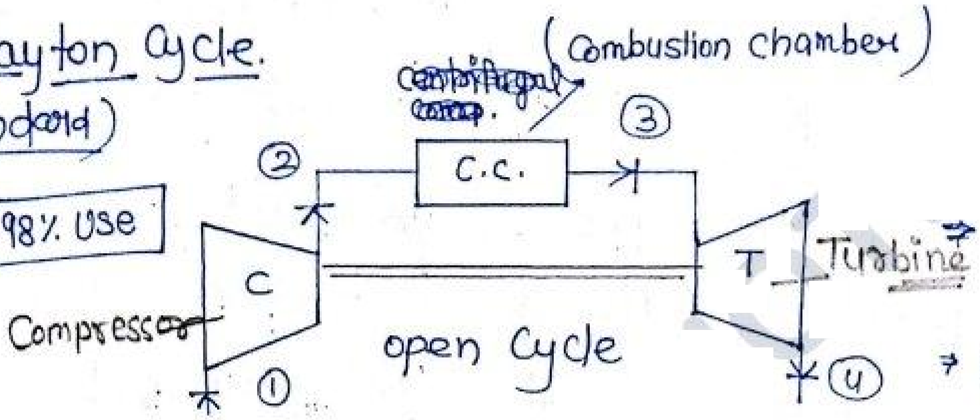
Important
- Regeneration
- Reheating
- Intercooling

Imp

Gas Turbine :-

Brayton Cycle.
(Airstandard)

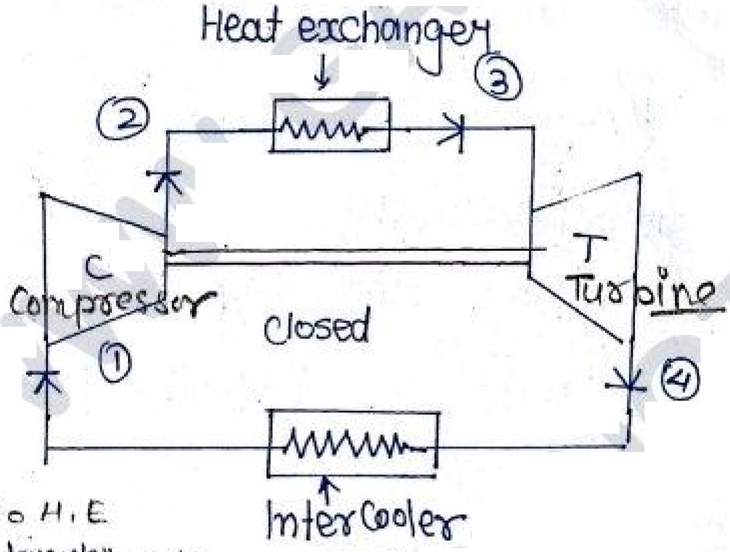
98% use



⇒ Always work above Patm.
⇒ High Grade fuel.

2% use

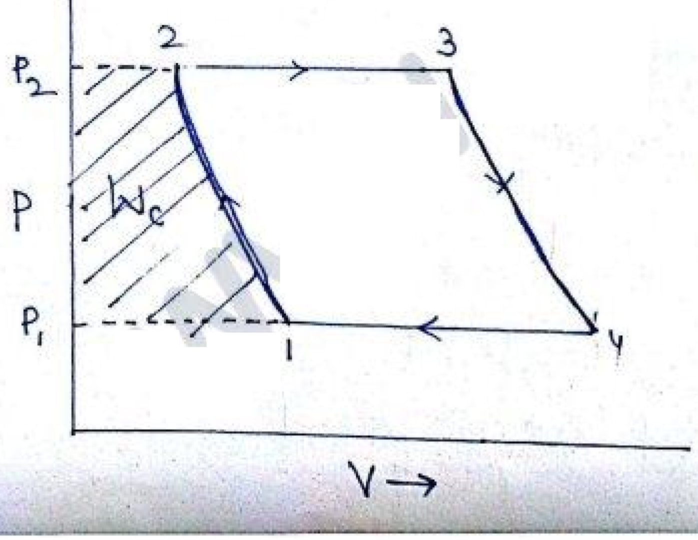
Normally ships & submarine

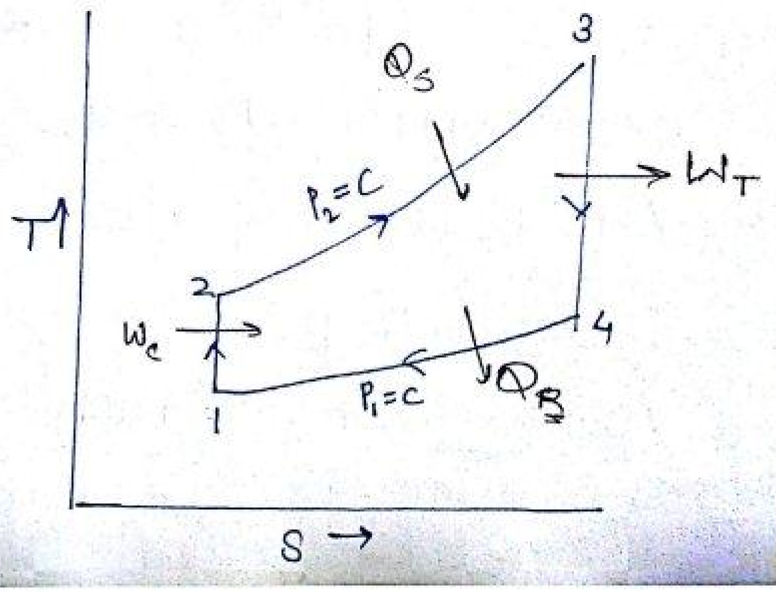


⇒ Can also work below atm. pressure.
⇒ low Grade fuel can also use.
⇒ due to -ve pressure Air mix up & chemical Compⁿ change.

due to H.E & Intercooler require more space

⇒ In open flow work obtain on P





* Brayton cycle is the practicle working cycle and it consist of p four process.

1-2 Rev. adiabatic compression from lower to higher pressure in a compressor.

2-3 Constant pressure heat addition process either directly in the combustion chamber or indirectly in heat exchanger

3-4 Reversible adiabatic expanssion in Gas turbine.

4-1 Constant pressure heat rejection process either directly to atmosphere or indirectly in an intercoolar

Advantages of close cycle:-

① Between the same temprature limit it is more efficient and compact.

② Any better properties working substance like Helium, Argon can be used.

③ Any lower Grade fuel can be used as working substance is not mixed with fuel.

④ It can work below atmospheric pressure.

⑤ There is no problem of turbine blade erosion.

Disadvantages of Close Cycle :-

① Cycle becomes Complicated, Costly, & bulky

② Absolute leakproofing of below Patm is very difficult.

③ Because of being bulky can not be used for aircraft application.

Air standard Assumption :-

① Air is the working substance throughout and it's chemical Composition doesn't change.

② C_p, C_v & γ, Values remain Constant irrespective of temp. change.

③ Changes in kinetic & potential energy are neligible.

④ Compression and expansion process are adiabatic i.e. there is no heat loss.

⑤ There is no loss of pressure while flow takes place through Various Component

1) Process 1 - 2 (W_c)

By steady flow energy eq^n ① & ②

$$\Rightarrow h_1 + \frac{V_1^2}{2} + z_1 \cdot g + Q_{1-2} = h_2 + \frac{V_2^2}{2} + z_2 \cdot g + W_{1-2}$$

$V_1 = V_2$, $z_2 = z_1$, $Q_{1-2} = 0$

$W_{1-2} = -W_c \rightarrow$ work done on system.

$$\Rightarrow \quad h_1 = h_2 - W_c$$

$$\boxed{W_c = h_2 - h_1 = C_p(T_2 - T_1)}$$

2) Process 2-3 (Q_s)

By SFEE ② & ③

$$\Rightarrow h_2 + \frac{V_2^2}{2} + z_2 \cdot g + Q_{2-3} = h_3 + \frac{V_3^2}{2} + z_3 \cdot g + W_{2-3}$$

$V_2 = V_3$, $z_2 = h_3$, $W_{2-3} = 0$ (H.E.)

