~~* Expression for Efficiency of Dual~~

(3) Diesel cycle:- It is a theoritical cycle used for compression ignition or Diesel engines.

→ In this cycle, The heat addition process takes place at constant pressure.

→ Hence this cycle is also called as constant pressure cycle.

* The following processes take place in Diesel cycles.

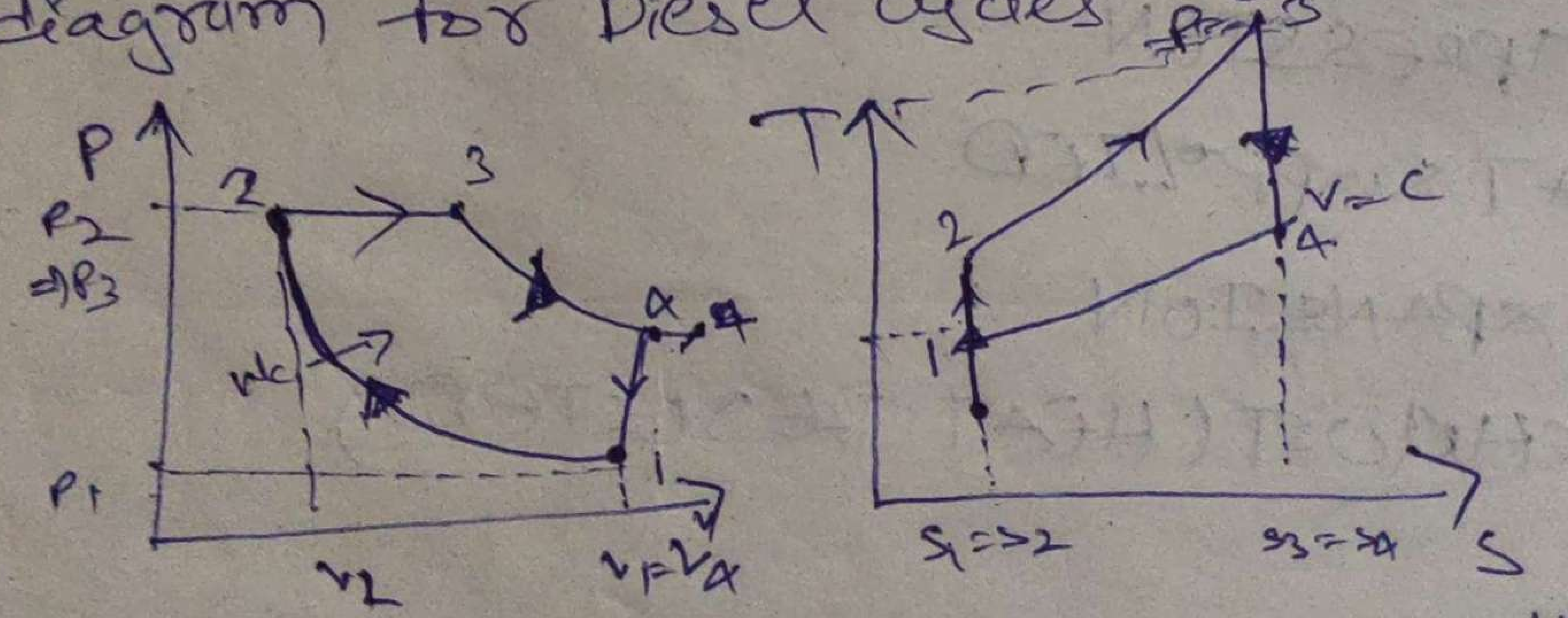
(i) Process 1-2 = Reversible adiabatic (isentropic) compression

(ii) Process 2-3 = constant pressure heat-addition

(iii) process 3-4 = Reversible adiabatic (isentropic) Expansion

(iv) process 4-1 = constant volume heat-rejection.

* P-V ⇒ pressure & volume T-S ⇒ Temperature & Entropic diagram for Diesel cycles




i) At point 1, only air is taken in to the cylinder of engine.

(ii) After Air has entered the engine it is compressed isentropically. $(s_1 = s_2)$

During the compression process volume of air decreases but there is an increase in pressure and temperature of the air

(iii) At point 2, the fuel injection Diesel starts fuel is added at constant pressure upto point 3 so process 2-3 is constant pressure. heat addition

(iv) from point 3 the expansion of Air takes place which pushes the piston & we get mechanical work output from the engine.

