* GAS TURBINE *

[redacted]

Advantage of Gas Turbine over I.C. engine ⇒

1. High speed can be obtained
2. Easy Balancing.
3. They are compact. $\left(\frac{W}{P}\right)$ [weight to power Ratio is less]
4. simple mechanism.

DISadvantage ⇒

1) As compressor is used in gas turbine system the work of compression is large and hence Network is less this Result in lower efficiency.
2) As gas turbine system are subjected to higher temp. continuously high heat resistant costly material is Required.
3) Additional Reduction gear box is required as the speed are very high

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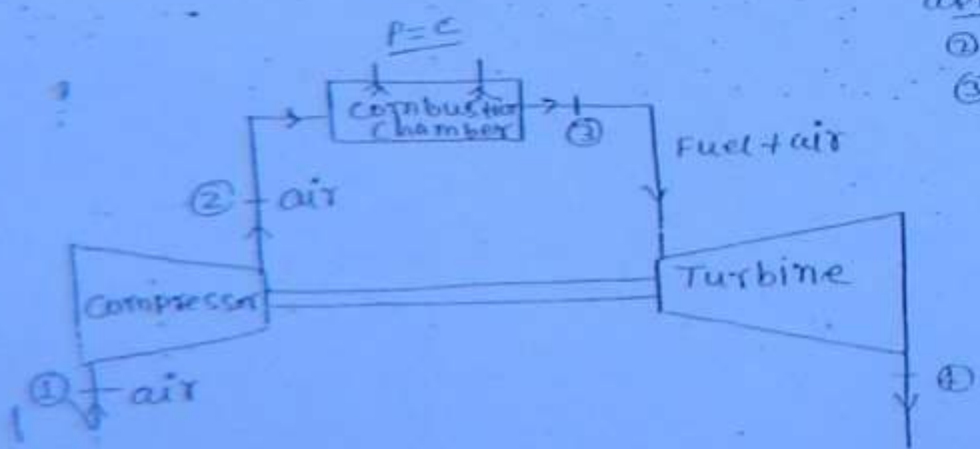
Open cycle gas Turbine ⇒ works on (Joule / Brayton cycle)

application ⇒ ① aircraft.
② automotive (bus and truck)
③ industrial gas turbine installation.

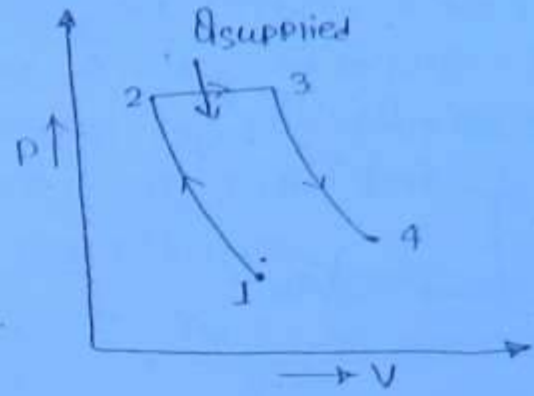


I.C. engine Called

1-2 → Reversible adiabatic compression (Isentropic)

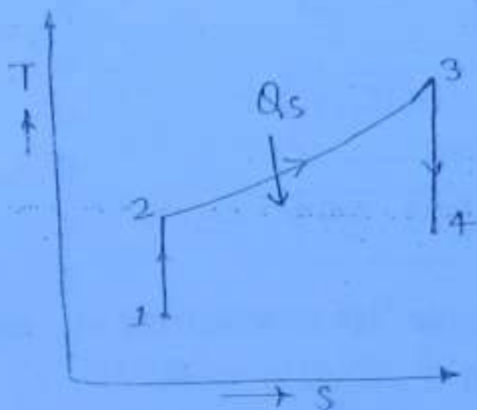
2-3 → constant pressure heat addition

3-4 → Rev. adiabatic expansion. (Isentropic)



$\cancel{p}V = \cancel{m}\cancel{R}T$

$V \propto T$



Note ⇒ The Brayton cycle is the air standard cycle for the gas turbine power plant.

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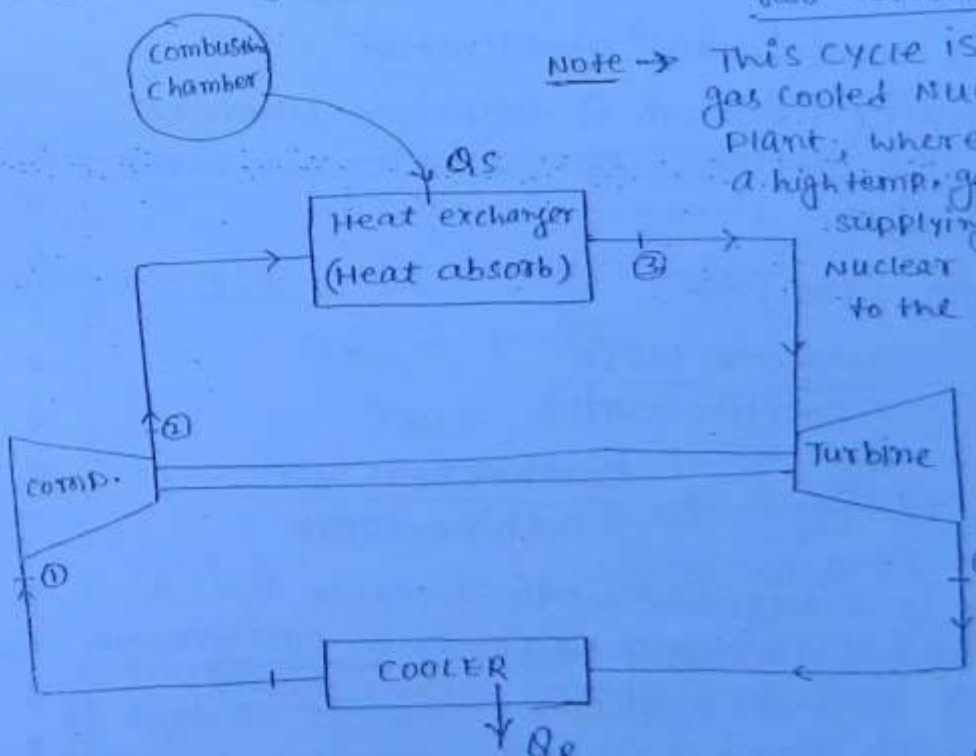
② close cycle gas Turbine → ⇒ two Reversible isobars and two reversible adiabatic

Note → This cycle is used in a gas cooled Nuclear reactor plant, where the source is a high temp. gas cooled Reactor supplying heat from nuclear fission directly to the working fluid (a gas)



A

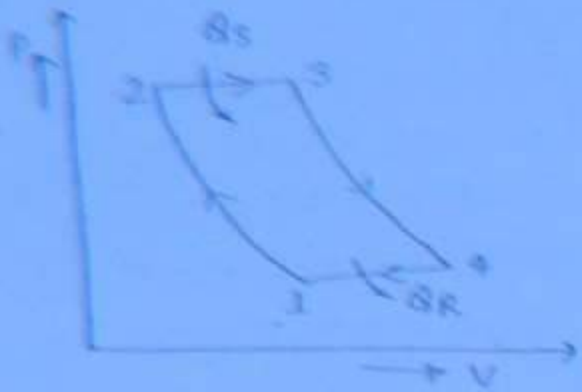
external Combustion engine

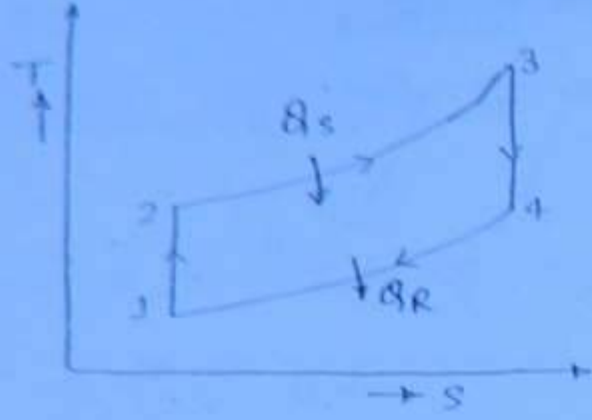
1 - 2 → Rev. adiabatic compression (Isentropic)

2 - 3 → Constant pressure heat addition (Isobar)

3 - 4 → Rev. adiabatic expansion (Isentropic)

...... heat rejection.





(BRAYTON CYCLE)

- Gas Turbine cycle work on Brayton cycle.

Advantage of closed cycle gas Turbine ⇒

1) It can work on any working fluid but open cycle gas turbine must work on air only.
2) any cheaper fuel can be used because the product of combustion do not come directly in contact with turbine blade.

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Disadvantages ⇒

① The system is complicated and costly
② Additional cooling medium is required. whereas an open cycle gas turbine atmospheric air work as a cooling medium.