$Q_{2-3} = Q_s$

$$h_2 + Q_s = h_3$$

$$\boxed{Q_s = h_3 - h_2 = C_p(T_3 - T_2)}$$

③ Process 3 - 4 (W_T)

$$h_3 = h_4 + W_T$$

$$\boxed{W_T = h_3 - h_4 = C_p(T_3 - T_4)}$$

4) Process 4-1 (Q_R)

$$h_4 - Q_R = h_1$$

$$\boxed{Q_R = h_4 - h_1 = C_p(T_4 - T_1)}$$

Now

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

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

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

*
$$\boxed{W_{net} = Q_S - Q_R = W_T - W_c}$$

$\Rightarrow$ $E_{in} = E_{out}$

$$Q_s + W_c = Q_R + W_T$$

$$\boxed{Q_s - Q_R = W_T - W_c}$$

Process 1-2 is isentropic

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

Pressure Ratio $= r_p = \dfrac{P_2}{P_1}$

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

process 3-4

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

$$P_2 = P_3 \ \& \ P_4 = P_1$$

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

**

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

Temp. ratio Always equal for simple brayton cycle.

Efficiency for simple brayton Cycle:

$$\eta = 1 - \frac{Q_R}{Q_S} = 1 - \frac{h_4 - h_1}{h_3 - h_2}$$

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

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

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

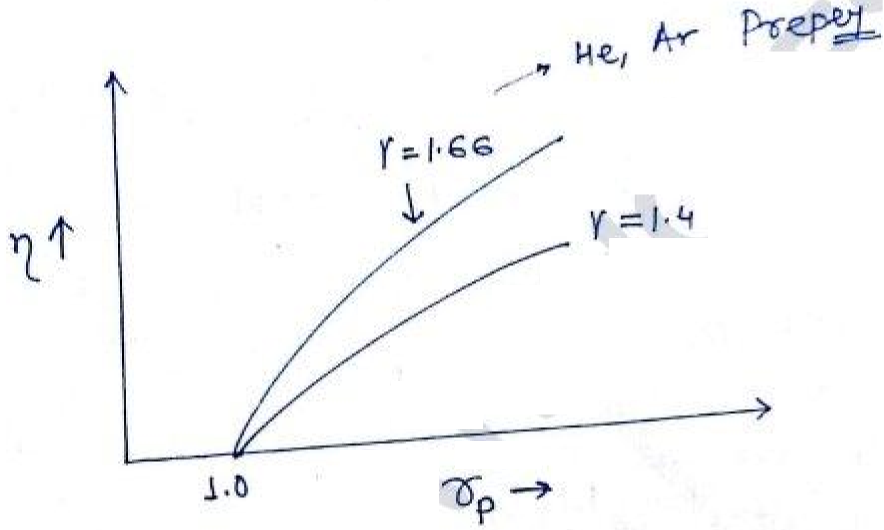
$$\frac{T_4}{T_1} = \frac{T_3}{T_2}$$

*

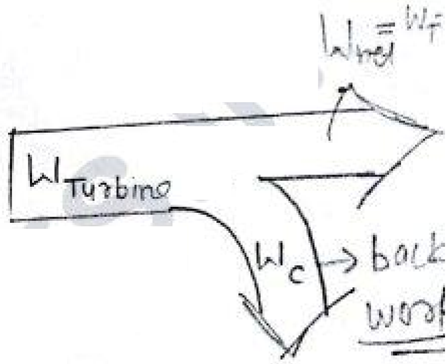
$$\boxed{\eta = 1 - \frac{T_1}{T_2} = 1 - \frac{1}{\left(T_2/T_1\right)}}$$

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

Note:- For a simple brayton cycle efficiency increases with increase in pressure Ratio and γ value.



* Back Work Ratio (r_{bw})



$$r_{bw} = \frac{-\text{ve work in cycle}}{+\text{ve work in cycle}}$$

*

$$\boxed{r_{bw} = \frac{W_c}{W_T}}$$

This should be less

* Gas turbine P.P. → 40% to 60%.
* Steam P.P. → 1% to 2%.

* Work Ratio :- (r_w)

$$r_w = \frac{\text{Net work in a Cycle}}{+\text{ve work in a cycle}}$$

This should be more

*

$$\boxed{r_w = \frac{W_{net}}{W_T} = \frac{W_T - W_c}{W_T} \Rightarrow 1 - \frac{W_c}{W_T}}$$

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

work ratio $r_{bw} = 1 - r_{bw}$ This should be high

Gas Turbine → 40% to 60%

Steam P.P. → 98% to 99%

* <u>Air Rate</u>:- (AR): It is the mass flow rate of Air require to produced 1 kW power output

$$\boxed{AR = \frac{\dot{m}_a}{P}} \quad \begin{matrix} \leftarrow kg/s \\ \leftarrow kW \end{matrix}$$

$$\boxed{P = \dot{M}_a \cdot W_{net}}$$

$$\underset{kW}{P} \quad \underset{kg/s}{\dot{M}_a} \quad \underset{kJ/kg}{W_{net}}$$

$$\boxed{AR = \frac{1}{W_{net}}} \quad \frac{kg}{kJ} \text{ or } \frac{kg}{kWs}$$

$$\boxed{AR = \frac{3600}{W_{net}}} \quad \frac{kg}{kWh}$$

* Specific ~~fuel~~ Air consumption:-

$$\left(\frac{kg}{kWh}\right)$$

$$SFC = \frac{\dot{m}_f\,(kg/h)}{W_{net}\,(kW)}$$

Que:- A brayton cycle has pressure ratio 6 has inlet Cond^n of 1 bar & 27°c find mass flow rate of air require to produce 500 kW of power output if max. temp. in cycle is 1000°c ($r = 1.4$ & $C_p = 1$ kJ/kg

Sol^n

$$P = m_a W_{net} \qquad W_{net} = W_T - W_c$$

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

$$\frac{T_2}{T_1} = (r_p)^{\frac{r-1}{r}} \qquad W_{net} = -C_p(T_2 - T_1) + C_p(T_3 - T_4)$$

$$T_2 = 300(6)^{\frac{1.4-1}{1.4}} = \underline{500.55K} \qquad W_{net} = C_p[-T_2 + T_1 + T_3 - T_4]$$

$$T_3 = 1273K$$

$$T_4 = \frac{1273}{(6)^{\frac{1.4-1}{1.4}}} \qquad \frac{T_2}{T_1} = \frac{T_3}{T_4} \Rightarrow T_4 = \frac{300 \times 1273}{500.55}$$

$$T_4 = \underline{762.95 K}$$

$$W_{net} = 1[-500.55 + 300 + 1273 - 762.95]$$

$$P = 500kW = m_a \cdot W$$

$$m = 1.612 \text{ kg/s}$$

Ques Air enter the compressor at 1 bar, 27°C having a pressure ratio 5. If the turbine work is 2.5 time compressor work find out the cycle eff. & max. temp. of cycle.

