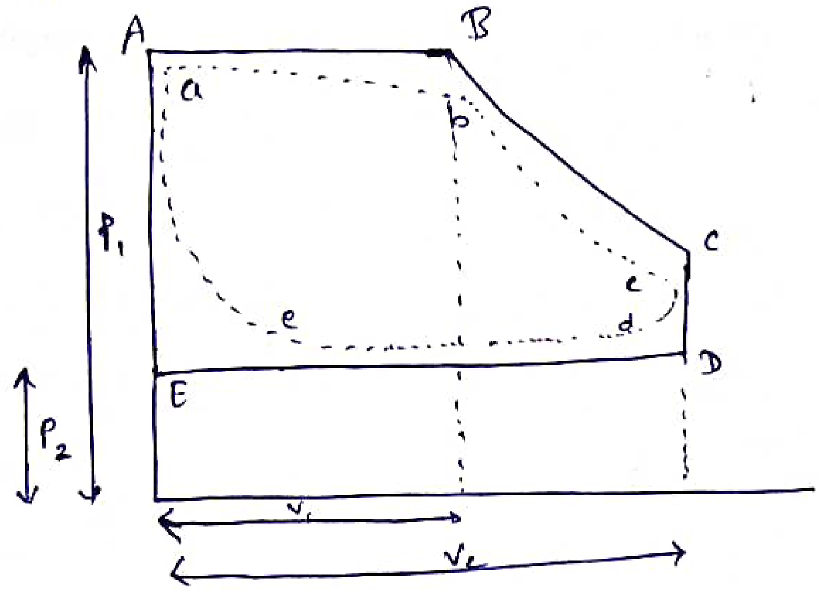
ⓐ Stationary	ⓑ Locomotive	ⓒ Marine
eg:- used to drive pump, generator etc	eg:- used is Railway	eg.- used in ships

⑥ Speed :- ⓐ Low speed | ⓑ Medium | ⓒ High speed

ⓐ Low speed	ⓑ Medium	ⓒ High speed
$<$100 RPM	100-300 RPM	$>$300 RPM



Hypothetical Indicator Diag.

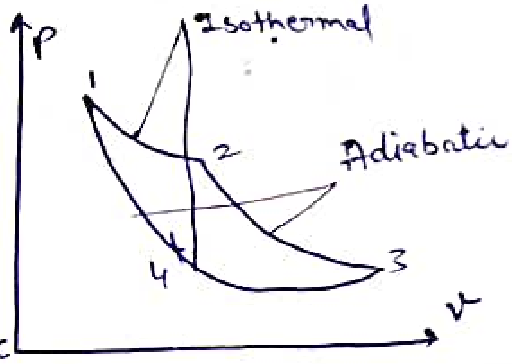


Actual Indicator Diag.

Thermodynamic Cycle :→ Heat engine convert heat energy into mechanical energy. Heat engine like steam engine or I.C engine work in a cyclic manner. A cycle is a sequence of steps or process which occure repeatedly, in a fixed order. For a cycle to be completely successfully it is necessary that all of its processes must get completed in proper time duration and in the proper order.

A thermodynamic cycle is a sequence of thermodynamic process like compression (Isothermal, adiabatic) and expansion (Isothermal, adiabatic) heat addition constant pressure and heat addition at constant volume etc.

* Carnot Cycle :→ In 1824 Sadi Carnot discovered that a thermodynamic cycle working on reversible processes has the highest efficiency. He proposed an ideal cycle. This cycle having maximum possible efficiency but cannot applied in actual practice. cycle complete in four processes. Two isothermal and two isentropic or adiabatic