- Back work Ratio (r_{bw}) ⇒

$$r_{bw} = \frac{\text{Negative work}}{\text{positive work}}$$

$$r_{bw} = \frac{W_C}{W_T} \Rightarrow \frac{\text{Compressor work}}{\text{Turbine work}}$$

compressor work is a Negative work because it is a open system whearas Turbine work is a positive work because this is a closed system $\boxed{W_c = -\int v\,dp}$

- It is the Ratio of Negative work to the positive work.

In case of gas Turbine power plant the Back work ratio are around 40 to 60%. Whearas in the case of steam power plant (vapour power cycle / Rankine cycle) the Back work ratio are 1 to 2 %.

(ii) Work Ratio (R_w) ⇒

$$r_w = \frac{\text{Net work}}{\text{Turbine work}} = \frac{W_{net}}{+\text{ve work}} \Rightarrow \frac{W_{net}}{W_T}$$

$$r_w = \frac{W_T - W_C}{W_T}$$

$$\boxed{r_w = 1 - \frac{W_C}{W_T}} \quad \text{because} \quad \boxed{r_{bw} = \frac{W_C}{W_T}}$$

$$\boxed{r_w = 1 - r_{bw}}$$

* The work Ratio of Rankine cycle (vapour power cycle) is almost unity (1).

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* Brayton cycle

$$r_{bw} = 0.4 \text{ to } 0.6$$

$$r_w = 1 - 0.4 \Rightarrow 0.6$$

$$= 1 - 0.6 \Rightarrow 0.4$$

$$\boxed{r_w = 0.4 \text{ to } 0.6}$$

* Rankine cycle

$$r_w = 1 - r_{bw}$$

$$r_{bw} = 1 \text{ to } 2\%$$

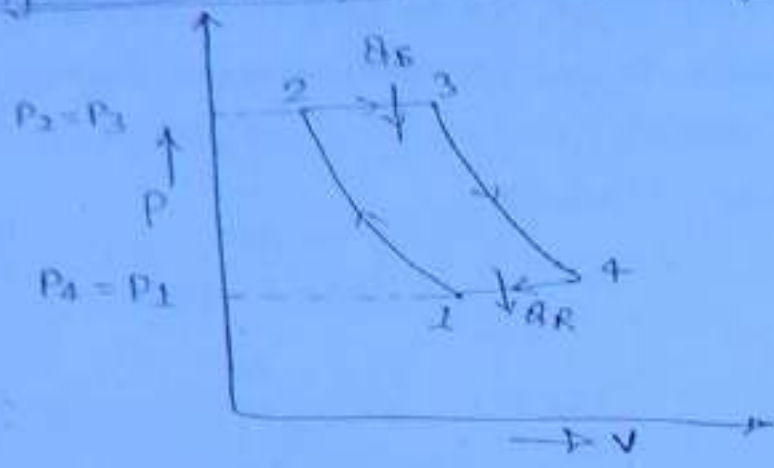
$$= 0.01 \text{ to } 0.02$$

$$r_w = 1 - 0.01 \Rightarrow 0.99$$

$$= 1 - 0.02 \Rightarrow 0.98$$

Note → Rankine cycle (vapour power cycle) work ratio is higher because pump are less work consume whearas Brayton cycle in compressor are more work is consume. (more power is consu-

> Efficiency of a simple gas Turbine cycle on p-v diagram



$$\eta_T = \frac{W_{net}}{Q_s \text{ (Heat supplied)}}$$

$$\eta = \frac{Q_s - Q_R}{Q_s}$$

$$\eta = 1 - \frac{Q_R}{Q_s}$$

where $Q_R = h_4 - h_1 \Rightarrow C_p(T_4 - T_1)$

$Q_s = h_3 - h_2 \Rightarrow C_p(T_3 - T_2)$

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

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$$\eta = 1 - \frac{T_1\left(\frac{T_4}{T_1} - 1\right)}{T_2\left(\frac{T_3}{T_2} - 1\right)} \quad \text{—— (1)}$$

Pressure Ratio $(r_p) = \frac{P_2}{P_1} = \frac{P_3}{P_4}$

1-2 → Reversible adiabatic compression

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

$$\frac{T_2}{T_1} = (r_p)^{\frac{\gamma-1}{\gamma}} \quad \text{—— (2)}$$

3-4 → Reversible adiabatic expansion.

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

$$\frac{T_3}{T_4} = (r_p)^{\frac{\gamma-1}{\gamma}} \quad \text{—— (3)}$$

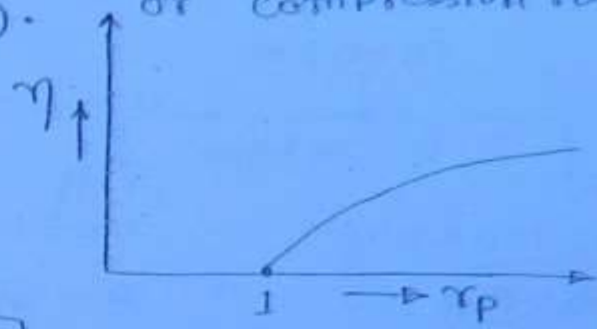
*** $\boxed{\frac{T_2}{T_1} = \frac{T_3}{T_4}}$ $\boxed{\frac{T_4}{T_1} = \frac{T_3}{T_2}}$

$$\eta = 1 - \frac{T_1}{T_2}$$

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

note → For the same compression ratio, the Brayton cycle efficiency is equal to the otto cycle efficiency.

Note ⇒ The efficiency of brayton cycle depend on the pressure ratio (r_p). or compression ratio.



* when $r_p = 1$, then $\eta = 0$, and r_p increases than η also increases.

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

Note ⇒
This equation of η is valid only when compression and expansion are Isentropic.

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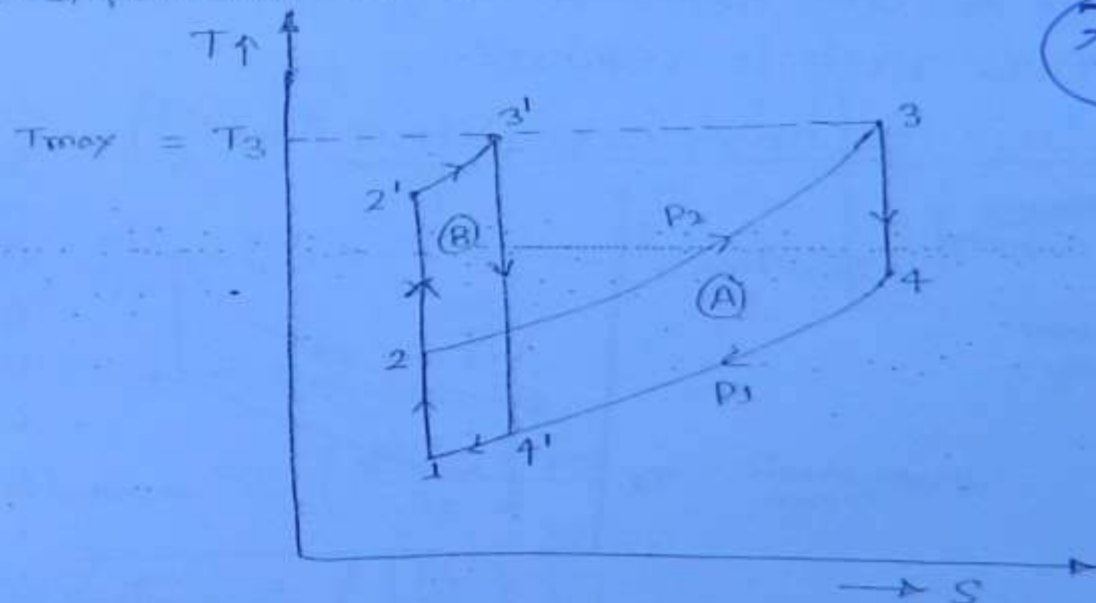

$$\eta = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$$

$$\boxed{\eta_B > \eta_A}$$

⇒ It means efficiency depend on pressure ratio. because B cycle pressure ratio is more compare to cycle A.

$W_A > W_B$ → Area of A cycle is more compare to cycle B.

so when mass flow rate is more than area is much required then cost is high. So we are not take more pressure ratio.

case → SAME capacity to take.