Sol^n $r_p = 5$ $P_1 = 1$ bar, $T_1 = 300K$

$W_T = 2.5\, W_c$

$(T_3 - T_4) = 2.5\,(T_2 - T_1)$

$\frac{T_2}{T_1} = (5)^{2/7}$

$T_2 = 300(5)^{2/7}$

$T_2 = 475.14$

$\Rightarrow \frac{T_2}{T_1} = \frac{T_3}{T_4} = \frac{475.14}{300}$

$T_3 = 1.583\, T_4$

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

$T_4 = 0.631 T_3$

0.368 $T_3 = 2.5(475.14 - 300)$

$T_3 =$

$T_3 = \underline{1187.8\,K}$

$\Rightarrow \eta = 1 - \frac{1}{(r_p)^{\frac{1-r}{r}}} = 1 - \frac{1}{(5)^{2/7}}$

$\eta = 36.86\%$

Ques Air enters in a compressor of a Gas turbine operating on brayton cycle 1 bar, 27°C the pressure ratio is 6. Cal. the max. temp. in cycle when back work ratio is 0.35.

$$\gamma_b = 0.35 = \frac{W_c}{W_T}$$

$$(T_2 - T_1) = 0.35\,(T_3 - T_4)$$

$$\frac{T_2 - T_1}{T_3 - T_4} = 0.35$$

$$\Rightarrow 0.35 = \frac{T_2}{T_3}$$

$$\frac{T_2}{T_1} = (\gamma_p)^{\frac{\gamma-1}{\gamma}} = (6)^{\frac{1.4-1}{1.4}} = 300(6)^{\frac{0.4}{1.4}}$$

$$T_2/T_1 = T_3/T_4 \qquad T_3 = \frac{T_2 \cdot T_4}{T_1}$$

$$T_3 = 300(6)^{2/7} \times \frac{1}{0.35}$$

$$T_3 = 1430\,\underline{\underline{K}}$$

$$\gamma_b = \frac{W_c}{W_T} = 0.35$$

$$\frac{T_2 - T_1}{T_3 - T_4} = 0.35 \Rightarrow \frac{T_2\left(1 - \frac{T_1}{T_2}\right)}{T_3\left(1 - T_4/T_3\right)} = 0.35$$

$$\cancel{T_1\left(\frac{T_2}{T_1} - 1\right)}$$

$$T_2/T_3 = 0.35 = \frac{T_1}{T_4}$$

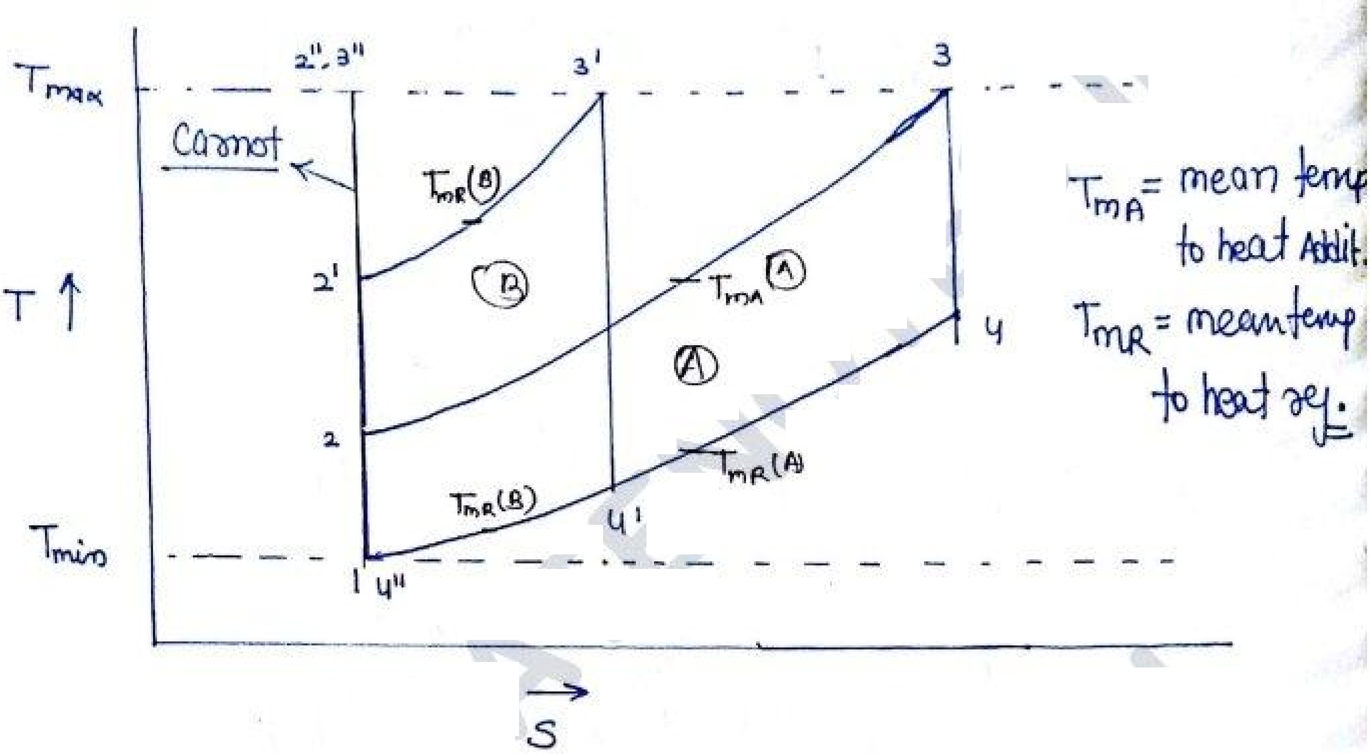
$$T_2/T_1 = T_3/T_4$$

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

$$T_3 = 300\,(6)^{2/7} \times \frac{1}{0.35}$$

$$T_3 = 1430\,K$$

Effect of pressure ratio on efficiency & Net work output.



* In actual working gas turbine cycle work between the two temp. limit one is the maximum temp. that depands upon the metallorgical condition of turbine blade and second the mini. temp. which depands upon atmospheric condition.

* When $r_p = 1$ both efficincy and W_{net} will be zero as r_p increases both start increasing and ~~ma~~ become max^m when the compression process end at max. temp limit. at this point ~~eff~~ η become equal to carnot but W_{net} again becomes zero. because $Q_s = 0$

Pressure Ratio for maximum efficiency :-

$$* \quad (r_p)_{max} = \left(\frac{T_{max}}{T_{min}}\right)^{\gamma/\gamma-1}$$

$\frac{T_{max}}{T_{min}} = (r_p)^{\frac{\gamma-1}{\gamma}}$

$r_p = \frac{P_{max}}{P_{min}}$

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

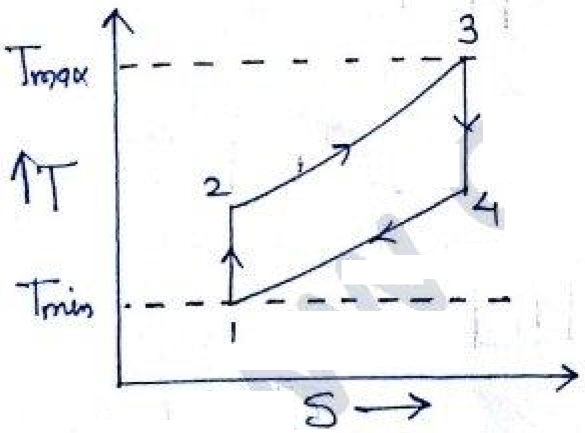
$$* \quad \boxed{\eta_{max} = 1 - \frac{T_{min}}{T_{max}}} = \text{efficiency of Carnot}$$

- As $r_p \uparrow$, $\eta \uparrow$ because $T_{mA} \xrightarrow{\text{Approach}} T_{max}$

$T_{mR} \xrightarrow{\text{approach}} T_{min}$

- $\eta = \frac{W_{net} \to 0}{Q_S \to 0}$ Net workdone, heat supplied Also zero.

