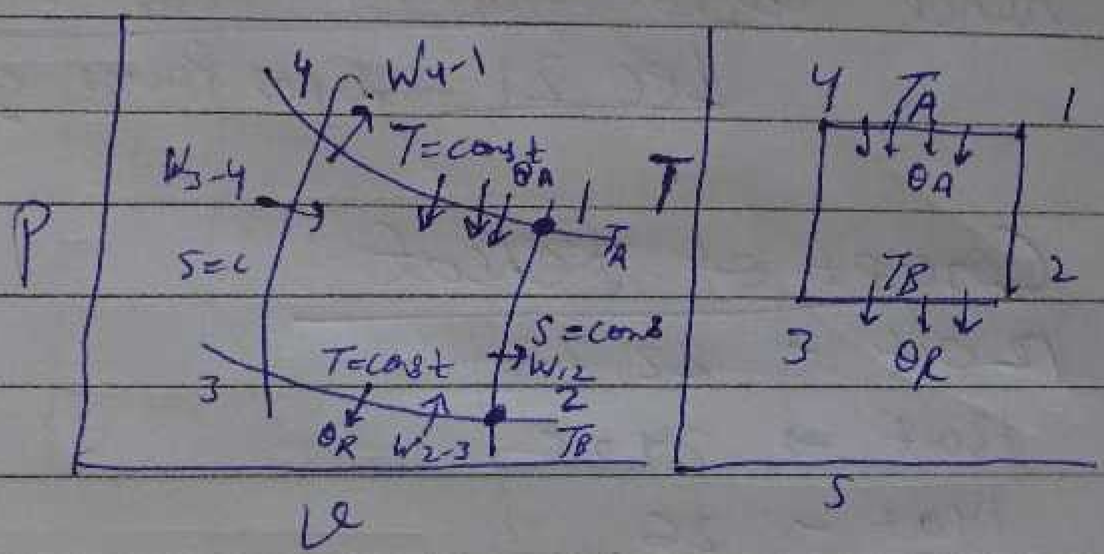
Gas Power Cycles I

Carnot cycle - Ideal Gas/Air

Non flow Process



Process	ΔU	W (Work done)	Q (heat added)
1 - 2	$C_v(T_2 - T_1)$	$C_v(T_1 - T_2)$	0
2 - 3	0	$RT_B \ln(v_3/v_2)$	$RT_B \ln(v_3/v_2)$
3 - 4	$C_v(T_4 - T_3)$	$C_v(T_3 - T_4)$	0
4 - 1	0	$RT_A \ln(v_1/v_4)$	$RT_A \ln(v_1/v_4)$
	$\Sigma \Delta U = 0$	$\Sigma W =$	ΣQ

$$Q = \Delta U + W$$

$$T_1 = T_4 = T_A$$

$$T_2 = T_3 = T_B$$

$W = \int P\,dv$ (non flow Process)

$$RT_B \ln \frac{V_3}{V_2}$$

$$\eta = 1 + \frac{R T_B \ln(v_3/v_2)}{R T_A \ln(v_1/v_4)}$$

$$= 1 - \frac{T_B}{T_A} \frac{\ln(v_2/v_3)}{\ln(v_1/v_4)}$$

$PV^{\gamma} = \text{const}$ $\quad \gamma = C_p/C_v$

$PV = RT$

$TV^{\gamma-1} = \text{const}$

$$\frac{v_1}{v_2} = \left(\frac{T_1}{T_2}\right)^{1/1-\gamma} \qquad \frac{v_4}{v_3} = \left(\frac{T_4}{T_3}\right)^{\frac{1}{1-\gamma}}$$