$\boxed{\text{Power} = \text{mass} \times \text{network}}$

1500 KW

$P = \dot{m} W_{net}$

A

$W_A = 150\ kJ/kg$

$1500 = \dot{m}_A \times 150$

$\dot{m}_A = 10\ kJ/kg$

B

$W_B = 15\ kJ/kg$

$P = \dot{m}_B \times 15$

$1500 = \dot{m}_B \times 15$

$\dot{m}_B = 100\ kJ/kg$

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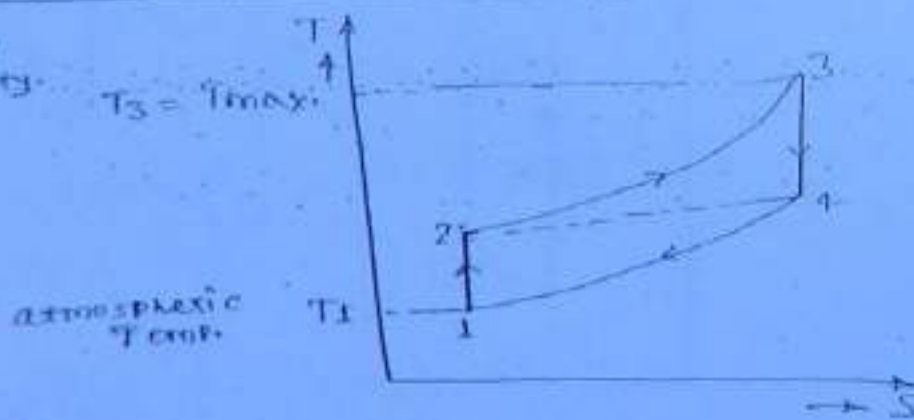
* Though the efficiency of $\eta_B > \eta_A$ the net work in B < cycle A and hence for a given capacity. greater mass flow rate is required.

Optimum pressure for max. work output ⇒

where T_3 → Temp. constant because material property.

T_1, T_3 → Temp. constant (not change)



$W_{net} = W_T - W_C$

$W_{net} = (h_3 - h_4) - (h_2 - h_1)$

$W_{net} = C_p(T_3 - T_4) - C_p(T_2 - T_1)$

$W_{net} = C_p(T_3 - T_4 - T_2 + T_1)$

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

$T_4 = \frac{T_3 T_1}{\ }$

$$W_{net} = C_p\left[T_3 - \frac{T_1 T_3}{T_2} - T_2 + T_1\right]$$

For max. W_{net} $= \dfrac{dW_{net}}{dT_2} = 0$

$$\frac{dW_{net}}{dT_2} = C_p\left[0 - T_1T_3\left(-\frac{1}{T_2^2}\right) - 1 + 0\right] = 0$$

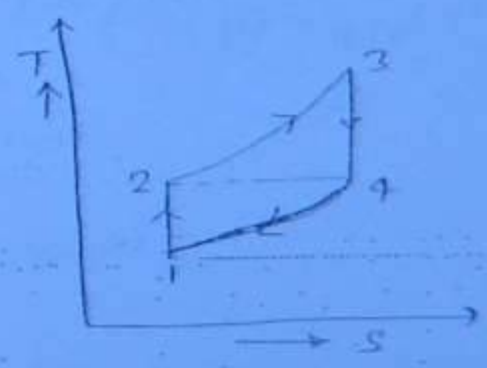
$$\frac{T_1T_3}{T_2^2} - 1 = 0$$

$$T_1T_3 = T_2^2 \Rightarrow T_2 = \sqrt{T_1T_3}$$

$$T_4 = \frac{T_1T_3}{\sqrt{T_1T_3}} \Rightarrow T_4 = \sqrt{T_1T_3}$$

** $\boxed{T_2 = T_4 = \sqrt{T_1T_3}}$

<u>pressure ratio condition for max. work ⇒</u>



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

then $\dfrac{P_2}{P_1} = (r_p)^{\frac{\gamma-1}{\gamma}}$

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

$$(r_p)_{optimum} = \left(\frac{\sqrt{T_1T_3}}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$$

$$(r_p)_{optimum} = \left(\sqrt{\frac{T_3}{T_1}}\right)^{\frac{\gamma}{\gamma-1}}$$

** $$\boxed{(r_p)_{optimum} = \left(\frac{T_3}{T_1}\right)^{\frac{\gamma}{2(\gamma-1)}}}$$ Condition for max. work

Maximum pressure ratio $(r_p)_{max}$:-

pressure line

$T_2' = T_3 = T_{max}$

$W_C = W_T$

Wcompression = Wexpansion

then net work is zero

$\boxed{W_{net} = 0}$

1-2 → Rev. adiabatic process

$$(r_p)_{max} = \frac{P_2'}{P_1}$$

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

$$\left(\frac{T_3}{T_1}\right) = (r_p)_{max}^{\frac{\gamma-1}{\gamma}} \qquad \text{Because } \boxed{T_2' = T_3}$$

$$\frac{P_2'}{P_1} = (r_p)_{max} = \left(\frac{T_3}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$$

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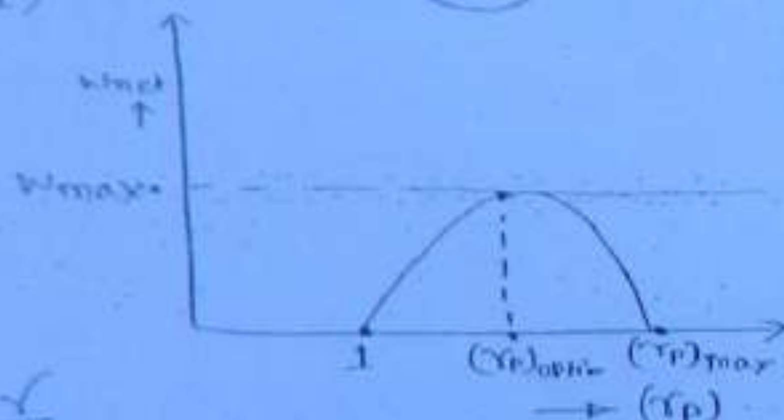


$$(r_p)_{max} = \left(\frac{T_3}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$$

$$(r_p)_{optimum} = \left(\frac{T_3}{T_1}\right)^{\frac{\gamma}{2(\gamma-1)}}$$

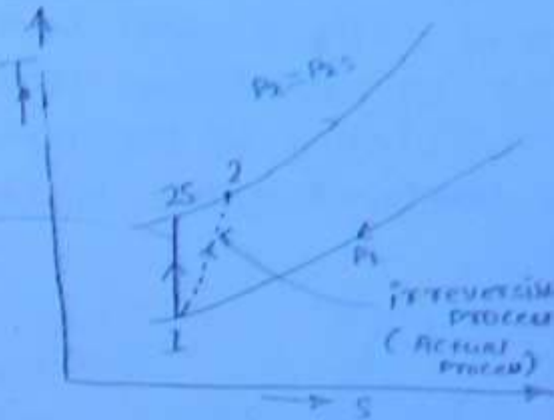
$$(r_p)^2_{optimum} = \left(\frac{T_3}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$$

$$\boxed{(r_p)^2_{optimum} = (r_p)_{max.}}$$

Isentropic efficiency of a compressor ⇒

That means irreversible process in entropy increased.

(Isentropic line) Reversible adiabatic process



$$\eta_c = \frac{\text{Isentropic work}}{\text{Actual work}}$$

$$\eta_c = \frac{\text{compressor work}}{\text{compressor Actual work}} \begin{matrix} \rightarrow \text{Less work} \\ \rightarrow \text{more work} \end{matrix}$$

(~~compressor net work are less work because more power is required and Turbine net work are more~~)

$$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1} = \frac{\text{Isentropic compression}}{\text{Actual compression}}$$

$$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1}$$

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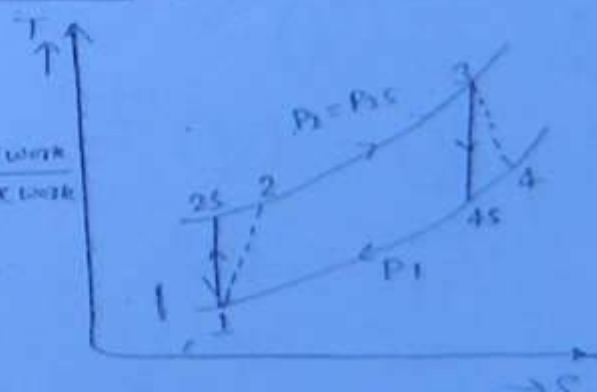
$$\frac{T_{2s}}{T_1} = \left(\frac{P_{2s}}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\boxed{\left(\frac{T_{2s}}{T_1}\right) = (r_p)^{\frac{\gamma-1}{\gamma}}} \quad *$$

(ii) isentropic efficiency of a Turbine ⇒



$$\eta_T = \frac{\text{Actual work}}{\text{Isentropic work}}$$

$$\eta_T = \frac{\text{Turbine actual work}}{\text{Turbine isentropic work}} \begin{matrix} \rightarrow \text{less work} \\ \rightarrow \text{more work} \end{matrix}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}}$$

$$\eta_T = \frac{T_3 - T_4}{T_3 - T_{4s}}$$

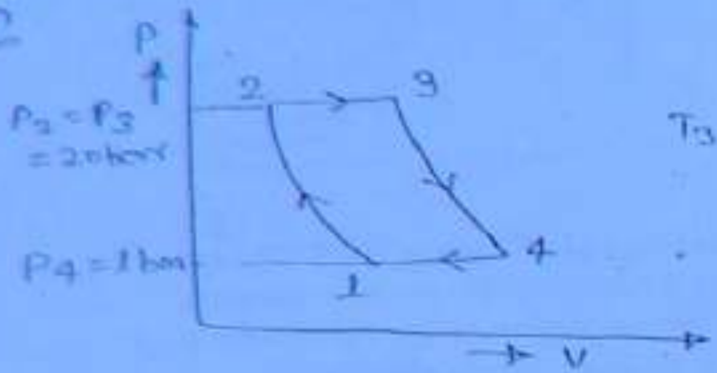
Note → Turbine work is opposite to compressor work.