Pressure Ratio (r_p) for max workoutput (W_{net})



$$W_{net} = W_T - W_C$$
$$= C_p[T_3 - T_4 - T_2 + T_1]$$

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

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

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

As T_3 & T_1 are fixed temp. for W_{net} to be maximum.

$$\frac{dW_{net}}{dT_2} = 0$$

$$-\frac{T_3 T_1(-1)}{T_2^2} - 1 = 0$$

$$T_2^2 = T_3 \cdot T_1$$

☆☆☆

$$\boxed{T_2 = \sqrt{T_3 \cdot T_1} = T_4}$$

maximum W_{net}

$$W_{net} = C_p\left[T_3 - T_4 - T_2 + T_1\right]$$

as $T_2 = T_4 = \sqrt{T_3 \cdot T_2}$

$$(W_{net})_{max} = C_p\left[T_3 - 2\sqrt{T_3 \cdot T_2} - T_1\right]$$

$$\boxed{(W_{net})_{max} = C_p\left[\sqrt{T_3} - \sqrt{T_1}\right]^2}$$

optimum pressure Ratio

$$(r_p)_{opt} = \left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}} = \left(\frac{\sqrt{T_3 \cdot T_1}}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$$

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

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

$$\boxed{(r_p)_{opt} = \left(\frac{T_3}{T_1}\right)^{\frac{\gamma}{2(\gamma-1)}} = \sqrt{(r_p)_{max}}}$$

$$r_{opt} = \left(\frac{T_3}{T_1}\right)^{\frac{2\gamma}{3(\gamma-1)}}$$

for two stage.

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

**

$$\boxed{\eta_{opt} = 1 - \sqrt{\frac{T_1}{T_3}}}$$

* Maximum workoutput

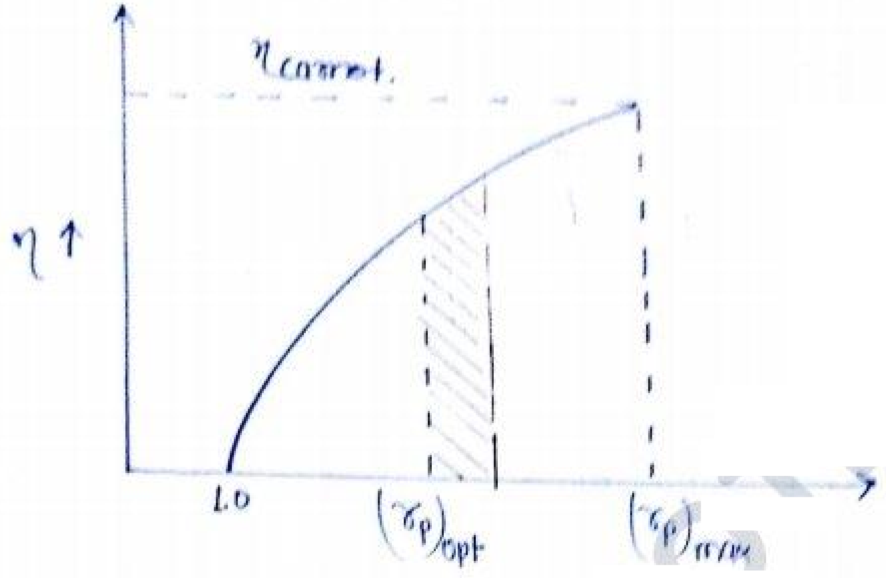
$$T_3 = T_{max} \quad , \quad T_1 = T_{min}$$

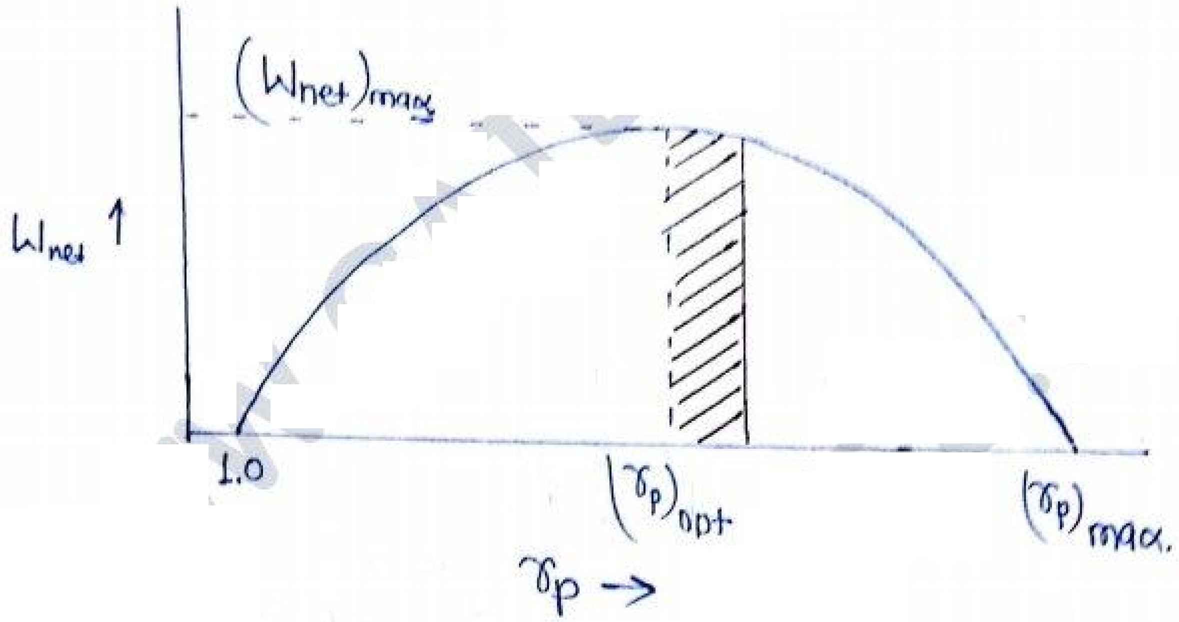
1) $T_2 = T_4 = \sqrt{T_{max} \cdot T_{min}}$

2) $(W_{net})_{max} = C_p\left[\sqrt{T_{max}} - \sqrt{T_{min}}\right]^2$

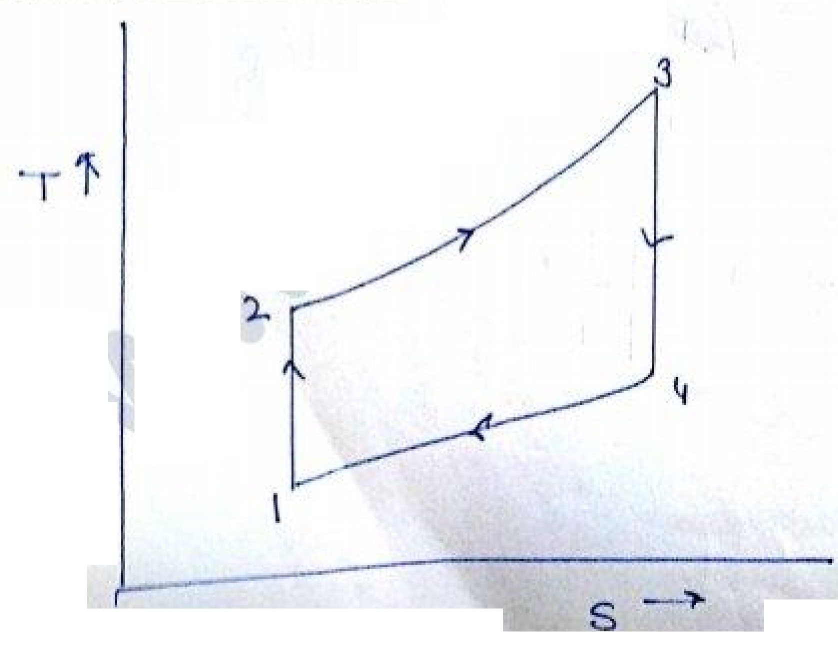
3) $(r_p)_{opt} = \left(\frac{T_{max}}{T_{min}}\right)^{\frac{\gamma}{2(\gamma-1)}} = \sqrt{(r_p)_{max}}$