$$T_1 = T_4, \; T_2 = T_3$$

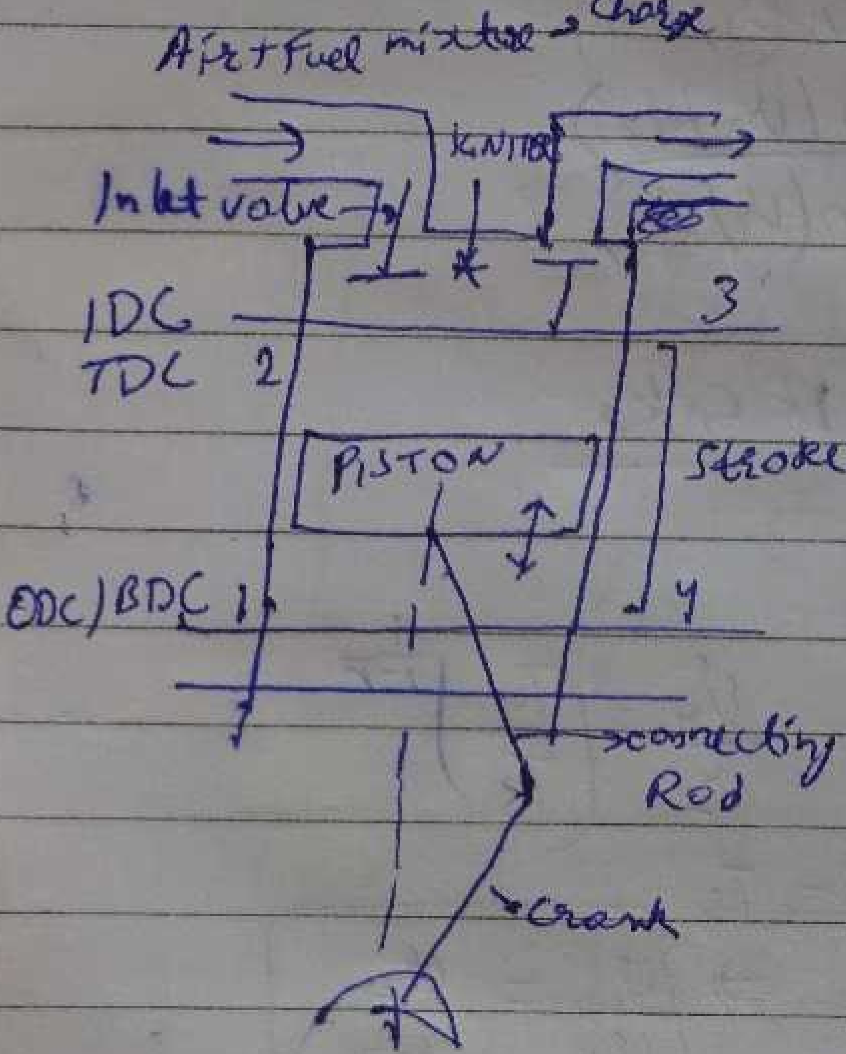
$$\frac{v_1}{v_2} = \frac{v_4}{v_3} \Rightarrow \boxed{\frac{v_1}{v_4} = \frac{v_2}{v_3}}$$

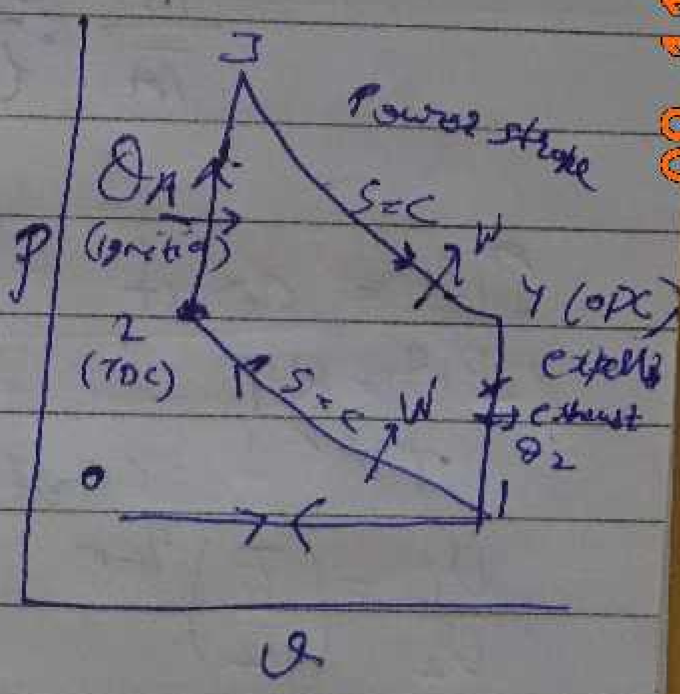
$$\eta = 1 - \frac{T_B}{T_A}$$

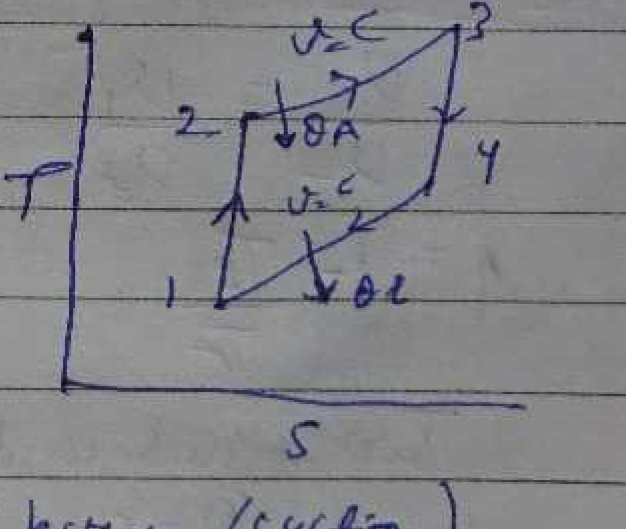
Two Areas under P-V & T-S curve are Same $\Sigma Q = \Sigma W$

Otto Cycle - Air standard

Reciprocating engine - spark plug







Inlet valve open
Piston Reaches IDC/TDC
Piston moves down
0-1 Gas expands V increase P decrease (suction)
Air comes In. (Charge) (0-1)
Piston Goes to ODC/BDC.