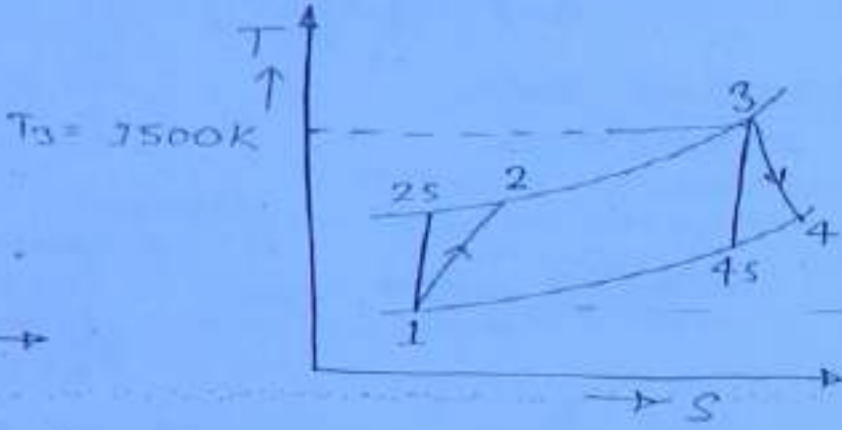
$$\frac{T_3}{T_{4s}} = \left(\frac{P_3}{P_{4s}}\right)^{\frac{\gamma-1}{\gamma}} \quad **$$

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

Q-10 In a gas turbine hot combustion product with $c_p = 0.98$ kJ/kg-K and $C_v = 0.7538$ kJ/kg-K enter the turbine at 20 bar, 1500K and leave at 1 bar. The isentropic efficiency of the turbine is 0.94 then find the work developed by the turbine per kg of gas.

Sol





$C_p = 0.98$ kJ/kg-K

$C_v = 0.7538$ kJ/kg-K

$P_2 = P_3 = 20$ bar $\quad T_3 = 1500$K

$P_4 = 1$ bar $\quad \eta = 0.94\%$

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$W_T = h_3 - h_4$

$W_T = C_p(T_3 - T_4)$

$\gamma = \frac{C_p}{C_v}$

$\gamma = \frac{0.98}{0.7538}$

$$\frac{T_3}{T_{4s}} = (r_p)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_3}{T_{4s}} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_3}{T_{4s}} = \left(\frac{20}{1}\right)^{\frac{1.3-1}{1.3}}$$

$$\frac{1500}{T_{4s}} = \frac{1.99}{1}$$

$$1.99 \times T_{4s} = 1500 \times 1$$

$$T_{4s} = \frac{1500}{1.99}$$

$$\boxed{T_{4s} = 751.35\text{ K}}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}}$$

$$\eta_T = \frac{T_3 - T_4}{T_3 - T_{4s}}$$

$$\eta_T (T_3 - T_{4s}) = T_3 - T_4$$

$$W_T = C_P (T_3 - T_4)$$

$$W_T = C_P [\eta_T [T_3 - T_{4s}]]$$

$$W_T = 0.98 [0.94 (1500 - 751.36)]$$

$$\boxed{W_T = 689.8 \text{ kJ/kg}}$$

PROB-(2) air enter the compressor of a gas Turbine operating on Brayton cycle at 27°C ($T_1 = 273 + 27 = 300K$). The pressure ratio is ($\frac{P_2}{P_1} = 6$). Calculate the max. Temp. in the cycle and cycle efficiency. Assume Turbine work = 2 Comp. work.

$$W_T = 2 W_C \quad , \quad \gamma = 1.4$$

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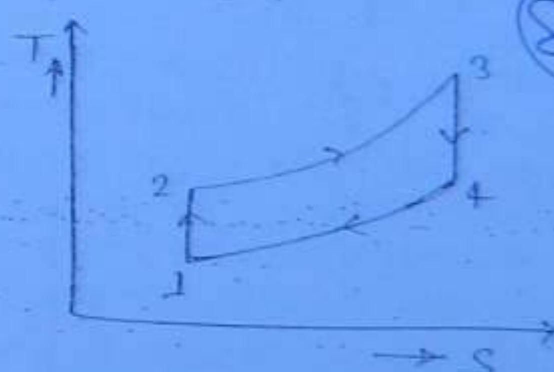
Soln

$\gamma = 1.4$

$W_T = 2.5 W_C$

$r_P = \frac{P_2}{P_1} = 6$

$T_1 = 300K$



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

$$\frac{T_2}{300} = (6)^{\frac{1.4 - 1}{1.4}}$$

$$\boxed{T_2 = 500.5K}$$

$$W_T = 2.5 W_C$$

$$(h_3 - h_4) = 2.5 (h_2 - h_1)$$

$$\cancel{C_P} (T_3 - T_4) = 2.5 \cancel{C_P} (T_2 - T_1)$$

$$T_2 T_4 = T_1 T_3$$

$$\underline{T_1 T_3}$$

$$T_3 - \frac{T_1 T_3}{T_2} = 2.5\,(T_2 - T_1)$$

$$T_3\left(\frac{T_2 - T_1}{T_2}\right) = 2.5\,(T_2 - T_1)$$

$$\frac{T_3}{T_2} = 2.5$$

$$T_3 = 2.5 \times T_2$$

$$T_3 = 2.5 \times 500.5$$

$$\boxed{T_3 = 1251.\,K}$$

$$\eta_T = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$$

$$\eta_T = 1 - \frac{1}{(6)^{\frac{1.4-1}{1.4}}}$$

$$\boxed{\eta_T = 0.4 \Rightarrow 40\%}$$ Ans:

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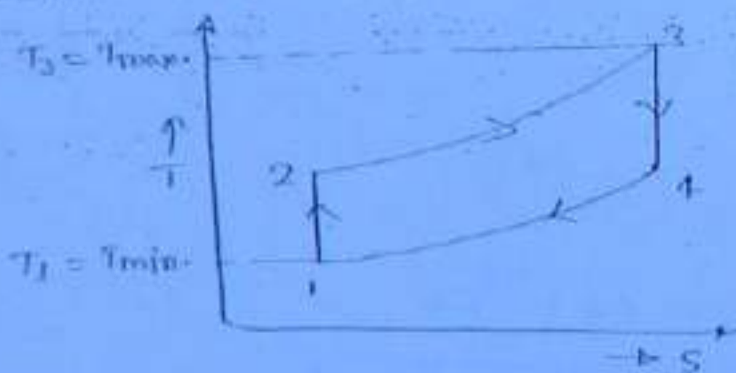
Q8-⑦ In a simple gas Turbine power plant T_1 is minimum Temp. and T_3 is the max. Temp. and what is the work ratio in terms of pressure ratio (r_p).

Sol.



$$r_w = \frac{W_{net}}{W_T}$$

$$r_w = \frac{W_T - W_C}{W_T}$$

$$r_w = 1 - \frac{W_C}{W_T}$$

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

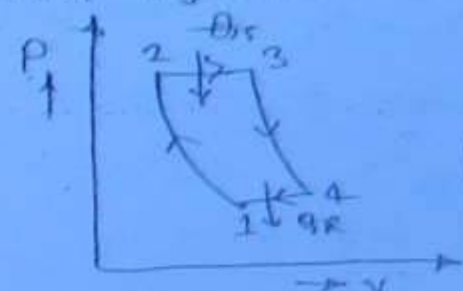
$$r_w = 1 - \frac{C_p(T_2 - T_1)}{C_p(T_3 - T_4)}$$

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

$$\eta_W = 1 - \left(\frac{T_1}{T_3}\left[\frac{(r_P)^{\frac{\gamma-1}{\gamma}}-1}{1-\frac{1}{(r_P)^{\frac{\gamma-1}{\gamma}}}}\right]\right)$$

$$\boxed{r_W = 1 - \frac{T_1}{T_3}(r_P)^{\frac{\gamma-1}{\gamma}}}$$ Ans:

PROB-④ A simple gas Turbine power plant working on Brayton cycle. the power required to drive the compressor is 175 kW Heat supplied during constant pressure heat addition is 675 kW turbine output obtained during expansion is 425 kW. find the heat rejection.