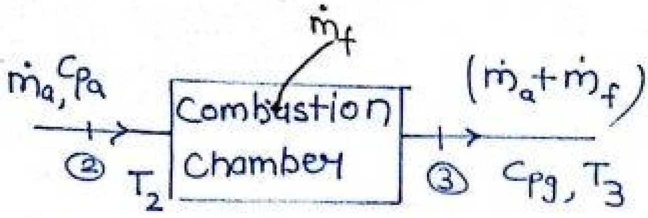
4) $\eta_{opt} = 1 - \sqrt{\frac{T_{min}}{T_{max}}}$





Combustion chamber:-





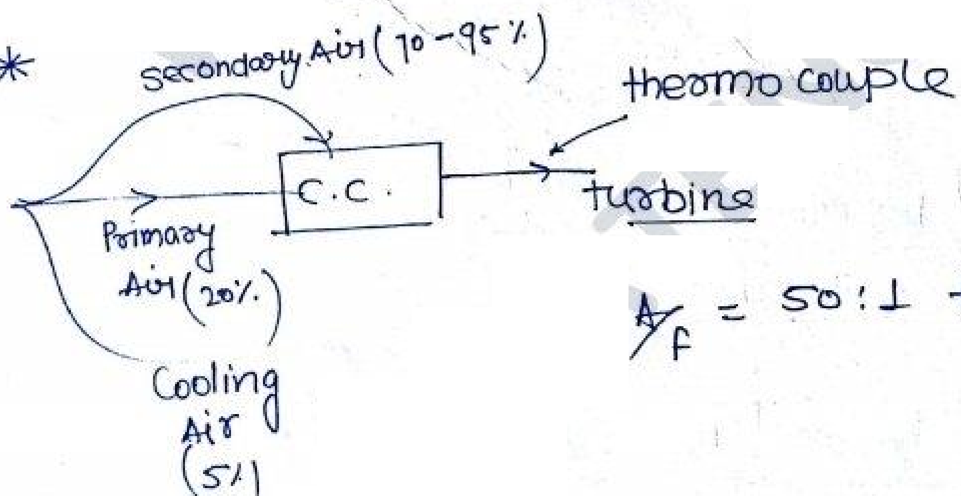
In open cycle gas turbine energy is released due to Combustion of fuel in combustion chamber under ideal condition energy released by fuel should be exactly equal to enthalpy rise of gas.

Heat released by fuel = enthalpy rise of gas.

* $$\boxed{\dot{m}_f \cdot CV \cdot \eta_{Comb.} = (\dot{m}_a + \dot{m}_f) C_{pg} T_3 - \dot{m}_a \cdot C_{pa} T_2}$$
↳ Exact solution

* $$\boxed{\dot{m}_f \cdot CV \cdot \eta_{comb.} = (\dot{m}_a + \dot{m}_f) C_p \cdot (T_3 - T_2)}$$
↳ Approximate solⁿ (objective)

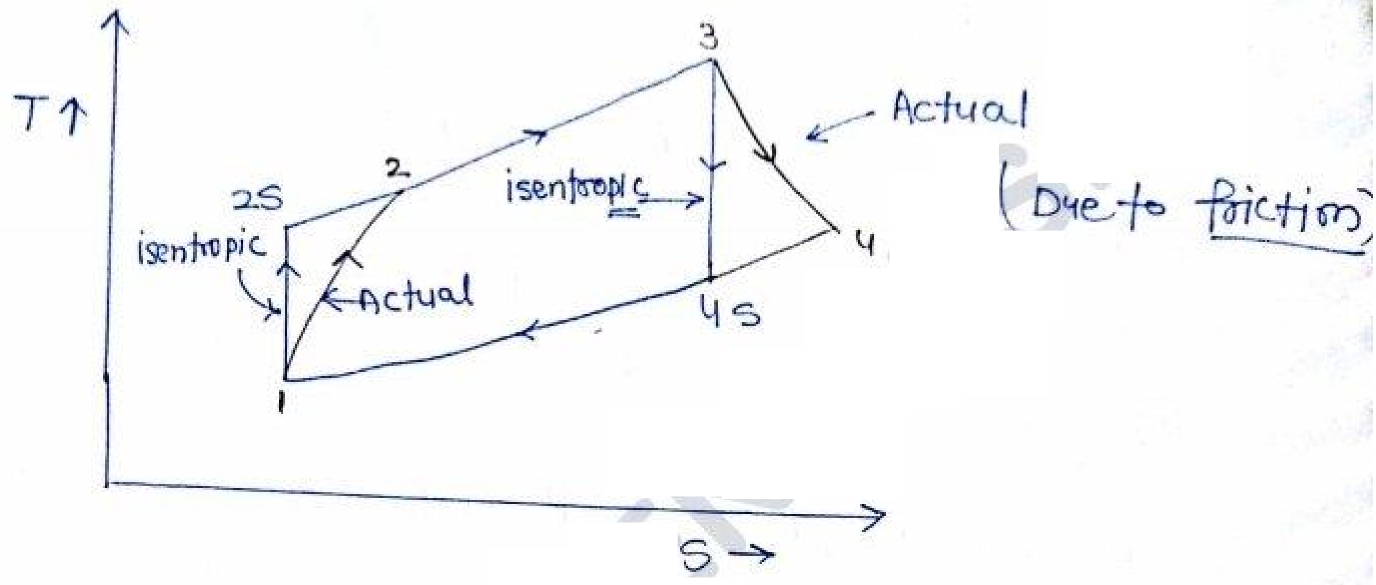
*



$A/F = 50:1$ to $80:1$

- 4-6% fuel loss in Gas turbine
- 10-12% fuel loss in 4-stroke
- 30-35% — " — 2-stroke.

Isentropic Efficiency:-



In actual working there is always friction within the system boundary and it is considered by isentropic efficiency due to internal irreversibility i.e. friction, compression require more work and turbine produces less work output.

Compressor

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

$$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1} = \frac{T_{2s} - T_1}{T_2 - T_1}$$

$$\eta_c \cong 80 \text{ to } 85\%$$

Turbine

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

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} = \frac{T_3 - T_4}{T_3 - T_{4s}}$$

$$\eta_T \simeq 85\% - 90\%$$

* **efficiency**

$$\downarrow\downarrow \eta = 1 - \frac{Q_R \uparrow}{Q_S \downarrow} \qquad \eta = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$$

→ Not valid here

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

Que An open cycle gas turbine uses a fuel of $CV = 40\ MJ/\text{kg of fuel}$ and Air fuel ratio is $A/F = 80:1$. It develops the net output of $80\ kJ/\text{kg Air}$ then determine thermal eff. of cycle.

Soln

$CV = 40\ MJ/kg \qquad A/F = 80/1 \qquad W_{net} = 80\ kJ/\text{kg Air}$

$$Q_S = 40 \times 10^3\ kJ$$

$$W = 80 \times 80\ kJ$$

$$\eta = \frac{80 \times 80}{40 \times 10^3} = 16\ \%$$

Ques

Find Air fuel ratio in a gas turbine whose eff. for turbine $\eta_T = 85\%$ & for Comp. $\eta_C = \underline{80\%}$ and $T_{max} = 875^\circ C$ take air as a working substance throught $C_p = 1\ kJ/kgK$. Air enters the compressor at 1 bar $27^\circ C$, $r_p = 4$, $CV = 42\ MJ/kg$ of fuel and there is loss of 10% of CV in combustion chamber. $T_3 =$

Sol^n

$$\dot{m}_{af}\ CV.\ \eta_C = (\dot{m}_a + \cancel{\dot{m}_f})\ C_p.\ (T_3 - T_2)$$

$$\dot{m}_f \times 42 \times 0.90 \times 10^3 = (\dot{m}_a + \cancel{\dot{m}_f}) \times 1 \left(\overset{665.8}{\cancel{702.20}}\right)$$

$$\Rightarrow \dot{m}_f(\text{kg fuel}) \times 42 \times 0.90 \times 10^3 = (m_a + m_f) \times \cancel{702.20}$$

$$\frac{T_{2s}}{T_1} = (r_p)^{\frac{r-1}{r}} \Rightarrow T_{2s} = 300(4)^{\frac{1.4-1}{1.4}}$$

$$T_{2s} = 445.79\ K$$

$$\frac{\dot{m}_a}{\dot{m}_f} =$$

$$\eta_C = 0.80 = \frac{T_{2s} - T_1}{T_2 - T_1}$$

$$T_2 = \underline{482.24}\ K,\ T_3 = 1148\ K$$

$$\frac{m_a + \cancel{m_f}}{m_a} = 5\cancel{6}.77$$

Q For an ideal brayton cycle net work output is 400 kJ/kg of Air and work ratio is 0.4. If issentropic eff. of both comp & turbine 80%. Then find out the actual net workoutput of cycle.