(v) Hence process 3-4 is called as Reversible adiabatic (or) isentropic expansion process.

(vi) After the expansion of Air & we get mechanical work, the heat which is there inside the engine must be rejected

(vii) Heat rejection starts at point 4 after expansion (it heat get rejected at constant volume from pt 4 to 1

In this way the Diesel cycle gets completed

Efficiency of Diesel cycle is given by :-

$$\eta_{Diesel} = 1 - \frac{1}{(r_c)^{\gamma-1}} \left[ \frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)} \right]$$

~~Where $r_c$ = compression ratio => volume before compression~~ volume

$\rho$ - row

where $r_c$ = compression ratio =>

$$\frac{\text{volume before compression}}{\text{volume after compression}}$$

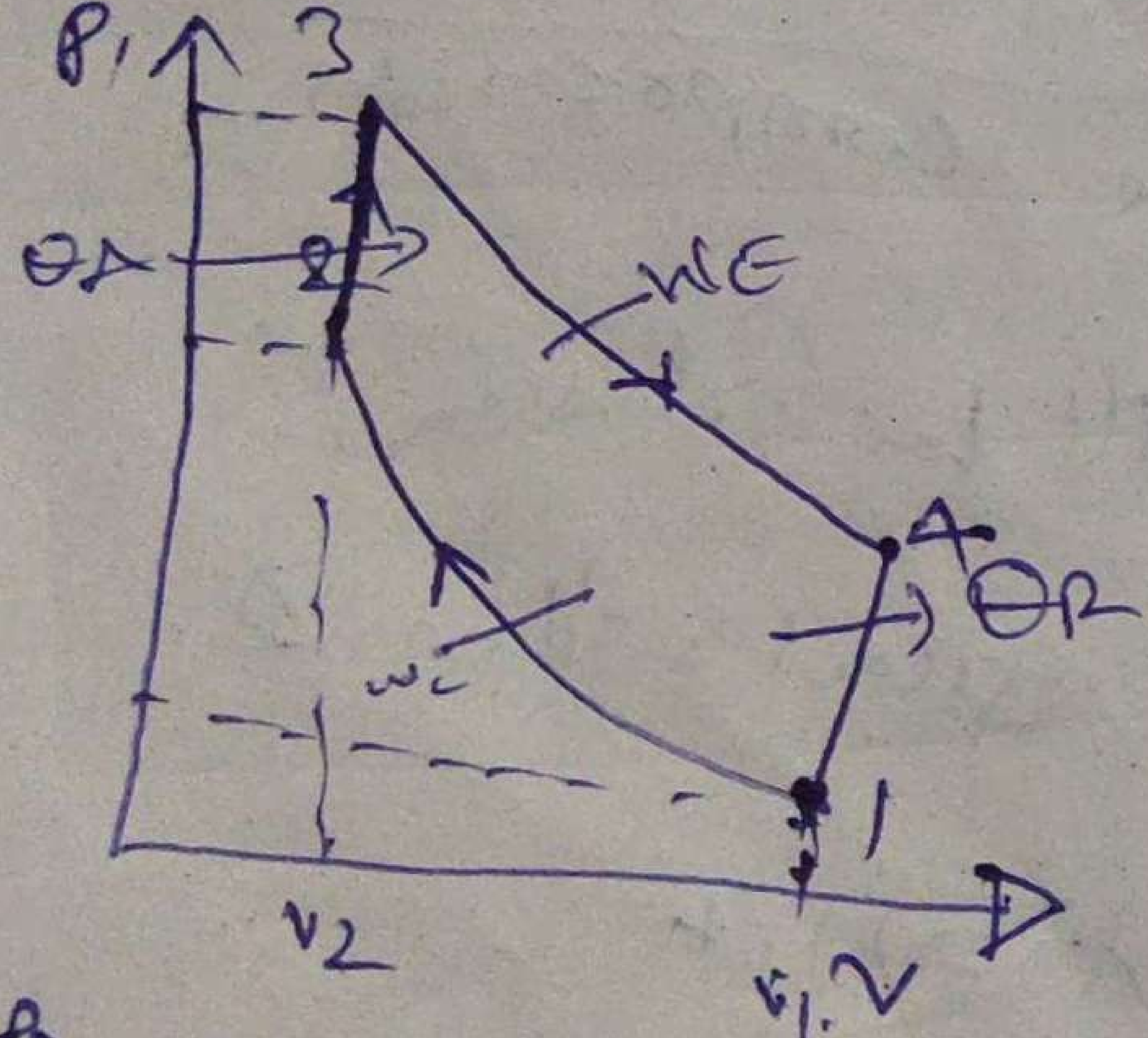
$r_c = \frac{V_1}{V_2}$ } It will be always greater than 1