Inlet Valve closes. (both close!)
1-2
TDC Piston Ascends up (1-2) s= const.
Charge compressed. (high P, T) [2nd stroke]
(2-3) IGNITER introduced, burning starts. (high P, T) rush. Piston at (TDC)
Pushes Piston down
const V

3-4

- Piston goes down (expanding products of combustion
- IDC to ODC Power stroke) [3rd stroke] [3-4] isentropic
- T, P reduced. (Piston at ODC/BDC)

4-1
- Outlet valve opens (even before Piston reaches ODC)
- Some gases expelled exhaust duct (Piston at ODC)

1-0
- Piston ascends upwards. [1—0]
- Mass Goes out [$P = P_{atm}$]
- Piston reaches (IDC/TDC) [initial condition]

Again Piston moves down (inducts fresh charge) new cycle

1 cycle = 4 movements or 4 strokes. (IDC to ODC)

Petrol engine - spark ignition engine

1-2 ~~Air taken in.~~ Goes to IDC

3-4 Goes to BDC.

Process	ΔU	W	Q
1-2	$C_v(T_2-T_1)$	$C_v(T_1-T_2)$	0
2-3	$C_v(T_3-T_2)$	0	$C_v(T_3-T_2)$
3-4	$C_v(T_4-T_3)$	$C_v(T_3-T_4)$	0
4-1	$C_v(T_1-T_4)$	0	$C_v(T_1-T_4)$
	$\Sigma \Delta U = 0$	$\Sigma W =$	ΣQ

closed system / non flow process

$$Q = \Delta U + W$$

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

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

Gas Power Cycles. II

Volumetric compression ratio

$$r_v = v_1/v_2$$

$$\eta = \left[1 - \frac{T_4 - T_1}{T_3 - T_2}\right]$$

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

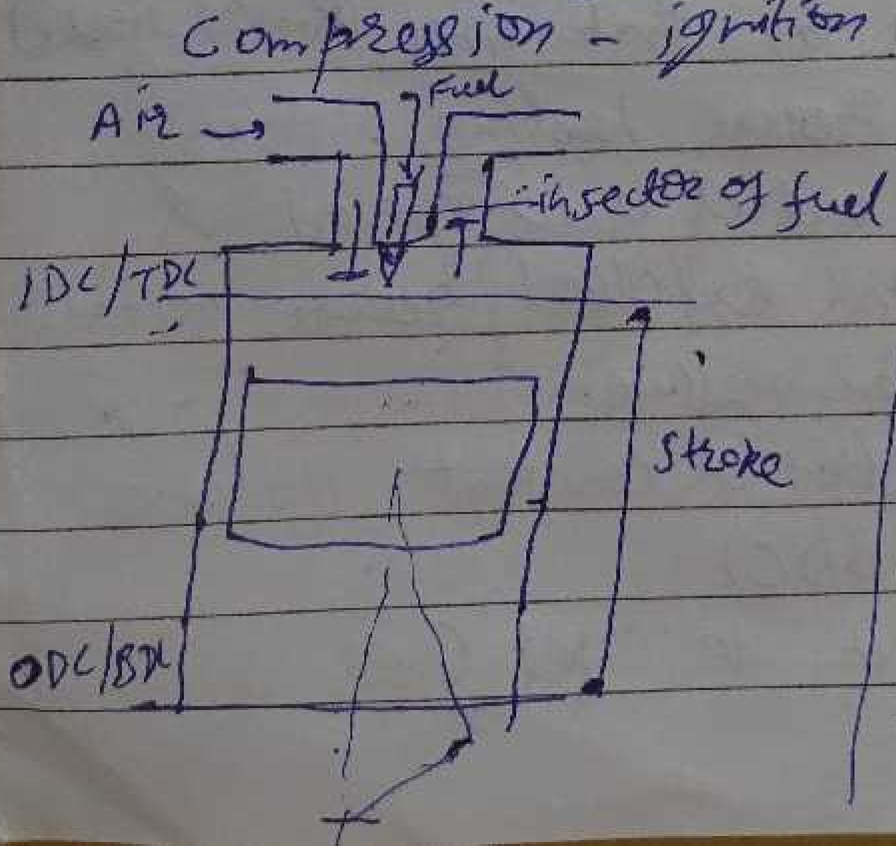
$$\frac{T_2}{T_1} = \frac{v_1}{v_2} = r_v^{\gamma-1}$$

$$\eta = 1 - \frac{1}{r_v^{\gamma-1}}$$

As we increase r_v, η increases monotonically.