Sol^n

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

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

$$0.4 = \frac{400}{W_T} \Rightarrow W_T = 1000 \ kJ/kg$$

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

$$W_C = 600 \ kJ/kg.$$

$$\eta_C = \frac{W_C}{W_{C\,actual}} \Rightarrow W_{C\,act} = \frac{600}{0.8} = 750 \ kJ/kg.$$

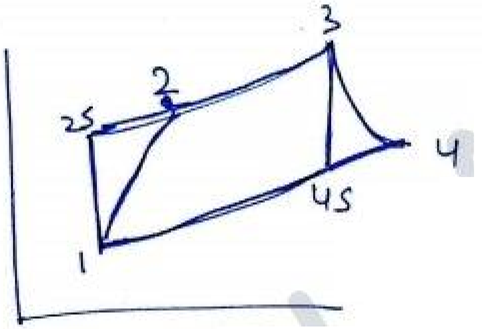
$$W_{T,act} = 1000 \times 0.8 = 800 \ kJ/kg.$$

$$W_{net} = W_{T,act} - W_{C,act}.$$

$$W_{net} = 50 \ kJ/kg$$

Que A gas turbine unit developes a power of 1500 KW and air at 1 bar, 20°C enter the compressor and pressure ratio is 6, $T_{max} = 1000°c$, $\eta_c = 80\%$ and η of Cycle is 25% then determine $\eta_T = ?$ and $\dot{m}$ of Air $C_p = 1\ KJ/kgK$, $\gamma = 1.4$

Sol^n



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

$$T_{2s} = 488.87$$

$$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1} = 0.80$$

$$\frac{195.87}{T_2 - 293} = 0.80$$

$$195.87 = 0.80\, T_2 - 0.80 \times 293$$

$$\underline{T_2 = 537.84.}$$

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

0.25 ⇒

$$0.75 = \frac{(T_4 - 293)}{(1273 - 537.84)}$$

$$T_4 = 844.35K$$

$$T_3 = 1273K, \quad \frac{T_3}{T_{4s}} = (6)^{\frac{2}{7}}$$

$$\underline{T_{4s} = 762.95\,K}$$

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

$$\underline{\eta_T = 84.02\%.}$$

$$\eta_{cycle} = \frac{W_{net}}{Q_s}$$

$$0.25 = \frac{1500 \times 10^3}{\dot{m}_a C_p (T_3 - T_2)}$$

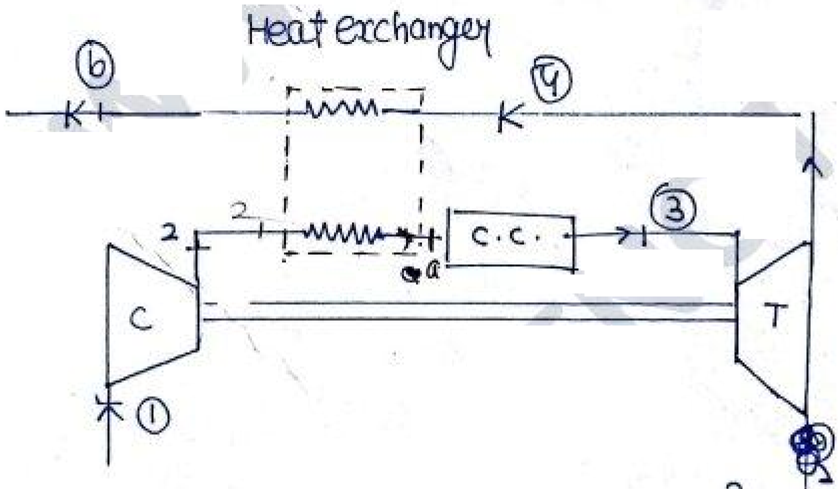
$$0.25 = \frac{1500 \times 10^3}{\dot{m}_a \cdot 1 \times (1273 - 537.84)}$$

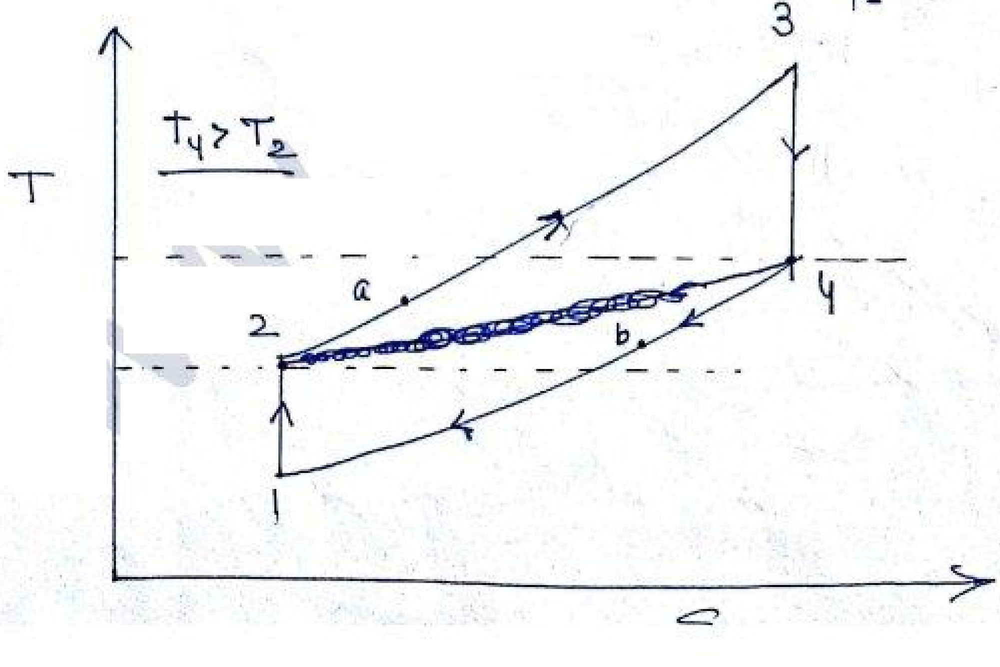
$$\dot{m}_a = \underline{8.16 \text{ kg/s}}$$

or

$$P = \dot{m}_a \cdot C_p \left((T_3 - T_4) - (T_2 - T_1) \right)$$

Regeneration





* Regeneration is a process in which high temp. gas coming out from the turbine is utilize for heating cold Air coming out from the compressor and before ~~Go~~ entering in the combustion chamber, this pre-heating of cold air decreases the fuel requirement in combustion chamber thus increasing the efficiency.

Effects of Regeneration :-

1) W_C - Same (No change)
2) W_T - Same
3) W_{net} - Same
4) Q_S - decrease (2-a)
5) Q_R - decrease (4-b)
6) T_{mA} - increase
7) T_{mR} - decrease

$\boxed{\text{8) } \eta \text{ - increase. } (\uparrow)}$

effective/ Thermal Ratio/ Degree of Regenration.

It is a term used to indicate the capability of Heat exchanger it transfering heat from hot body to cold body. It is the ratio of actual temp. rise to the max. temp rise possible in a heat exchanger.