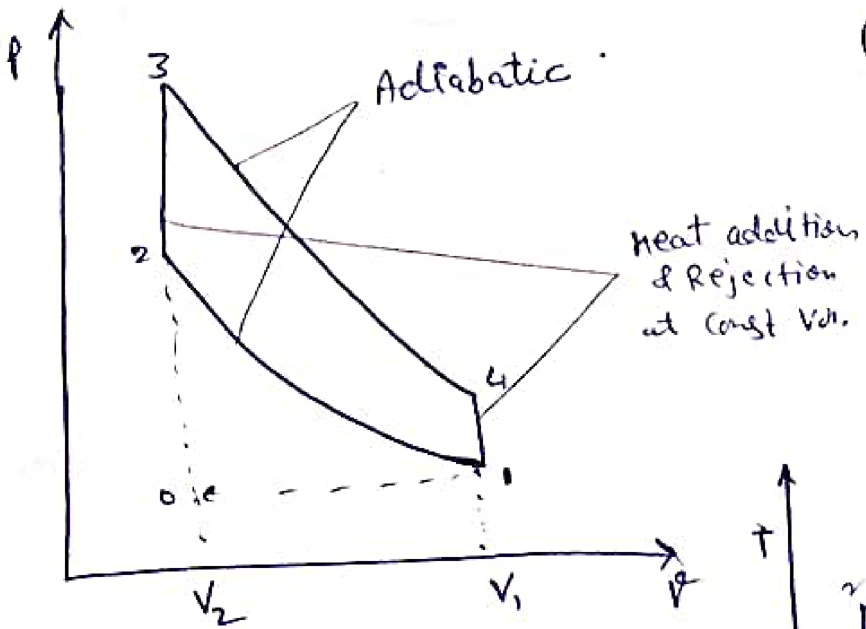
(1) Reversible Isothermal Expansion
(2) Reversible Adiabatic Expansion
(3) Reversible Isothermal Compression
(4) Reversible Adiabatic Compression

$$\eta = \frac{T_1 - T_2}{T_1}$$

Lowest temp in steam engine 40°C

Lowest temp in I.C engine 400°C & Highes temp 2300°C

Otto Cycle :→

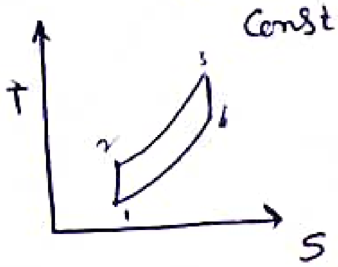


(a) Adiabatic Compression of working substance

(b) Heat Addition at const Volume

(c) Adiabatic expansion

(d) Heat Rejection at Const. Vol.



$$\eta = \frac{\text{Heat Supply} - \text{Heat Reject}}{\text{Heat Supply}}$$

$= \cancel{mc_v(T_3 - T_1)}$ $= 1 - \frac{\text{heat reject}}{\text{Heat Supply}}$

$Q = mc_v dt$

$$= 1 - \frac{mc_v(T_4 - T_1)}{mc_v(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2} \quad \text{---(i)}$$

for Adiabatic Process 1-2, and 3-4

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \quad \text{and} \quad \frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1}$$

$V_1 = V_4 \quad , V_2 = V_3$

$$\boxed{\frac{T_2}{T_1} = \frac{T_3}{T_4} = r^{\gamma-1}} \quad \text{---(ii)}.$$

γ - Ratio of specific Heat of Working Substance

r - Compression ratio

$$r = \frac{\text{Vol. before Compression}}{\text{Vol. After Compression}} = \frac{V_1}{V_2}$$

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} \Rightarrow \frac{T_4}{T_1} = \frac{T_3}{T_2} \rightarrow$$

-1 both side

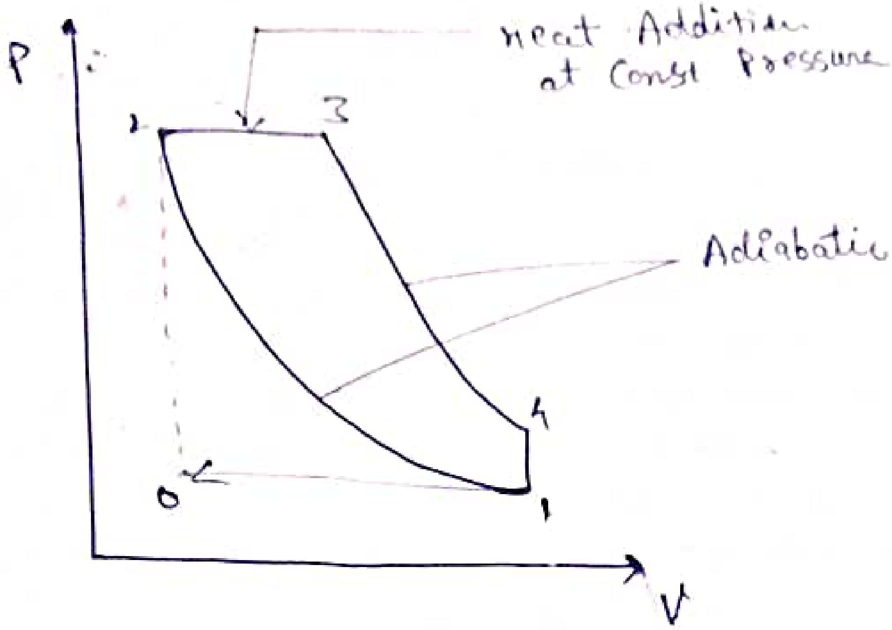
$$\frac{T_4}{T_1} - 1 = \frac{T_3}{T_2} - 1$$