Soln

$W_C = 175$ kW

$W_{net} = Q_S - Q_R$

$W_T - W_C = Q_S - Q_R$

$425 - 175 = 675 - Q_R$

$\boxed{Q_R = 425}$ kW Ans:

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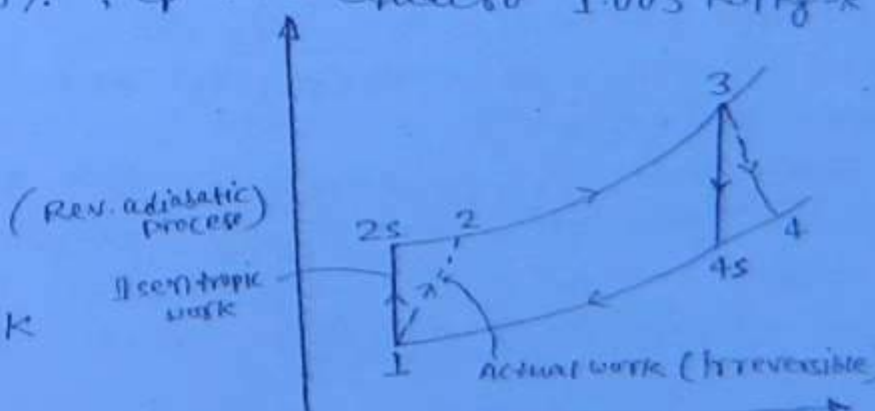
PROB-⑤ A closed cycle gas turbine unit develop a power of 1500 kW the pressure and temp. at the inlet to the compressor are 1 bar and 20°C. Pressure ratio is 6. the max. temp. to the inlet to the Turbine 800°C. find the isentropic efficiency of Turbine and mass flow rate of air if the isentropic efficiency of the compressor is 85% and overall efficiency is 20%. , C_p take equal to 1.005 kJ/kg-K $\gamma = 1.4$.

Soln.



$P = 1500$ kW

$P_1 = 1$ bar

$T_1 = 273 + 20 = 293$ K

$r_P = 6 = \frac{P_2}{P_1}$

$T_3 = 273 + 800 = 1073$ K

$\eta_c = 0.85$

$\eta_o = 0.20$

$$\eta_o = \frac{\cdots}{Q_s}$$

$$\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_{2s}}{293} = (6)^{\frac{1.4-1}{1.4}}$$

$$\boxed{T_{2s} = 488.8\,K}$$

$$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1}$$ $\frac{\text{isentropic work}}{\text{Actual work}}$ $\rightarrow$ less $\rightarrow$ more compression

$$\eta_c = \frac{488.8 - 293}{T_2 - 293}$$

$$0.85 = \frac{488.8 - 293}{T_2 - 293}$$

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$$\boxed{T_2 = 523.4\,K}$$

(2) $$\eta_o = \frac{W_{net}}{Q_s} = \frac{W_T - W_C}{Q_s}$$

$$\eta_o = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_2}$$

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

$$0.20 = \frac{(1073 - T_4) - (523.4 - 293)}{1073 - 523.4}$$

$$\boxed{T_4 = 732.6\,K}$$

$$\frac{T_3}{T_{4s}} = (r_p)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{1073}{T_{4s}} = (6)^{\frac{1.4-1}{1.4}}$$

$$\boxed{T_{4s} = 643.1\,K}$$

$$\eta_T = \frac{T_3 - T_4}{T_3 - T_{4s}} \begin{array}{l} \rightarrow \text{less work} \\ \rightarrow \text{more work (Because more expands decreated.)} \end{array}$$

$$\eta_T = \frac{1073 - 732.6}{1073 - 643.1}$$

$$\eta_T = 79\%$$

(3) $P = m \times W_{net}$

$P = m\,(\eta_0 \times q_s)$

Where $q_s = \underline{h_3 - h_2}$

$q_s = C_p(T_3 - T_2)$

$= 1.005\,(1073 - 523.4)$

$$\boxed{q_s = 552.31\ KJ/Kg}$$

$P = m \times W_{net}$

$1500 = m\,(552.31 \times 0.20)$

$$\boxed{m = 13.5\ Kg/sec}$$ * Ans:

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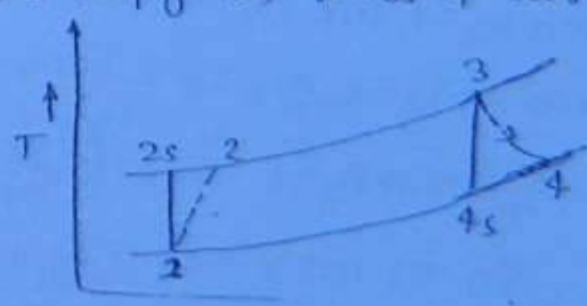
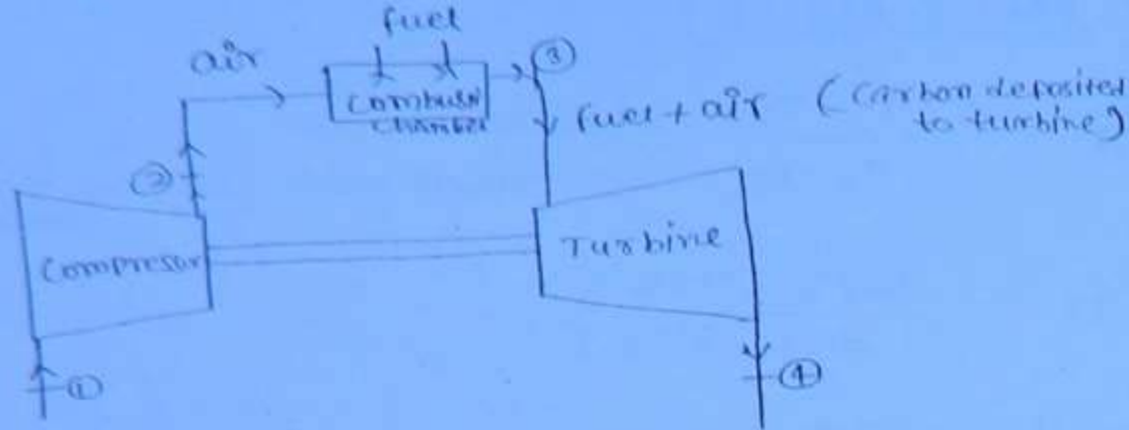
PROB. (6) Air enters the compressor of a gas turbine at a bar and 293K the pressure after compression is 6 bar. Air fuel ratio 60 the isentropic efficiency of compressor and Turbine are 0.84 and 0.88 respectively. Calculate the power developed by the units & its overall efficiency Assume γ to be same for air and combustion product. take specific heat of gases = 1.1 KJ/Kg-K, mass of air 5 kg/sec C_V = 40000 KJ/Kg.

soln





$T_1 = 293$, $\quad r_p = 6$

$\eta_c = 0.84$, $\quad \eta_T = 0.88 \qquad \underline{\gamma = 1.4}$

$$\frac{T_{2s}}{T_1} = (r_p)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_{2s}}{293} = (6)^{\frac{1.4-1}{1.4}}$$

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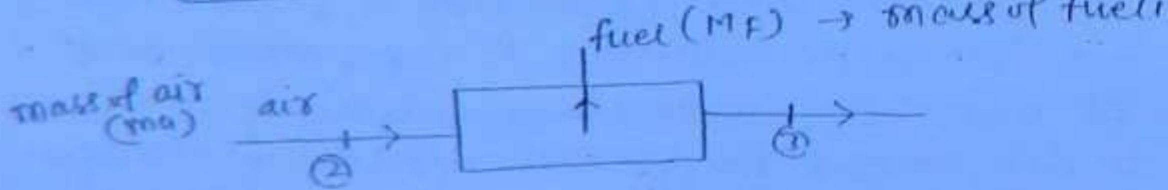
$$\boxed{T_{2s} = 488.87\,K}$$

$$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1} = \frac{\text{isentropic work} \rightarrow \text{less}}{\text{Actual work} \rightarrow \text{more}}$$

$$0.84 = \frac{488.87 - 293}{T_2 - 293}$$

$$\boxed{T_2 = 526.18\,K}$$



Energy eqn.