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

$$\boxed{\epsilon = \frac{T_a - T_2}{T_4 - T_2}}$$

$\epsilon \simeq 70\%$ to 80%

$$\eta = \frac{W_{net}}{C_p(T_3 - T_a)}$$

Ideal Regenrative cycle:-

In an ideal regenrative cycle cold air is heated upto turbine exit temp. in a regenrator. It is possible only for a infenitely large Heat exchanger and at that point $\epsilon = 100\%$.

$$T_a = T_4 \quad \& \quad T_b = T_2$$

η for ideal Regenrative cycle

$$\text{efficiency}(\eta) = 1 - \frac{Q_R}{Q_s} = 1 - \frac{(T_b - T_1)}{(T_3 - T_a)}$$

$$\eta = 1 - \frac{(T_b - T_1)}{(T_3 - T_a)}$$

$$T_a = T_4, \quad T_b = T_2$$

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

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

$$\eta = 1 - \frac{T_1}{T_3} \cdot \frac{T_2}{T_1} \frac{\left(1 - \frac{T_2}{T_1}\right)}{\left(1 - \frac{T_4}{T_3}\right)} \quad \because \frac{T_3}{T_4} = \frac{T_2}{T_1}, \quad \frac{T_1}{T_2} = \frac{T_4}{T_3}$$

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

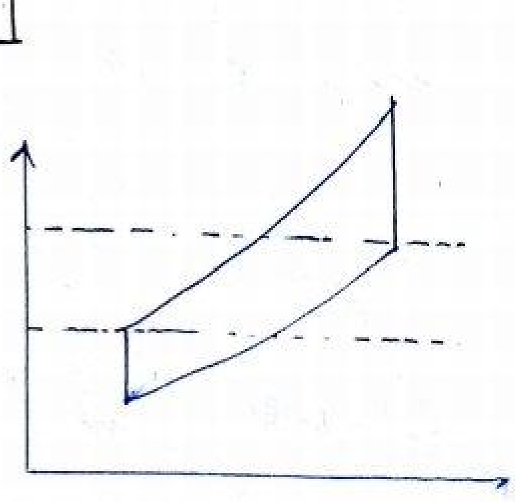
$$\boxed{\eta_{\substack{\text{ideal}\\ \text{Reg.}}} = 1 - \frac{T_1}{T_3} \cdot (r_p)^{\frac{\gamma - 1}{\gamma}}}$$

1) As $r_p \uparrow$, $\eta \downarrow$

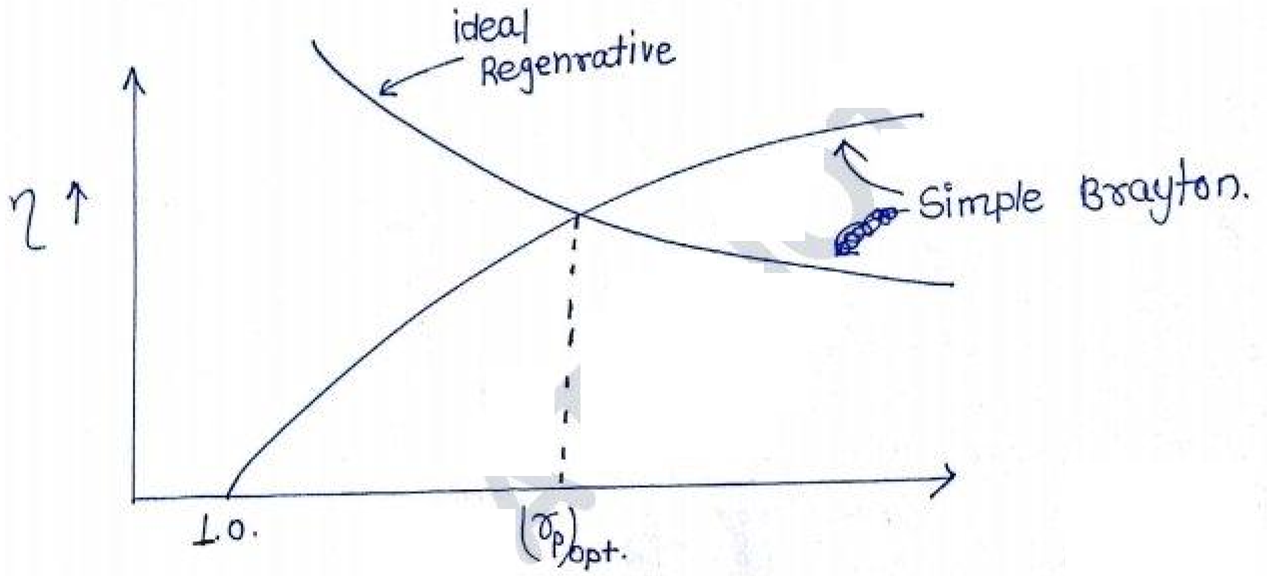
2) $\gamma \uparrow$, $\eta \downarrow$

3) $T_1 \uparrow$, $\eta \downarrow$

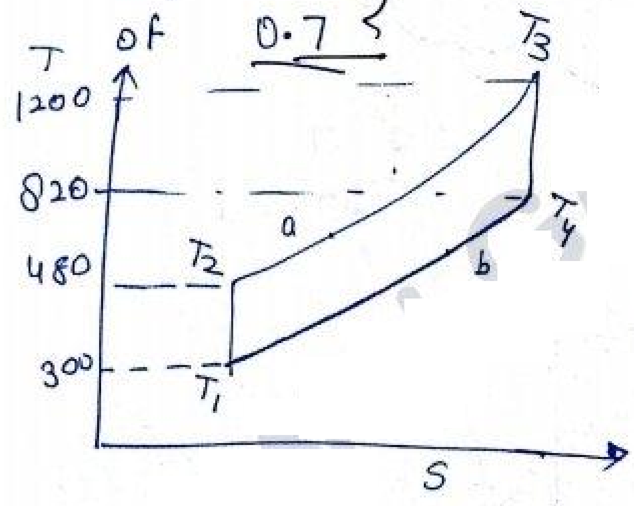
4) $T_3 \uparrow$, $\eta \uparrow$



* Beyond certain pressure ratio use of regenrator become ineffective because comp. outlet temp. become more than turbine exit temp.



Que Actual gas turbine cycle is as given below where temp. are given in kelvin find out the η of cycle also find the eff. when a regenrator is installed with an effectiveness of 0.7?



$$\eta_1 = 1 - \frac{(820-300)}{(1200-480)}$$

without Reg.

$$\boxed{\eta = 27.77\%}$$

$$\epsilon = 0.7 = \frac{T_a - T_2}{T_4 - T_2}$$

$$\Rightarrow T_4 - T_b = T_a - T_2$$

with regen

$$\boxed{T_b = 582}$$

$$0.7 = \frac{T_a - 480}{(820-480)} \Rightarrow \boxed{T_a = 718K}$$

$$\eta_1 = 1 - \frac{(582-300)}{(1200-718)} = 41.49\%$$

work output remain same

or without Reg.