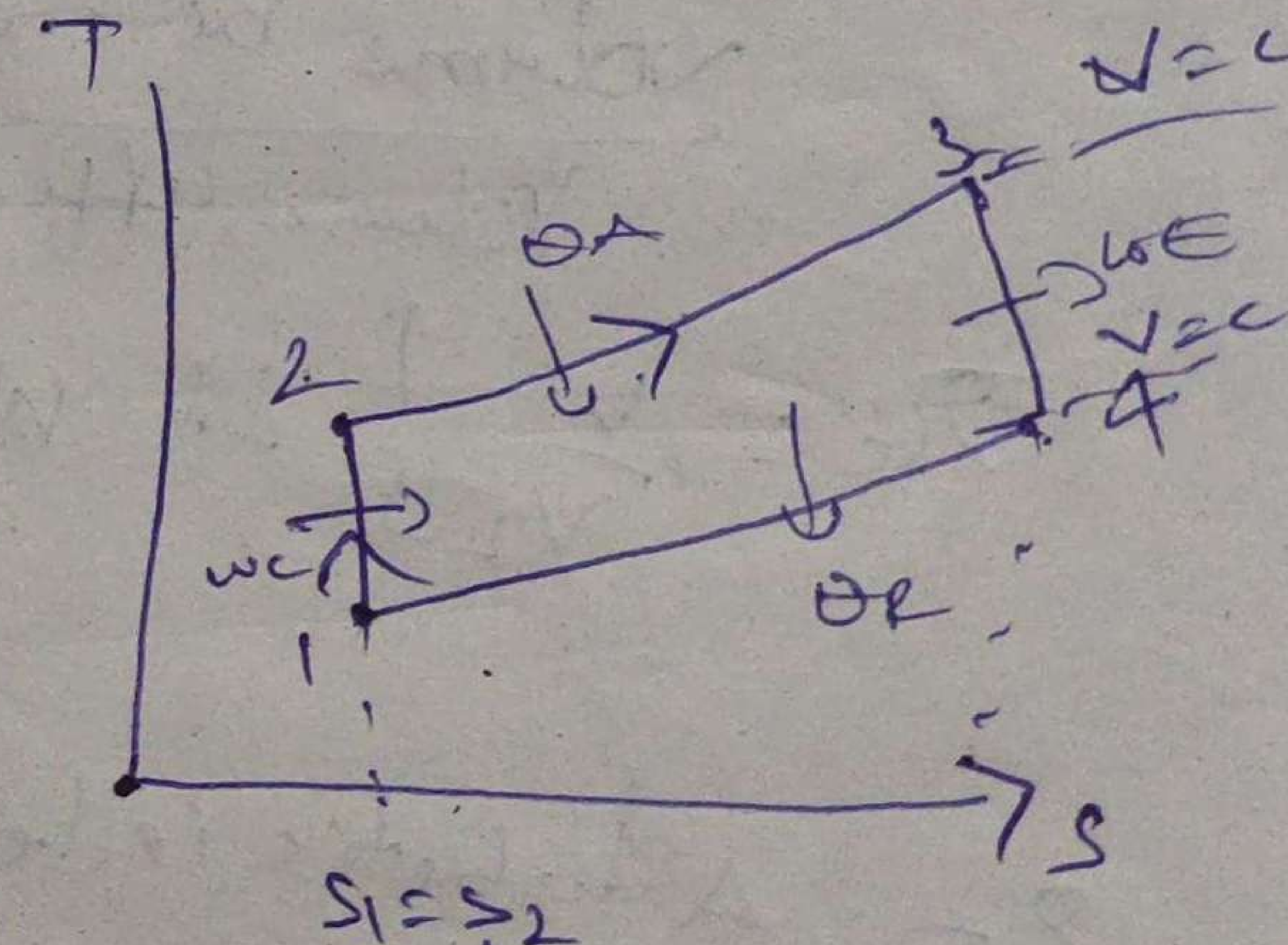
$\gamma$ = Adiabatic index => 1.4

$\rho$ = fuel-cutoff ratio => $\frac{\text{volume after cutoff}}{\text{volume before cutoff}}$