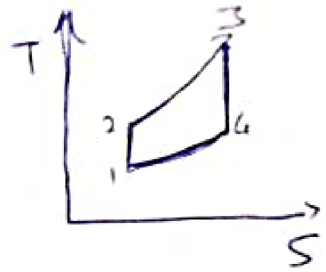
$$\frac{T_4 - T_1}{T_1} = \frac{T_3 - T_2}{T_2} \Rightarrow \frac{T_4 - T_1}{T_3 - T_2} = \frac{T_1}{T_2}$$

Put in (i).

$\eta = 1 - \frac{T_1}{T_2}$ then $\boxed{\eta = 1 - \left(\frac{1}{r}\right)^{\gamma-1}}$ Hence Proved

Diesel Cycle :→





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

$$= 1 - \frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)} = 1 - \frac{1(T_4 - T_1)}{\gamma(T_3 - T_2)} \quad (i)$$

Cut-off ratio $\rho = \frac{V_3}{V_2}$, $r = \frac{V_1}{V_2} = \frac{V_4}{V_2}$

$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$ for Adiabatic Compression or Isentropic $\underline{\underline{1\text{-}2}}$ $\quad \frac{T_2}{T_1} = r^{\gamma-1} \quad T_2 = T_1 r^{\gamma-1}$ (ii)

for Constant Pressure 2-3 $\quad \frac{T_3}{T_2} = \rho = \frac{V_3}{V_2}$

$\rho = \frac{\text{vol. after heat addition}}{\text{vol. before heat addition}}$

$PV = mRT$

$V \propto T$

$V_3 = T_3$

$V_2 = T_2$

$T_3 = T_2 \rho$

~~from~~ $T_3 = T_1 \rho r^{\gamma-1}$ from (ii).

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

$$\frac{T_4}{T_3} = \left[\rho \frac{V_2}{V_4}\right]^{\gamma-1} = \left(\frac{\rho}{r}\right)^{\gamma-1}$$

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

$$= T_1 \rho r^{\gamma-1} \frac{\rho^{\gamma-1}}{r^{\gamma-1}}$$

$$T_4 = T_1 \rho^{\gamma}$$

From ①.

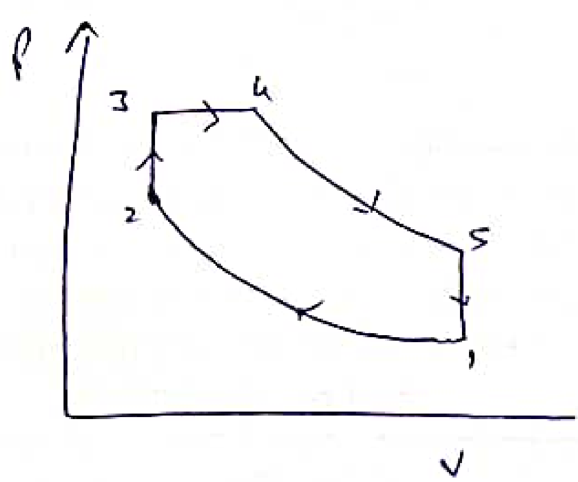
$$\eta = 1 - \frac{1}{\gamma} \frac{[T_1 \rho^{\gamma} - T_1]}{[T_2 \rho - T_2]}$$