Diesel Cycle

Compression - ignition

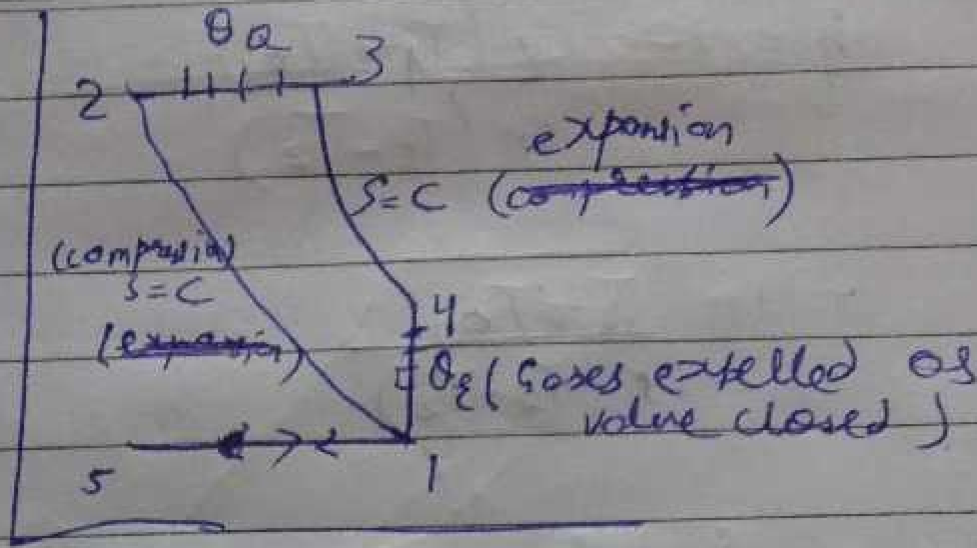


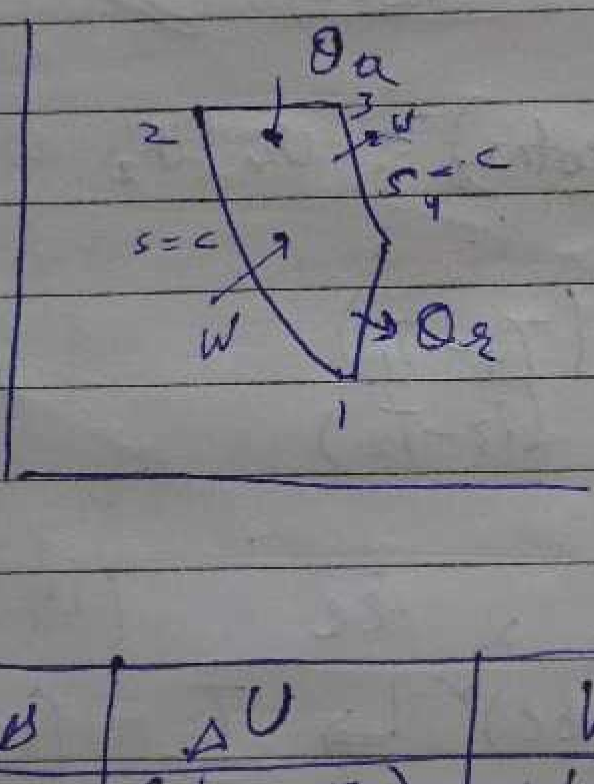
Inlet stroke

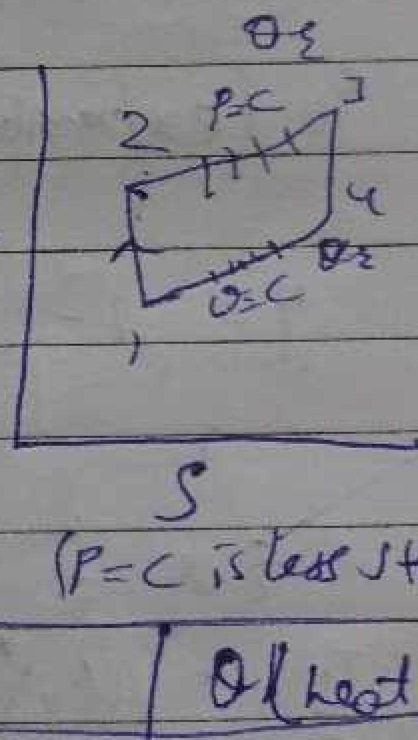
IDC to moves down suction created. Air moves in. Piston reaches BDC. Air is full, two valve closed. Piston ascends to IDC. ~~Pressure & Temp~~ at end of compression is higher. Auto ignition ~~temp~~.