## * Expression for efficiency of Otto cycle *

→ Assuming mass of air as 1 kg ; m = 1 kg.




i) Process 1–2 = Reversible adiabatic (Isentropic) Compression

ii) process 2-3 = constant volume heat addition

iii) process 3-4 = Reversible adiabatic (Isentropic) expansion

iv) process 4-1 = constant volume heat rejection

→ Heat addition at constant volume is given by:- $q_A = mc_v (T_3 - T_2)$

$$[q_A = C_v (T_3 - T_2)] \text{ kJ/kg}$$

→ Heat rejection at constant volume is given by:-

$$[q_r = mc_v (T_4 - T_1)]$$

$$\therefore [q_r = c_v (T_4 - T_1)] \text{ kJ/kg}$$

→ ∴ Work developed (or) work done by the engine:-

$$\boxed{WD = q_A - q_r}$$

$$\therefore W.D = C_v (T_3 - T_2) - C_v (T_4 - T_1)$$

$$\therefore W.D = C_v [(T_3 - T_2) - (T_4 - T_1)]$$

→ Efficiency of otto cycle is given by:-

$$\left\{ \eta_{otto} = \frac{W.D}{q_A} \right\}$$

$$\eta_{otto} = \frac{\cancel{C_v} [(T_3 - T_2) - (T_4 - T_1)]}{\cancel{C_v} (T_3 - T_2)}$$

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

$$\left[\eta_{otto} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}\right] \longrightarrow (1)$$

→ For process 1-2 : Reversible adiabatic process

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

$\left[\because r_c = \frac{\text{cylinder volume}}{\text{clearance volume}}\right]$

$$\therefore \left[T_2 = T_1 (r_c)^{\gamma-1}\right] \longrightarrow (2)$$

→ For process ~~For process~~ 3-4 : Reversible adiabatic process

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

$$\frac{T_3}{T_4} = (r_e)^{\gamma-1}$$

$$\therefore \left[T_3 = T_4 (r_e)^{\gamma-1}\right] \longrightarrow (3)$$

let $r_c = r_e = r$

∴ put "$T_2$" & "$T_3$" in equation (1)