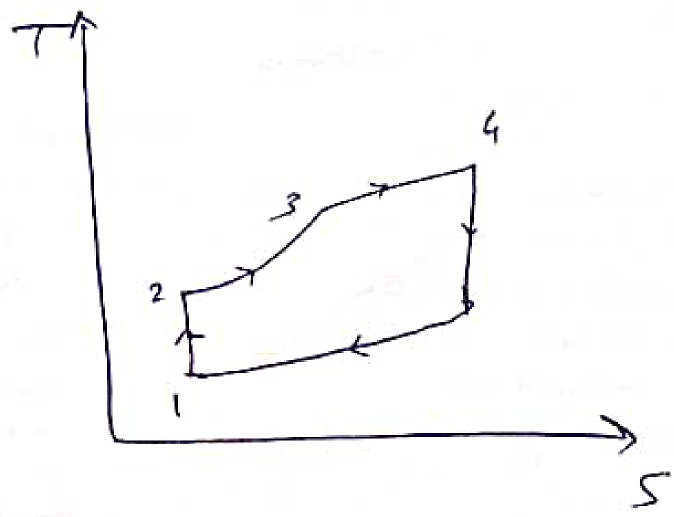
$$\eta = 1 - \frac{1}{\gamma} \frac{[\rho^{\gamma} - 1]}{\rho - 1} \frac{T_1}{T_2}$$

$$\cancel{\eta = 1 - \frac{1}{\gamma} \left[\frac{\rho^{\gamma}}{\ } - 1 \right.}$$

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

Dual cycle



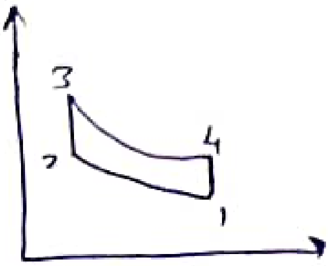


A four-stroke engine has a stroke of 90mm and bore of 100mm. The clearance volume is 70cc. The engine works on otto cycle. Determine theoritical efficiency of the engine.

Sol :→ $d = 100\,mm = 10\,cm$

Swept Vol. $\frac{\pi}{4} d^2 L$

$l = 90\,mm = 9\,cm$.



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

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

$$= \frac{\pi}{4} \times 10^2 \times 9$$

$$V_s = 706.89\,cm^3$$

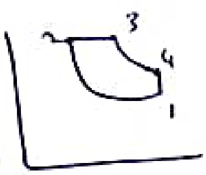
$$r = \frac{70 + 706.86}{70} = 11.1$$

$$\eta = 1 - \left(\frac{1}{(11.1)}\right)^{1.4-1} = 61.82\,\%$$

Q) A diesel engine has a compression ratio of 20 and cut off takes place 5% of the stroke. Find the air standard efficiency. Assume $\gamma = 1.4$

Sol

$$r = \frac{V_1}{V_2} \qquad V_1 = 20\,V_2 \qquad \rho = \frac{V_3}{V_2}$$



$$V_s = V_1 - V_2$$

$$V_s = 20V_2 - V_2 = 19\,V_2$$

$$V_3 =$$

$$0.05\,V_s = \frac{V_3}{V_2} \quad , \quad V_3 =$$

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

(3) process III – IV Const. pressure

$$T_3 \propto V_3 \quad , \quad T_4 \propto V_4$$

$$\frac{T_4}{T_3} = \frac{V_4}{V_3} \Rightarrow T_4 = T_3 \frac{V_4}{V_3} = \rho T_3$$

$$\boxed{T_4 = \rho\, r_p\, T_1\, r^{\gamma-1}} \text{ —— (iv).}$$

(4) process IV – V adiabatic expansion.

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

$$T_5 = T_4 \left(\frac{V_4}{V_5}\right)^{\gamma-1} = T_4 \left(\frac{V_4}{V_3} \times \frac{V_3}{V_2} \times \frac{V_2}{V_1}\right)^{\gamma-1}$$

$$T_5 = T_4 \left(\rho \times 1 \times \frac{1}{r}\right)^{\gamma-1}$$

$$T_5 = T_4 \left(\frac{\rho}{r}\right)^{\gamma-1} = \rho\, r_p T_1 r^{\gamma-1} \left(\frac{\rho}{r}\right)^{\gamma-1}$$

$$\boxed{T_5 = T_1\, r_p\, \rho^{\gamma-1}} \text{ —— (v).}$$

from eq^n (ii) (iii) (iv) & (v) put in eq^n (i).