Burning of liquid fuel. Mix vapor fuel & air. (molecular mixing)
Burning takes place in Gas phase.
IGNITION Delay. time for Auto ignition.
This takes place in carborator of petrol engine.
Inside the cylinder done in diesel engine
Injector directs a jet of diesel (spray of minute droplets - atomisation)
Surface Area increases → rate of vaporization increases.
Immediate vaporization - burning. (droplet combustion)
Ignition starts heterogeneously at different points (hotspots burning zones). Piston descends downwards by that time. (Power stroke)
Constant Pressure heating.
Then ~~ve~~ outlet valve opened & burning material expelled, Pressure restored to atmospheric pressure.
Heat rejection at constant volume (Piston at BDC)
Piston moves up to expel Gases

Diesel cycle







(P=C is less steep)

Process	ΔU	W	Q (heat added)
1-2	$C_v(T_2-T_1)$	$C_v(T_1-T_2)$	0
2-3	$C_v(T_3-T_2)$	$P_2(v_3-v_2)$	$C_p(T_3-T_2)$
3-4	$C_v(T_4-T_3)$	$C_v(T_3-T_4)$	0
4-1	$C_v(T_1-T_4)$	0	$C_v(T_1-T_4)$
	$\Delta U=0$	$\Sigma W =$	ΣQ

Non flow process

$Q = \Delta U + W$

$\delta Q = dU + P\,dV$

$dh\;\; d(U+PV)$ const P

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

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

$r_v = v_1 / v_2$ $\qquad$ $r_c = \frac{v_3}{v_2}$ (cut off ratio)

r_e (expansion ratio) $= v_4 / v_3$

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

$r_v = r_c \times r_e$ $\qquad$ $(v_1 = v_4)$

$\frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{r-1} = (r_e)^{r-1} \Rightarrow \frac{T_3}{T_4} = \left(\frac{r_v}{r_c}\right)^{r-1}$

$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{r-1} = (r_v)^{r-1}$

$\frac{T_3}{T_2} = r_c \left(\frac{v_3}{v_2}\right)$

$$\eta_{diesel} = 1 - \frac{1}{(r_v)^{r-1}} \cdot \frac{1}{r} \frac{r_c^{r} - 1}{r_c - 1}$$

write $r_c = 1+x$

$r_c > 1$ $\quad \frac{1}{\gamma}\left(\frac{r_c^{\gamma}-1}{r_c-1}\right) > 1$ $\quad \frac{1+\gamma x+ \dots}{\gamma x}$

$\eta_{otto} > \eta_{diesel}$

For same value of r_v

2 → 3 represents burning process

Brayton cycle :

Gas turbine plant. (Air craft engine) Rocket engine

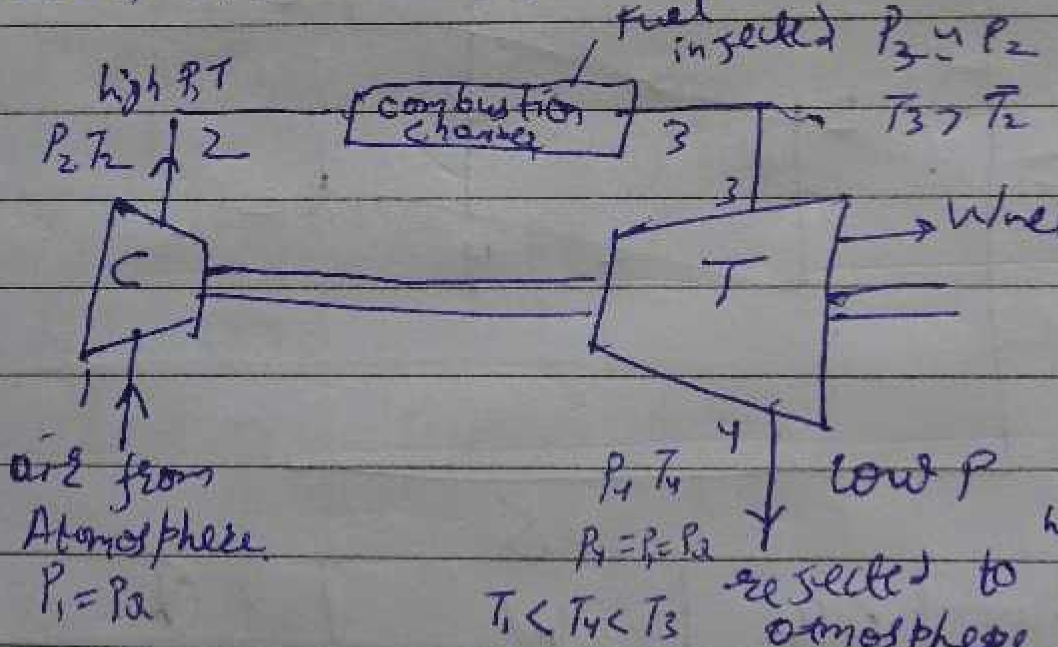
(Marine, Automobile)

(open cycle)