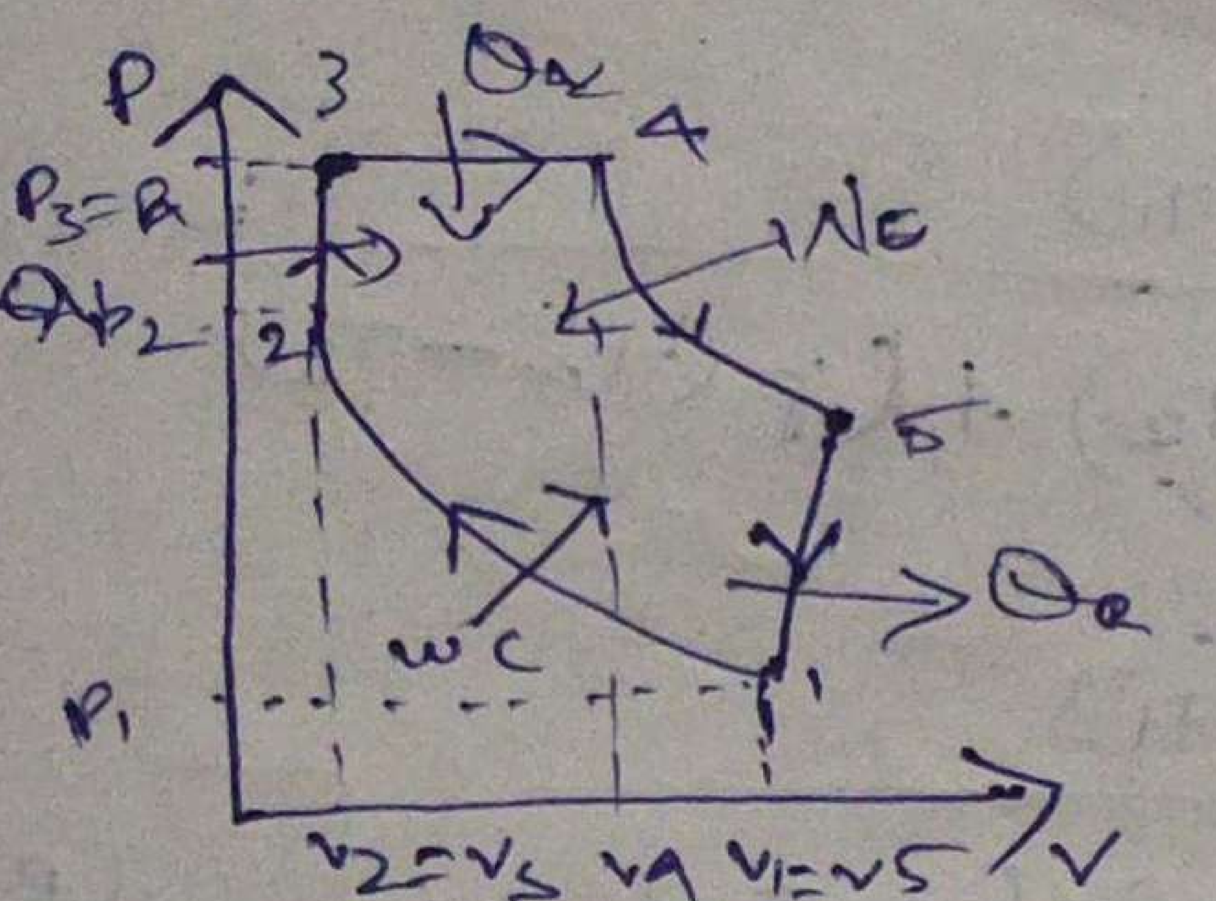
$$\eta_{otto} = 1 - \frac{(T_4 - T_1)}{T_4 (r)^{\gamma-1} - T_1 (r)^{\gamma-1}} = 1 - \frac{\cancel{(T_4 - T_1)}}{(r)^{\gamma}\,\cancel{[T_4 - T_1]}}$$

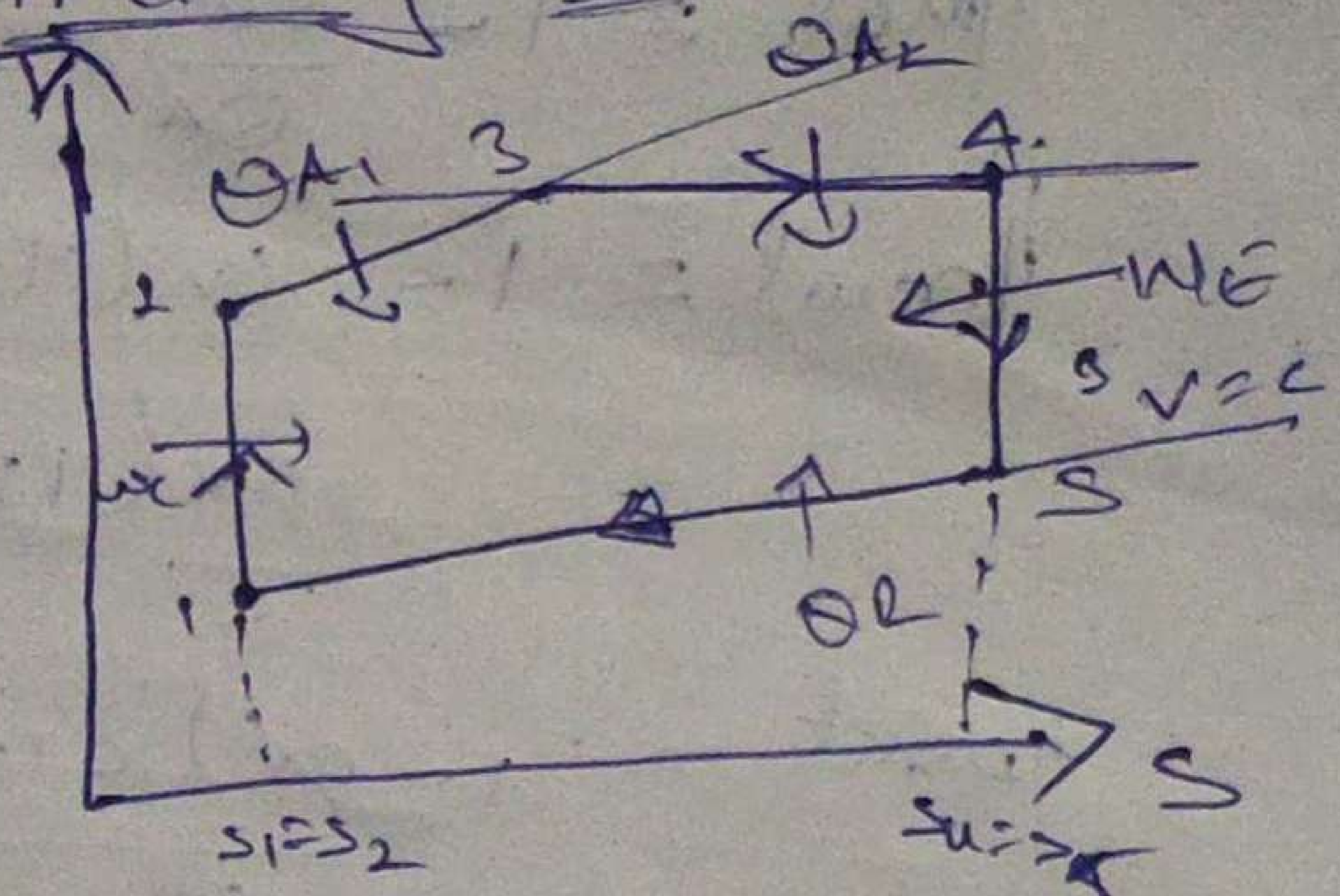
$$\boxed{\eta_{otto} = 1 - \frac{1}{(r)^{\gamma-1}}} \longrightarrow (4)$$