$$\eta_{Dual} = 1 - \frac{(\rho^{\gamma} r_p T_1 - T_1)}{(r_p T_1 r^{\gamma-1} - T_1 r^{\gamma-1}) + \gamma(\rho\, r_p T_1 r^{\gamma-1} - r_p T_1 r^{\gamma-1})}$$

$$\boxed{\eta_{Dual} = 1 - \left[\frac{(\rho^{\gamma} r_p - 1)}{(r_p - 1) + \gamma\, r_p (\rho - 1)}\right] \frac{1}{r^{\gamma-1}}}$$

when $r_p = 1$ then

$$\boxed{\eta_{Dual} = \eta_{Diesel}}$$

when $\rho = 1$

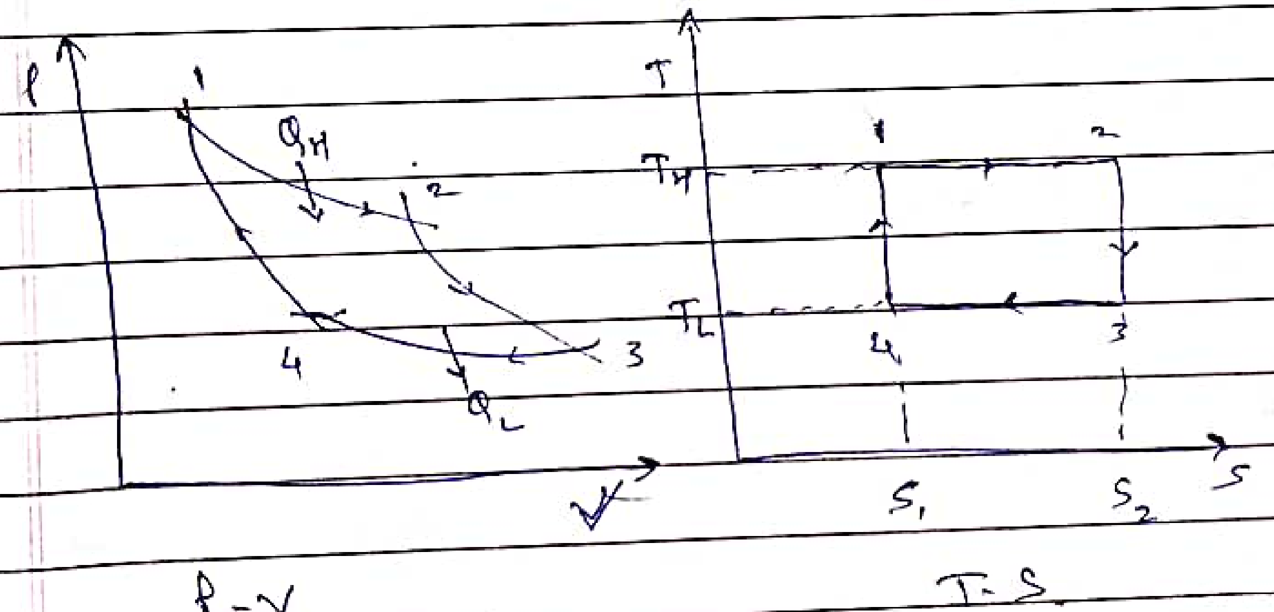
$$\boxed{\eta_{Dual} = \eta_{Otto}}$$

Carnot Cycle or Carnot Engine

It is a theoretically heat Engine, that Converts the maximum amount of energy into mechanical work. Carnot show that the efficiency of an engine depends on the difference b/w the highest and lowest temp reached during one cycle. The greater the difference, the greater the efficiency

It is also called reversible cycle

1. Reversible Isothermal Expansion.
2. Reversible Adiabatic Expansion (Isentropic)
3. Reversible Isothermal Compression and
4. Reversible Adiabatic Compression (Isentropic)



Assumption:- (1) Working Substance is perfect gas.
(2) Piston movement is perfect, No friction.
(3) The wall of the piston & cylinder Considered as perfectly insulated
(4) The heat supply and heat rejection are at Constant temp