$P_2 > P_1$

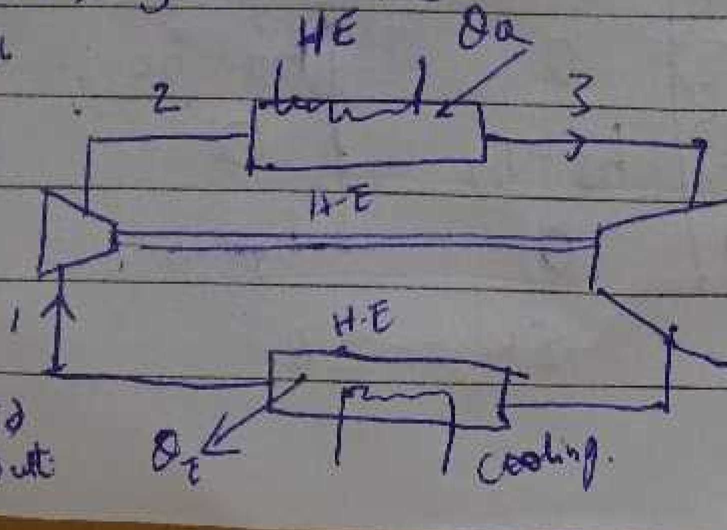
$T_2 > T_1$

P_1, T_1



Steady flow device

Thermodynamic (cycle)

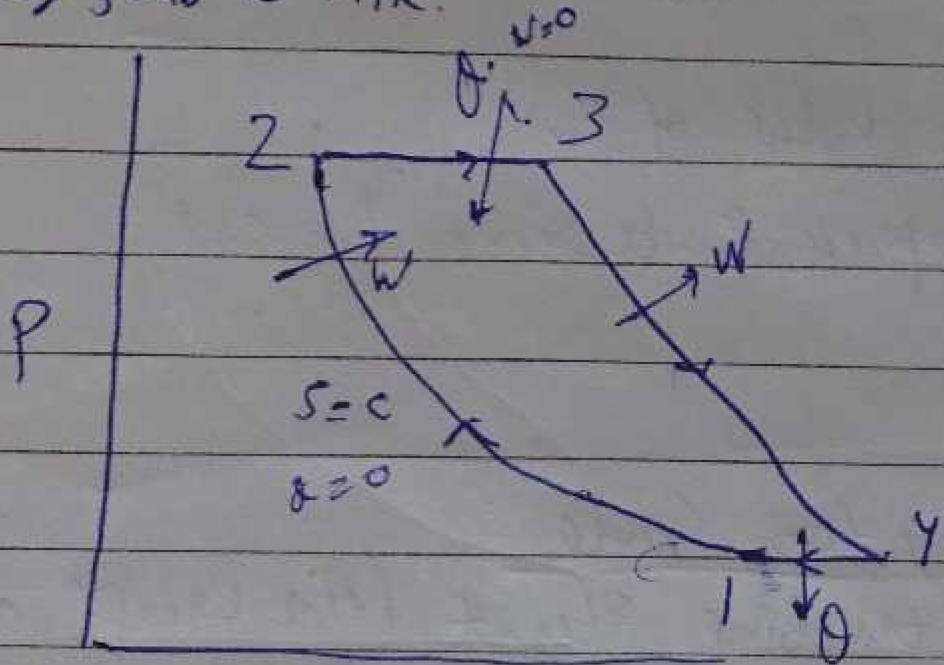


Same fluid throughout

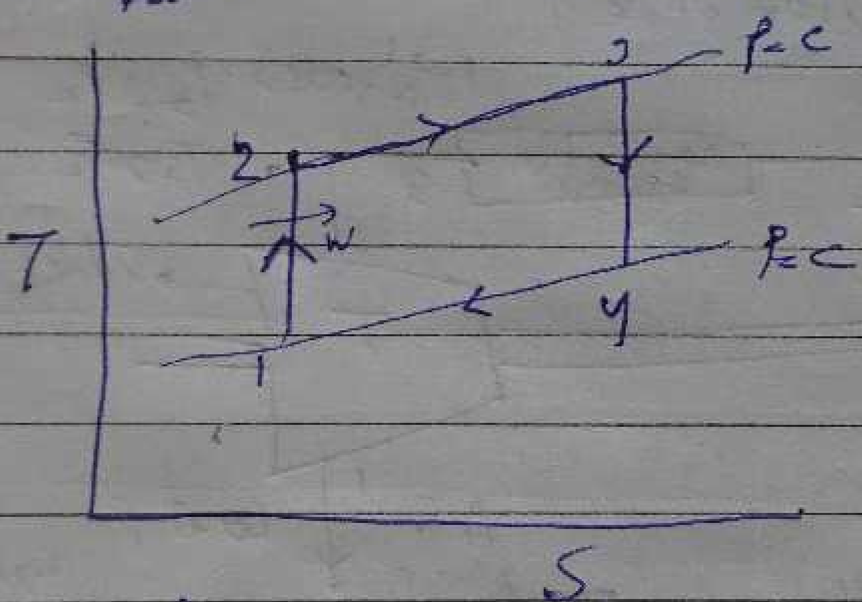
closed cycle Gas turbine plant (Nuclear reactor) [2-3] fission.