∴ Eqn no. (4) gives efficiency of Otto cycle

→ If 'r' increases then $\eta_{otto}$ increases.

# * Expression for efficiency of Dual cycle




Let mass of air (m) = 1 kg

i) Heat addition at constant volume is given by

$$Q_{A_1} = m c_v (T_3 - T_2)$$

$$\therefore \boxed{Q_{A_1} = c_v (T_3 - T_2)} \rightarrow (1)$$

ii) Heat addition at constant pressure is given by:-

$$Q_{A_2} = m c_p (T_4 - T_3)$$

$$\boxed{Q_{A_2} = c_p (T_4 - T_3)} \rightarrow (3)$$

iii) Total Heat addition is given by :-

$$Q_A = Q_{A_1} + Q_{A_2}$$

$$\boxed{Q_A = c_v (T_3 - T_2) + (T_4 - T_3)} \rightarrow (3)$$

(iv) Heat rejection at constant volume is given by :-

$$Q_R = m c_v (T_5 - T_1)$$

$$\boxed{Q_R = c_v (T_5 - T_1)} \rightarrow (4)$$

(v) Efficiency of Dual cycle is given by:-

$$\eta_{Dual} = \frac{W.D}{Q_A} \Rightarrow \frac{Q_A - Q_R}{Q_A}$$

$$\eta_{dual} = 1 - \frac{Q_R}{Q_A}$$

$$\eta_{dual} = 1 - \frac{c_v (T_5 - T_1)}{c_v (T_3 - T_2) + c_p (T_4 - T_3)}$$ [refer eqn. ...]

$$\therefore$$

$$\eta_{dual} = 1 - \frac{\cancel{c_v}[(T_5 - T_1)]}{\cancel{c_v}[(T_3 - T_2) + \frac{c_p}{c_v}(T_4 - T_3)]} \quad \left[\because \frac{c_p}{c_v} = \gamma\right]$$

$$\boxed{\eta_{dual} = 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma (T_4 - T_3)}} \rightarrow (A)$$