$$m_a h_2 + m_F C_V = (m_a + m_F)\, h_3$$

$$m_a C_p T_2 + m_F C_V = (m_a + m_F)\, C_{p\,gas} T_3$$

$$\hookrightarrow \frac{m_a}{m_F} C_p T_2 + C_V = \left(\frac{m_a}{m_F} + 1\right) C_{p\,gas} \cdot T_3$$

$$60 \times 1.005 \times 526.18 + 40000 = (60+1) \times 1.1 \times T_3$$

$$T_3 = 1050.3\,K$$

$$\frac{T_3}{T_{4s}} = \left(\frac{P_3}{P_{4s}}\right)^{\frac{\gamma-1}{\gamma}} = (r_p)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{1059.3}{T_{4s}} = (6)^{\frac{1.4-1}{1.4}}$$

$$\boxed{T_{4s} = 635\ K}$$

$$\eta_T = \frac{T_3 - T_4}{T_3 - T_{4s}}$$

$$0.88 = \frac{1059.3 - T_4}{1059.3 - 635}$$

$$\boxed{T_4 = 685.8\ K}$$

* $W_C = m_a (h_2 - h_1)$ → Compressor work

$$= m_a \times C_p (T_2 - T_1)$$

$$= 5 \times 1.005 (526.18 - 293)$$

$$\boxed{W_C = 1171.72}\ kW$$

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* Turbine work $W_T = (m_a + m_F)(h_3 - h_4)$

$$= (m_a + m_F)\, C_{p_{gas}} (T_3 - T_4)$$

$$= \left(5 + \frac{5}{60}\right) \times 1.11 \times (1059.3 - 685.5)$$

$$\boxed{W_T = 2107\ kW}$$

$$W_{net} = W_T - W_C$$

$$= 2107 - 1171.72$$

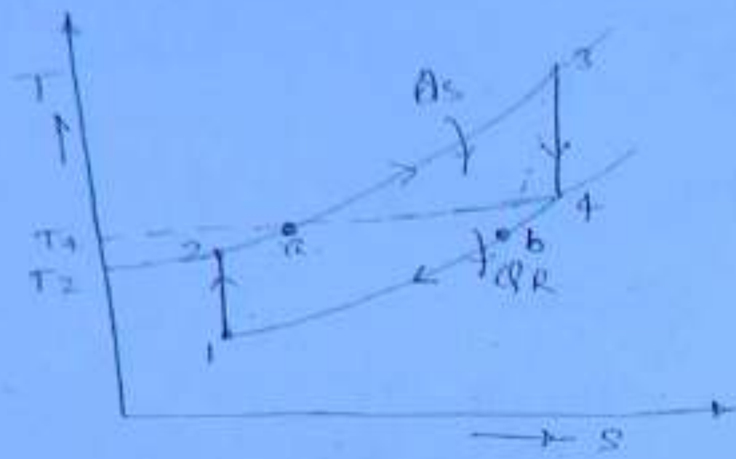
$$\boxed{W_{net} = 935.7}$$

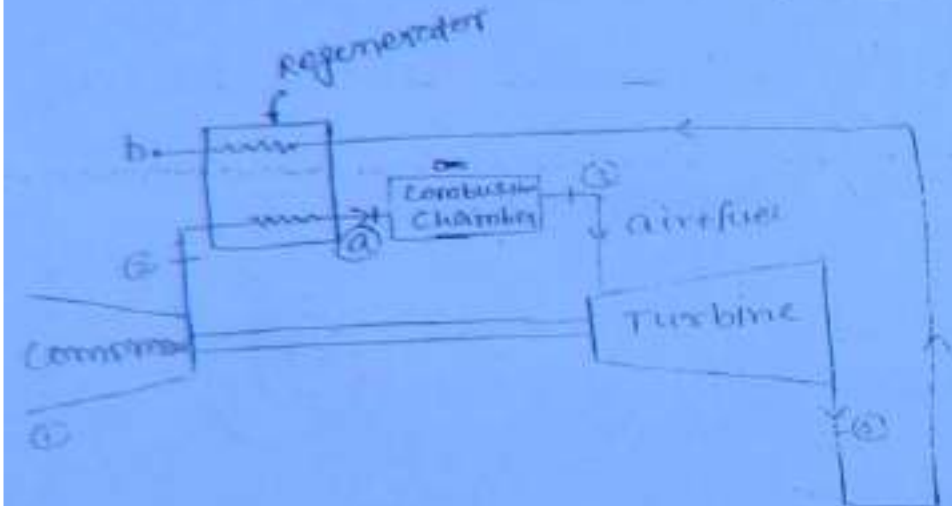
$$q_s = m_F \times C_V$$

$$\eta_o = \frac{W_{net}}{q_s} \Rightarrow \frac{W_{net}}{m_F \times C_V} \Rightarrow \frac{935.7}{\frac{5}{60} \times 40000}$$

$$\eta_o = 0.2807 \quad \text{(Ans.)}$$

USE OF REGENRATOR IN GAS TURBINE ⇒





$$\eta_0 = \frac{W_{net}}{Q_S} = \frac{W_T - W_C \rightarrow \text{constant}}{Q_S \downarrow \text{decreases}}$$

When ~~than~~ Q_S is decreases than efficiency of gas turbine increases.

effect of Regeneration ⇒

① No change in compressor work.
② No change in Turbine work.
③ No change in Net work.
④ Reduction in heat supplied.
⑤ Increase in Turbine efficiency.

$$\eta = \frac{W_T - W_C}{Q_S} \Rightarrow \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_a}$$

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

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

(#) effectiveness of Regenerator ⇒

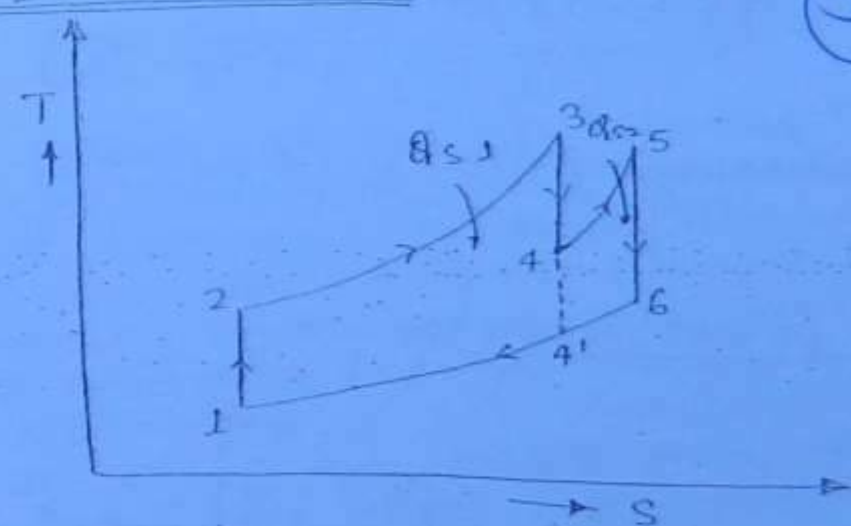
It is the ratio of Actual rise in temp. to the ideal Rise in Temperature.

$$\epsilon = \frac{\text{Actual rise in temp.}}{\text{Ideal rise in temp.}}$$

$$\boxed{\epsilon = \frac{t_a - t_2}{t_4 - t_2}} \quad **$$

For effective utilisation of Regenerator the temp. differen between T_4 and T_2 should be large.

(#) USE OF REHEATING IN GAS TURBINE ⇒ 93



W_T (simple cycle) $= h_3 - h_4' = (h_3 - h_4) + (h_4 - h_4')$

W_T (Reheat cycle) $= (h_3 - h_4) + (h_5 - h_6)$

$W_{net} = W_T - W_C$ when W_C = constant then W_T increase the network increa

As constant pressure line diverge

$$h_5 - h_6 > h_4 - h_4'$$

$\therefore W_T$ (reheat cycle) $> W_T$ (without reheat)

$$\eta = \frac{W_{net} \uparrow}{Q_s \uparrow}$$ then efficiency will be decreases

→ with reheating the net work increases this does not mean an increase in efficiency of the cycle cause with reheating the reheat supplied is also increased th reheat because the temp $T_6 > T_4'$ and hence however reheating is used it is generally coupled th regeneration. Therefore Regeneration from efficiency increases and due to Reheating from W_{net} increases.

$$\eta = \frac{W_T - W_c}{Q_s}$$

$$\eta = \frac{[(h_3-h_4)+(h_5-h_6)] - [h_2-h_1]}{(h_3-h_2)+(h_5-h_4)}$$

$$\eta = \frac{[(T_3-T_4)+(T_5-T_6)] - [T_2-T_1]}{(T_3-T_2)+(T_5-T_4)}$$

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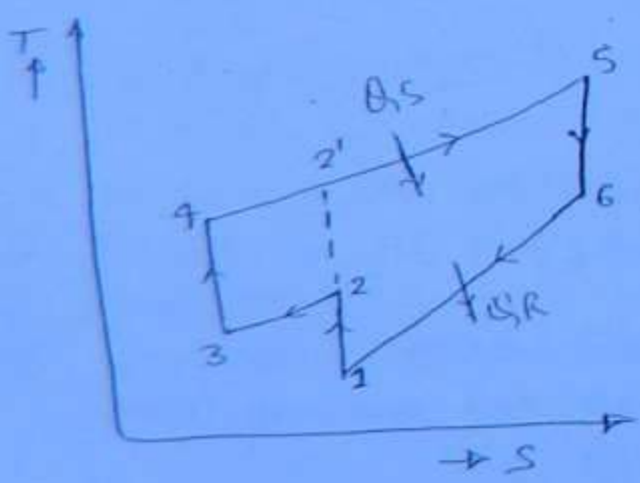
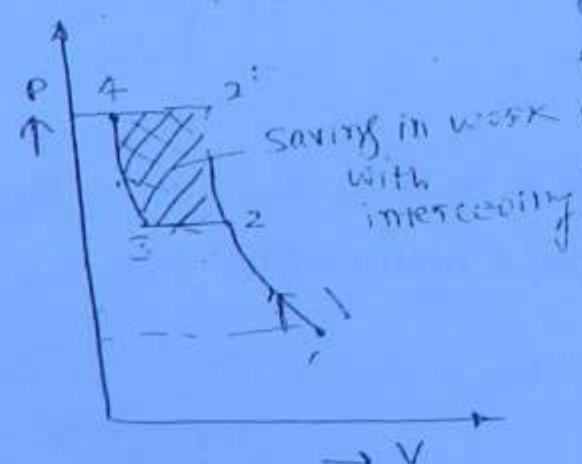
∴ Due to Reheating efficiency of the cycle decreases (↓)