Brayton / Joule cycle

Working fluid is AIR.



Steady flow process



Process	Δu	W	Q
1-2	$C_v(T_2-T_1)$	h_2-h_1	0
2-3	$C_v(T_3-T_2)$	0	h_3-h_2
3-4	$C_v(T_4-T_3)$	h_3-h_4	0
4-1	$C_v(T_1-T_4)$	0	h_4-h_1

$\Sigma \Delta U = 0$ $\quad \Sigma W = \Sigma Q$.

$$\eta = \frac{W_{net}}{Q_{Added}} = 1 - \frac{Q_{rejected}}{Q_{Added}}$$

$$= 1 - \left(\frac{h_4 - h_1}{h_3 - h_2}\right)$$

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

$$PV^{\gamma} = \text{const}$$

$$PV = RT$$

$$P\left(\frac{RT}{P}\right)^{\gamma} = \text{const} \qquad \frac{T}{P^{\gamma-1/\gamma}} = \text{const}$$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\gamma-1/\gamma} = (r_p)^{\gamma-1/\gamma}$$

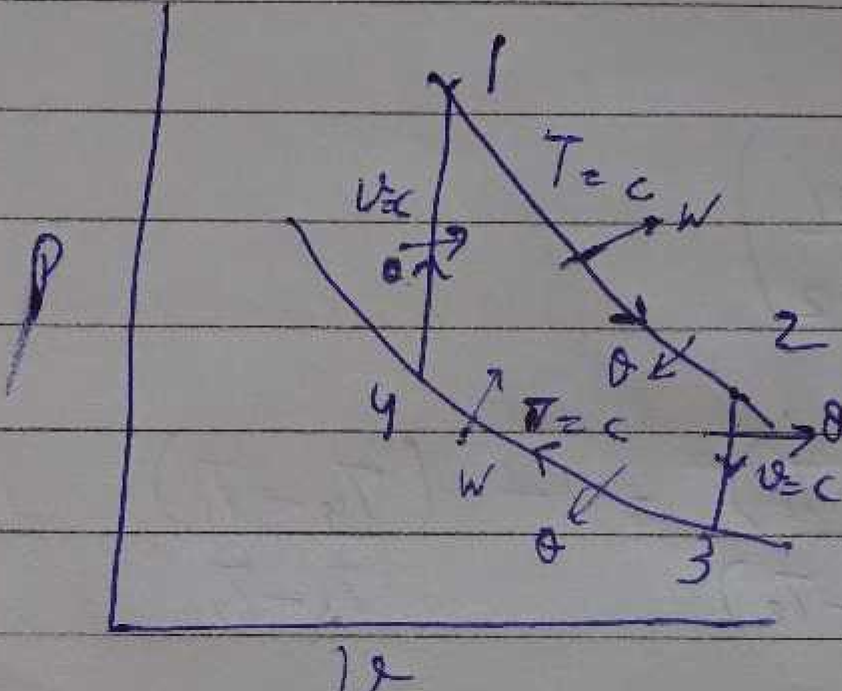
$$r_p = \frac{P_3}{P_4} = \text{Pressure Ratio}$$

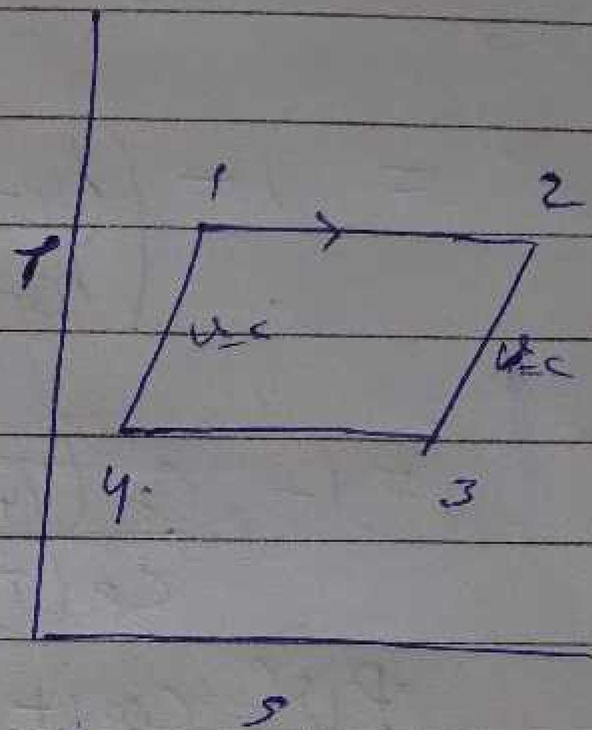
$$\frac{T_2}{T_1} = (r_p)^{\gamma-1/\gamma}$$