$\therefore$ For process 1-2 : Reversible adiabatic process

$$\left[\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}\right] \Rightarrow \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_2}{T_1} = (r_c)^{\gamma-1}$$ [$\because$ $r_c$ = compression ratio $\Rightarrow \frac{V_1}{V_2} \Rightarrow \frac{\text{cylinder volume}}{\text{clearance volume}}$]

$$\left[T_2 = T_1 (r_1)^{\gamma-1}\right] \rightarrow (5)$$

Now, For process 2-3 constant volume heat addition

$$\frac{P_2 \cancel{V_2}}{T_2} = \frac{P_3 \cancel{V_3}}{T_3} \quad [\because V_2 = V_3]$$

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

let $\frac{P_3}{P_2}$ = pressure ratio $\Rightarrow \beta$.

$$\therefore \frac{T_3}{T_2} = \beta$$

Hence $\left[T_2 = \frac{T_3}{\beta}\right] \leftarrow (6)$

put $T_2 = \frac{T_3}{\beta}$ in equation no (5)

$$\frac{T_3}{\beta} = T_1 (r_1)^{\gamma-1}$$

$$\boxed{T_1 = \frac{T_3}{(r_1)^{\gamma-1} \beta}} \rightarrow (7)$$

∴ <u>For process 3-4</u> = constant pressure heat-addition

$$\frac{\cancel{P_3} V_3}{T_3} = \frac{\cancel{P_4} V_4}{T_4} \quad \left[\because P_3 = P_4\right]$$

$$T_4 = \frac{V_3}{V_3} \cdot T_3$$

$\boxed{\rho = \text{row}}$

$$\boxed{T_4 = \rho T_3} \rightarrow (8) \quad \left[\because \rho = \text{fuel-cutoff ratio} \Rightarrow \frac{V_4}{V_3} \Rightarrow \frac{V_4}{V_3}\right]$$

<u>For process</u> 4-5 : Reversible adiabatic expansion

$$\left[\frac{T_4}{T_5} = \left(\frac{V_5}{V_4}\right)^{\gamma-1}\right] \Rightarrow \left(\frac{P_4}{P_5}\right)^{\frac{\gamma-1}{\gamma}}$$

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

$$\frac{T_4}{T_5} = \left(r_c \times \frac{V_3}{V_4}\right)^{\gamma-1} \Rightarrow \left(\frac{r_c}{\rho}\right)^{\gamma-1} \quad \left[\because \frac{1}{\rho} = \frac{V_3}{V_4}\right]$$

$$T_5 = \frac{T_4 \, \rho^{\gamma-1}}{(r_c)^{\gamma-1}} \Rightarrow \frac{\rho T_3 \cdot \rho^{\gamma-1}}{(r_1)^{\gamma-1}}$$

$$\boxed{T_5 = \frac{\rho T_3 \, \rho^{\gamma-1}}{(r_c)^{\gamma-1}}} \rightarrow (9)$$

Put $T_1$ $T_2$, $T_4$ & $T_5$ in Equation 00A

$$\eta_{Dual} = 1 - \frac{\left(\frac{\rho T_3 \cdot \rho^{\gamma-1}}{(r_c)^{\gamma-1}}\right) - \frac{T_3}{\beta (r_c)^{\gamma-1}}}{\left(T_3 - \frac{T_3}{\beta}\right) + \gamma (\rho T_3 - T_3)}$$

$$\eta_{Dual} = 1 - \frac{1}{(r_c)^{\gamma-1}} \left[\frac{\rho^{\gamma} - \frac{1}{\beta}}{\left(1 - \frac{1}{\beta}\right) + \gamma(\rho - 1)}\right]$$

$$\eta_{Dual} = 1 - \frac{1}{(r_c)^{\gamma-1}} \left[\frac{\frac{\beta \rho^{\gamma} - 1}{\beta}}{\frac{\beta - 1}{\beta} + \frac{\gamma(\rho - 1)}{1}}\right]$$

$$\eta_{Dual} = 1 - \frac{1}{(r_c)^{\gamma-1}} \left[\frac{\frac{\beta \rho^{\gamma} - 1}{\cancel{\beta}}}{\frac{(\beta - 1) + \beta(\gamma)(\rho - 1)}{\cancel{\beta}}}\right]$$

$$\boxed{\eta_{Dual} = 1 - \frac{1}{(r_c)^{\gamma-1}} \left[\frac{\beta \rho^{\gamma} - 1}{(\beta - 1) + \beta \cdot \gamma (\rho - 1)}\right]}$$

From eq no B Efficiency of Dual cycle can be calculated.