Inter cooling in GAS Turbine ⇒





$W_{net} = W_T - W_c$

$$\downarrow \eta = \frac{W_{net} \uparrow}{Q_s \uparrow}$$

⊕ Intercooling in gas Turbine :→

In Inter cooling the work of compression decreases and this result in increase in Net work but this does not mean an increase in efficiency because the heat supplied also increases. but with inter cooling the scope of for Regeneration increases because $T_4 < T_2'$. and hence inter cooling is generally coupled with regeneration. →

① due to inter cooling efficiency of cycle decreases (↓)

$$\eta = \frac{W_T - W_C}{Q_S}$$

$$\eta = \frac{(h_5 - h_6) - [(h_2 - h_1) + (h_4 - h_3)]}{h_5 - h_4}$$

$$\boxed{\eta = \frac{(T_5 - T_6) - [(T_2 - T_1) + (T_4 - T_3)]}{T_5 - T_4}}$$

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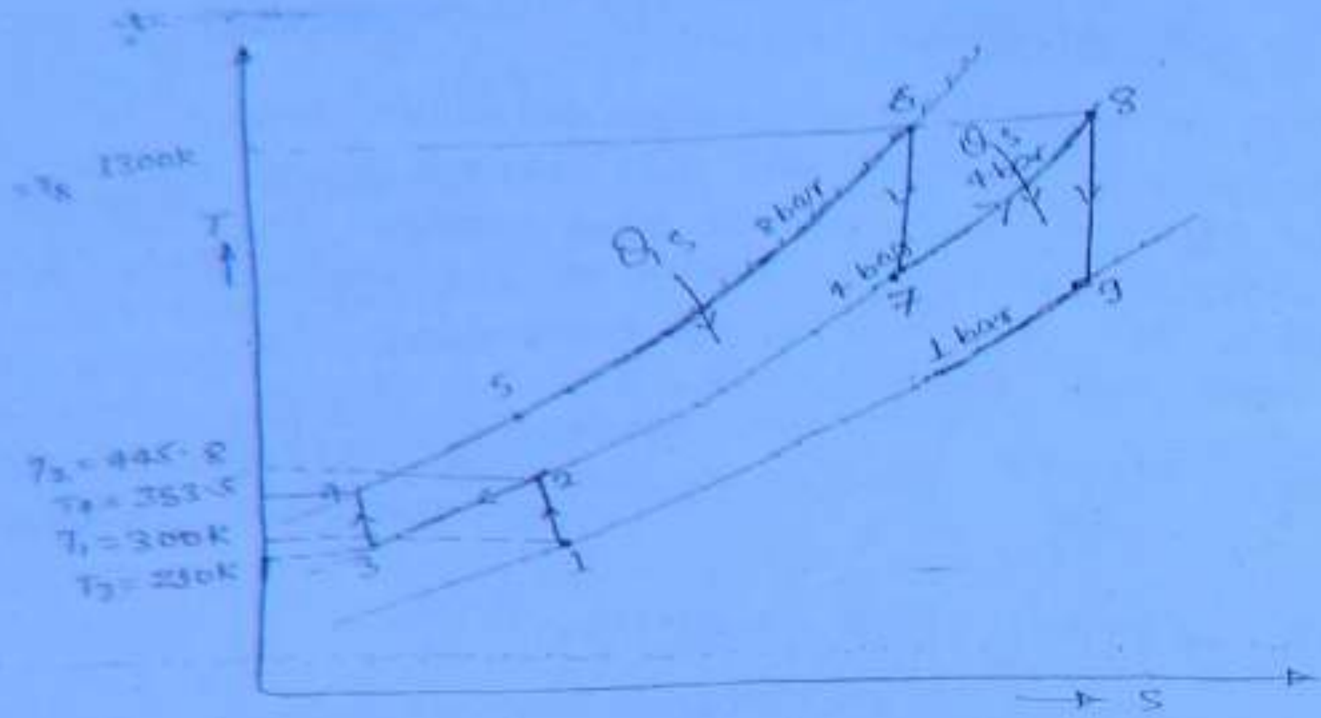
PROB-① A Regenerative reheat cycle has air entering at 1 bar, 300K into the compressors, having inter cooling in between two stage of compression air leaving first stage of compression is cooled upto 290K and 4 bar pressure in intercooler and subsequently compressed to 8 bar compressed air leaving second stage compressor is passed through a regenerator having an effectiveness of 0.8. subsequent combustion its 1300K at inlet to the turbine having expansion upto 4 bar and then heated upto 1300K before being expand upto 1 bar. exhaust from turbine is passed to regenerator. find the total turbine work and efficiency consider compression and expansion to the isentropic and air as the working fluid through out the cycle.



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

$$\frac{T_2}{300} = \left(\frac{4}{1}\right)^{\frac{1.4-1}{1.4}}$$

$$\boxed{T_2 = 445.8K}$$

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

$$\frac{T_4}{290} = \left(\frac{8}{4}\right)^{\frac{1.4-1}{1.4}}$$

$$\boxed{T_4 = 353.5K}$$

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$$\frac{T_6}{T_7} = \left(\frac{P_6}{P_7}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{1300}{T_7} = \left(\frac{8}{4}\right)^{\frac{1.4-1}{1.4}}$$

$$\boxed{T_7 = 1066.4K}$$

$$\frac{T_8}{T_9} = \left(\frac{P_8}{P_9}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{1200}{T_9} = \left(\frac{4}{1}\right)^{\frac{1.4-1}{1.4}}$$

$$\boxed{T_9 = 874.83K}$$

$$\epsilon = \frac{T_5 - T_4}{T_9 - T_4}$$

$$0.8 = \frac{T_5 - 353.5}{874.83 - 353.5}$$

$$\boxed{T_5 = 770.6K}$$

$$W_T = (h_6 - h_7) + (h_8 - h_9)$$

$$W_T = C_p(T_6 - T_7) + C_p(T_8 - T_9)$$

$$= 1.005(1300 - 1066.4) + 1.005(1300 - 874.8)$$

$$\boxed{W_T = 662 \text{ KJ/kg}}$$

$$\eta = \frac{W_T - W_C}{Q_s}$$

$$W_C = (h_2 - h_1) + (h_4 - h_3)$$

$$= C_p(T_2 - T_1) + C_p(T_4 - T_3)$$

$$= 1.005(445.8 - 300) + 1.005(353.5 - 290)$$

$$\boxed{W_C = 210 \text{ KJ/kg}}$$

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$$Q_s = (h_6 - h_5) + (h_8 - h_7)$$

$$Q_s = C_p(T_6 - T_5) + C_p(T_8 - T_7)$$

$$= 1.005(1300 - 770.5) + 1.005(1300 - 1066.4)$$

$$\boxed{Q_s = 766.8}$$

$$\eta = \frac{W_T - W_C}{Q_s} \Rightarrow \frac{662 - 210}{766.8}$$

$$\eta = 0.589$$

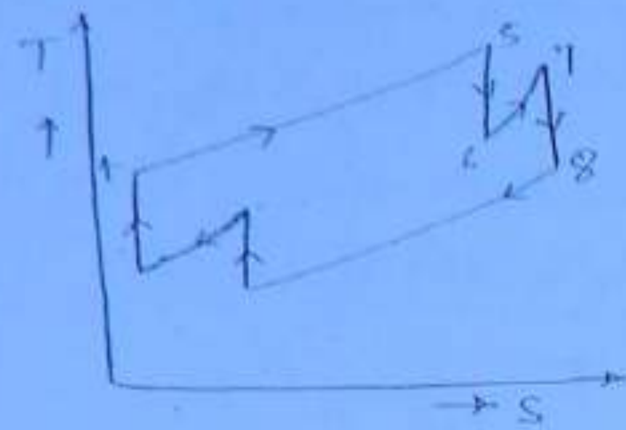
$$\boxed{\eta = 58.9\%}$$ Ans

I.E.S

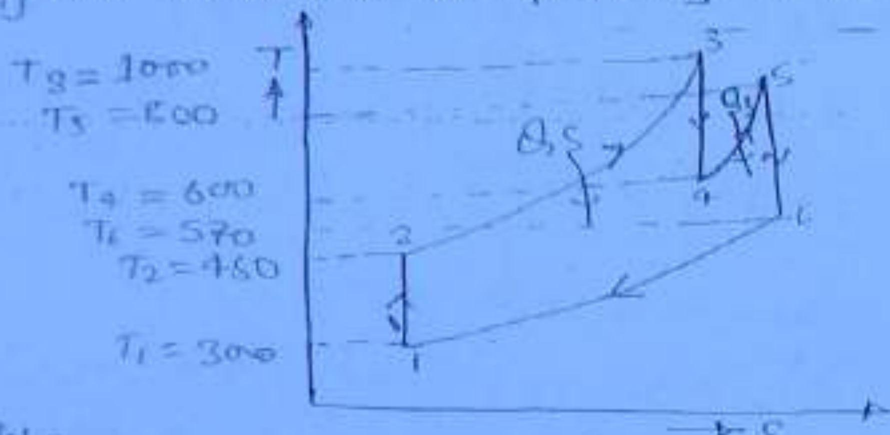
PROB-2 The cycle shown in figure represent a gas turbine cycle with inter cooling and reheating on T-S diagram.

match list 1 — match list 2

1. Inter cooler → 2-3
2. combustor → 4-5
3. Reheater → 6-7
4. High press. compressor → 3-4



Q.(3) The given figure shows a gas turbine cycle employing reheating on T-S diagram then find the efficiency of the cycle.