$$\boxed{\eta = 1 - \frac{1}{(r_p)^{\gamma-1/\gamma}}}$$

Stirling Cycle

working system - AIR
non-flow $Q = \Delta U + W$





Process	ΔU	Q	W
1-2	0	$RT_1 \ln(v_2/v_1)$	$RT_1 \ln(v_2/v_1)$
2-3	$C_v(T_3-T_2)$	$C_v(T_3-T_2)$	0
3-4	0	$RT_3 \ln(v_4/v_3)$	$RT_3 \ln(v_4/v_3)$
4-1	$C_v(T_1-T_4)$	$C_v(T_1-T_4)$	0
	$\Sigma \Delta U = 0$	$\Sigma Q =$	ΣW

$$\eta = 1 - \frac{Q_{res}}{Q_{Add}} = 1 - \frac{\left[C_v(T_2-T_3) + RT_3 \ln(v_3/v_4)\right]}{RT_1 \ln v_2/v_1 + C_v(T_1-T_4)}$$

2-3 & 4-1 are counter.

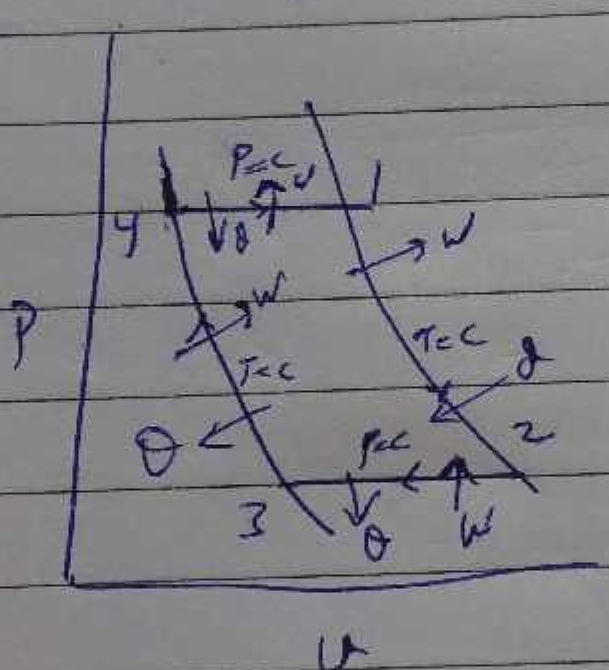
Neglect: $C_v(T_2-T_3)$ $C_v(T_1-T_4)$

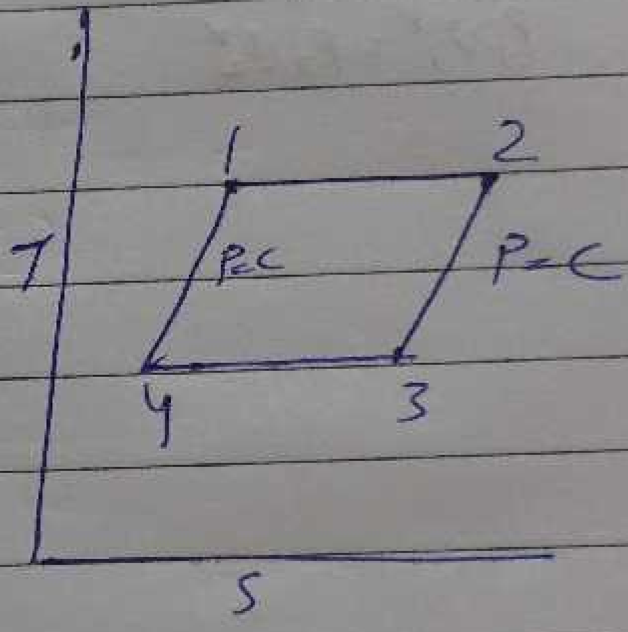
$$\frac{v_3}{v_4} = \frac{v_2}{v_1}$$

$$\eta = 1 - \frac{T_3}{T_1} \rightarrow \text{Carnot efficiency.}$$

<u>Ericsson cycle</u> : working system Air

non flow. $Q = \Delta U + W$





Process	ΔU	Q	W
1-2	0	$R T_1 \ln(v_2/v_1)$	$R T_1 \ln v_2/v_1$
2-3	$C_v(T_3 - T_2)$	$\cancel{p_2(v_3 - v_2)}$ $h_3 - h_2$	$p_2(v_3 - v_2)$
3-4	0	$R T_3 \ln(v_4/v_3)$	$R T_3 \ln(v_4/v_3)$
4-1	$C_v(T_1 - T_4)$	$h_1 - h_4$	$p_1(v_1 - v_4)$

$$\eta = 1 - \left[\frac{R T_3 \ln v_3/v_4 + C_p(T_2 - T_3)}{R T_1 \ln(v_2/v_1) + C_p(T_1 - T_4)}\right]$$

$Q_{41} \rightarrow Q_{23}$

Only 1-2 & 3-4 :

$$\eta = 1 - \frac{T_3}{T_1}$$

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

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