Soln

$$\eta = \frac{W_T - W_C}{Q_S}$$

(98)

$$= \frac{[(h_3 - h_4) + (h_5 - h_6)] - (h_2 - h_1)}{(h_3 - h_2) + (h_5 - h_4)}$$

$$= \frac{(T_3 - T_4) + (T_5 - T_6) - (T_2 - T_1)}{(T_3 - T_2) + (T_5 - T_4)}$$

$$\eta = \frac{(1000 - 600) + (800 - 570) - (450 - 300)}{(1000 - 450) + (800 - 600)}$$

$$\eta = 0.64 = 64\% \text{ Ans}$$

Prob-10 In a simple gas turbine power plant operating on standard Brayton cycle 175 kW is Required to drive the compressor heat supplied during constant pressure heat addition process is 675 kW The turbine power is 425 kW than what is the heat rejection

Soln

$$Q_S = 675$$
$$W_T = 425$$
$$W_C = 175$$

$Q_R = ?$

$$\Sigma Q = \Sigma W$$
$$Q_S - Q_R = W_T - W_C$$
$$675 - Q_R = 425 - 175$$
$$\boxed{Q_R = 425}$$ Ans.

Optimum pressure ratio for min. work input ⇒ (with perfect intercooling)

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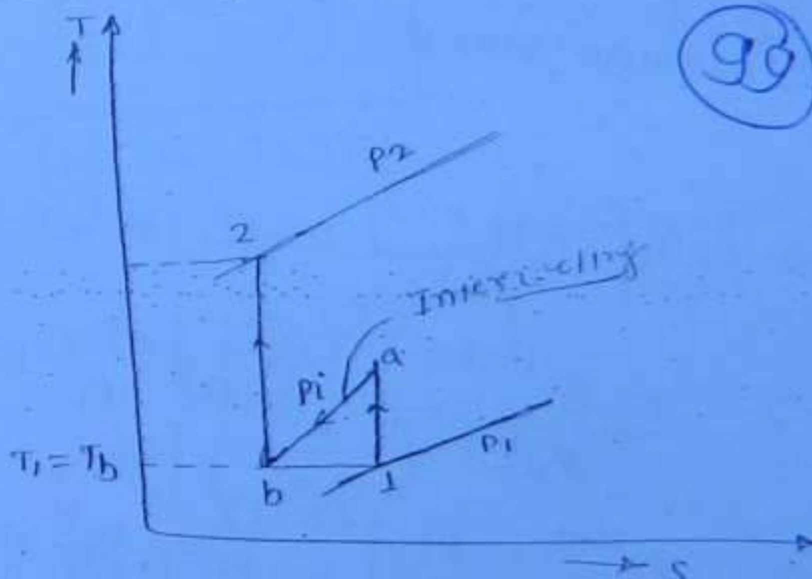

$$W_C = W_{C_1} + W_{C_2}$$
$$W_C = (h_a - h_1) + (h_2 - h_b)$$
$$W_C = C_p(T_a - T_1) + C_p(T_2 - T_b)$$
$$W_C = C_p\left[T_a - T_1 + T_2 - T_b\right]$$
$$W_C = C_p T_1\left[\frac{T_a}{T_1} - 1 + \frac{T_2}{T_q} - \frac{T_b}{T_1}\right]$$

because $\boxed{T_b = T_1}$

$$W_c = C_p T_1 \left[\frac{T_a}{T_1} - 1 + \frac{T_2}{T_1} - 1 \right]$$

$$W_c = C_p T_1 \left[\left(\frac{P_i}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 2 + \left(\frac{P_2}{P_i} \right)^{\frac{\gamma-1}{\gamma}} \right]$$

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

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

Let $\frac{\gamma-1}{\gamma} = K$ Constant

$$W_c = C_p T_1 \left[\left(\frac{P_i}{P_1} \right)^K - 2 + \left(\frac{P_2}{P_i} \right)^K \right]$$

$$W_c = C_p T_1 \left[\frac{P_i^K}{P_1^K} - 2 + \frac{P_2^K}{P_i^K} \right]$$

P_1 and P_2, C_p, T, K constant only variable P_i

For minimum work

$$\frac{dW}{dP_i} = 0$$

$$\Rightarrow C_p T_1 \left[\frac{K P_i^{K-1}}{P_1^K} - 0 + P_2^K \left(-K P_i^{-K-1} \right) \right]$$

$$\Rightarrow \frac{K P_i^{K-1}}{P_1^K} = K P_2^K P_i^{-(K+1)}$$

$$\Rightarrow P_i^{K-1} \cdot P_i^{+(K+1)} = P_2^K P_1^K$$

$$P_i^{2K} = (P_1 \cdot P_2)^K$$

$$P_i^2 = P_1 P_2$$

$$\boxed{P_i = \sqrt{P_1 P_2}}$$ ✱ ✱ ✱ ✱ ✱

Intermediate pressure = Geometric Mean of P_1 and P_2

$P_1 \rightarrow$ Inlet ~~compressor~~ pressure for compressor 1

$$\boxed{W_{c1} = W_{c2}}$$

$$W_c = W_{c1} + W_{c2} = 2 W_{c1}$$

$$\boxed{W_c = 2 C_p T_1 \left[\left(\sqrt{\frac{P_2}{P_1}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]}$$

For perfect inter cooling equal work input for each compressor will required.

$$W_{c1} = h_a - h_1$$

$$W_{c1} = C_p (T_a - T_1)$$

$$= C_p T_1 \left[\frac{T_a}{T_1} - 1 \right]$$

$$= C_p T_1 \left[\left(\frac{P_i}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

where $P_i = \sqrt{P_1 P_2}$

$$W_{c1} = C_p T_1 \left[\left(\frac{\sqrt{P_1}\sqrt{P_2}}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

$$\boxed{W_{c1} = C_p T_1 \left[\left(\sqrt{\frac{P_2}{P_1}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]}$$

(a)

$$W_{c2} = h_2 - h_b = C_p (T_2 - T_b)$$

$$= C_p T_b \left[\frac{T_2}{T_b} - 1 \right]$$

where $T_b = T_1$

$$= C_p T_1 \left[\left(\frac{P_2}{P_i} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

$$= C_p T_1 \left[\left(\frac{P_2}{\sqrt{P_1 P_2}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

$$W_{c2} = C_p T_2 \left[\left(\sqrt{\frac{P_2}{P_1}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

$$W_{c2} = W_{c1}$$

$$W_c = W_{c1} + W_{c2}$$

$$W_c = 2 W_{c1}$$

$$\boxed{W_c = 2 C_p T_1 \left[\left(\sqrt{\frac{P_2}{P_1}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]}$$

Vapour power cycles (Rankine cycle)

Reason for using water as a working fluid in vapour power cycle.

1) It is cheap.
2) It is chemically stable.
3) It is harmless substance.

Specific steam consumption :→

$$SSC = \frac{\text{mass of steam}}{P_{net}} = \frac{m_s}{P_{net}} \rightarrow \frac{kg/s}{kJ/sec}$$

$$SSC = \frac{m_s}{m_s \times W_{net}} \rightarrow \frac{kg/s}{kg/s \cdot kJ/kg}$$

$$SSC = \frac{1}{W_{net}\ kJ/kg} \Rightarrow \frac{kg}{W_{net}\ kJ}$$

$$SSC = \frac{kg}{W_{net}\ \frac{kJ \times sec}{sec}}$$

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$$SSC = \frac{kg}{W_{net}\ kW sec}$$

$$SSC = \frac{kg}{W_{net}\ kW \times \frac{1}{3600}\ hr}$$

$\because$ 1 hr = 3600 sec

$\Rightarrow$ $\frac{1}{3600}$ hr = 1 sec

$$SSC = \frac{3600\ kg}{W_{net}\ kW\ hr}$$

If the net work is more specific steam consumption is less and hence mass flow rate of steam will be less and hence the size of the plant will be small.

Carnot cycles :⇒

$$\boxed{W_{net} = W_T - W_C}$$