$$\eta = \frac{W_T - W_c}{Q_s} = \frac{(T_3 - T_4) - (T_2 - T_1)}{(T_3 - T_2)}$$

$$\eta = \frac{380 - 180}{720} = 27.7\%$$

with Reg

$$\epsilon = 0.7 = \frac{T_a - T_2}{T_4 - T_2}$$

$$T_a = 718\ K$$

$$\eta = \frac{380 - 180}{1200 - 718} = 41.49\%$$

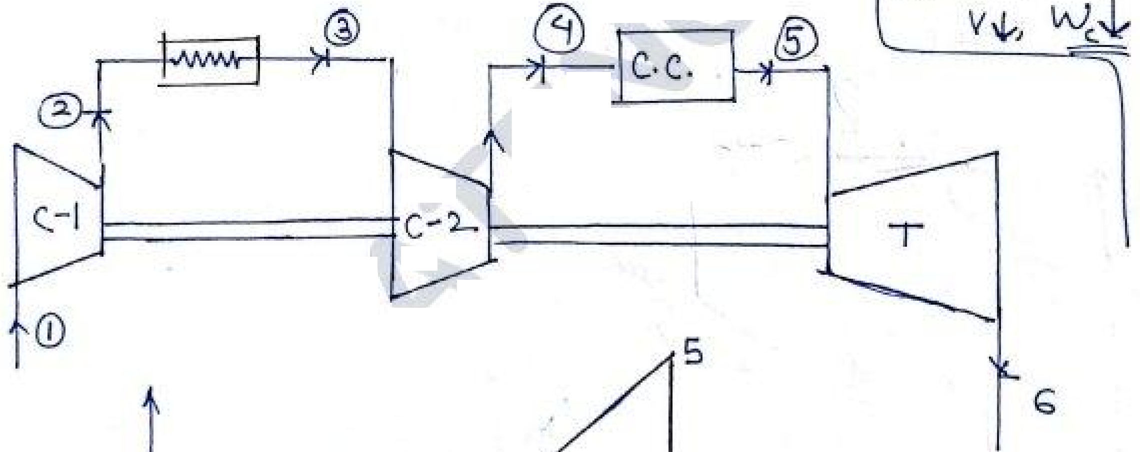
Intercoolings

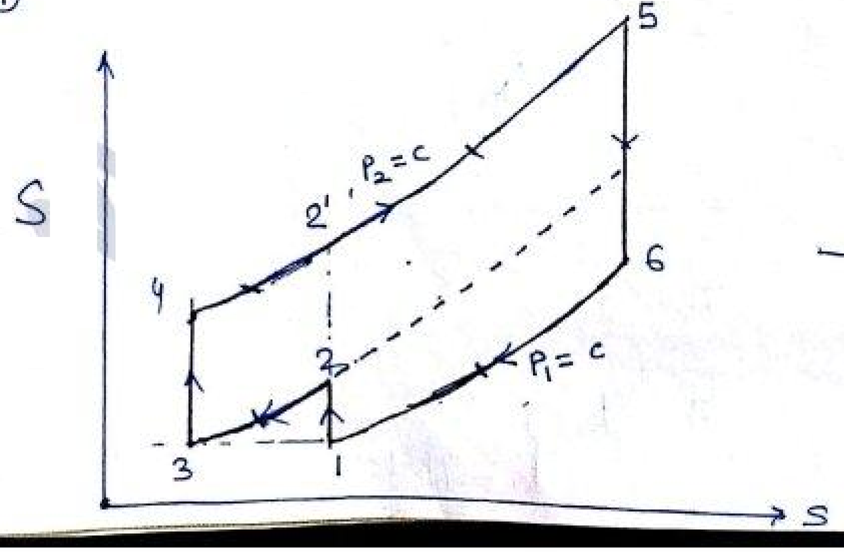
Aim - To increase $W_{net} = W_T - W_c$

Reheating. intercooling

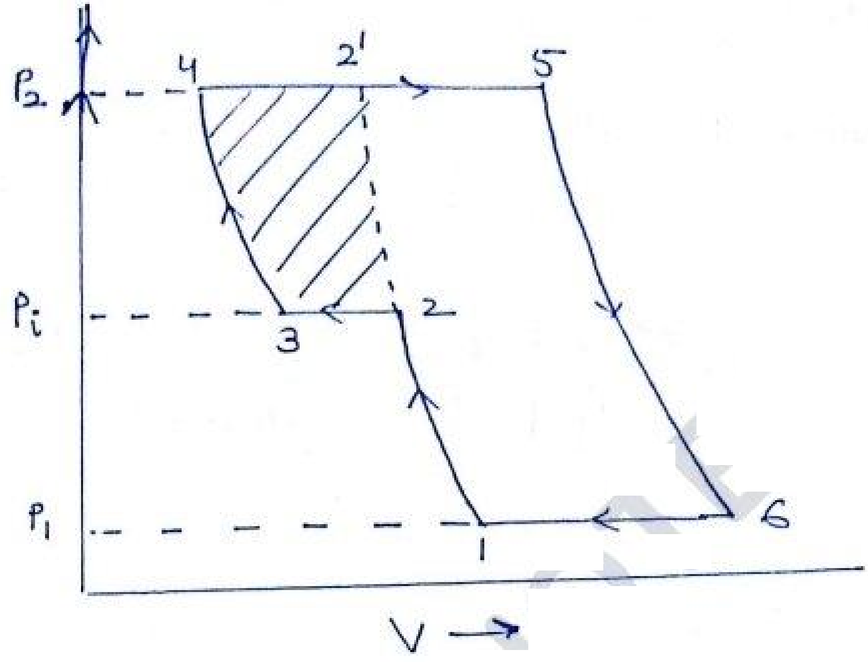
$W = V\,dp$

$V\downarrow,\ W_c\downarrow$





$T_1 = T_3$ perfect inter cooling



* mean temp. of heat addition decreases ~~at~~ faster as compare mean temp. of heat rejection.

* $T_{mA} \downarrow\downarrow$, $T_{mR} \downarrow$ $\quad \underset{(4\text{-}5\%\downarrow)}{\eta \downarrow} \Rightarrow \frac{P_2}{P_1} > \frac{P_2}{P_i} \Rightarrow P_i > P_1$ ~~$\Rightarrow \frac{P_i+P}{2} > \frac{P_1+P}{2}$~~

→ In order to increase the the net work output one method is to decrease the work required by compressor and this is obtained by using several stages of compressor with intercooling of air in b/w stages.

<u>Effect of intercooling</u>

1) $W_c \downarrow$
2) W_T same
3) $W_{net} \uparrow$
4) $Q_s \uparrow (4\text{-}2')$
5) $Q_R \uparrow (2\text{-}3)$
6) $T_{mA} \downarrow\downarrow$
7) $T_{mR} \downarrow$
8) $P_{mean} \downarrow$?
9) $\boxed{\eta \downarrow}$

10) scope of regenrator increase as Compare outlet temp. decrease

*** Intermediate pressure for min work input by Compressor with perfect intercooling :-**
$(T_3 = T_1)$

$$W_c = W_{c_1} + W_{c_2}$$

$$= C_p \left[T_2 - T_1 + T_4 - T_3 \right]$$

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

perfect intercooling
$T_3 = T_1$

$$W_c = C_p T_1 \left[\frac{T_2}{T_1} + \frac{T_4}{T_3} - 2 \right]$$

$$\frac{T_2}{T_1} = \left(\frac{P_i}{P_1}\right)^{\frac{r-1}{r}} = \left(\frac{P_i}{P_1}\right)^{x} \qquad x = \frac{r-1}{r}$$

$$\frac{T_4}{T_3} = \left(\frac{P_2}{P_i}\right)^{x}$$

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

$$\frac{dW_c}{dP_i} = 0,$$

$$\frac{x \cdot P_i^{x-1}}{P_1^{x}} + \frac{P_2^{x}(-x)}{P_i^{x+1}} = 0$$

$$\frac{P_i^{x-1}}{P_1^{x}} = \frac{P_2^{x}}{P_i^{x+1}} \Rightarrow P_i^{2x} = P_2^{x} \cdot P_1^{x}$$

$*$ $\boxed{P_i = \sqrt{P_2 \cdot P_1}}$ $*$ $\boxed{\frac{P_i}{P_1} = \frac{P_2}{P_i}}$

$$\Rightarrow \frac{T_2}{T_1} = \left(\frac{P_i}{P_1}\right)^{\frac{r-1}{r}}, \quad \frac{T_4}{T_3} = \left(\frac{P_2}{P_i}\right)^{\frac{r-1}{r}}$$

as $T_3 = T_1$ & $\frac{P_i}{P_1} = \frac{P_2}{P_i}$

$$\Rightarrow \boxed{T_4 = T_2}$$

$$W_{C_1} = C_P(T_2 - T_1), \quad W_{C_2} = C_P(T_4 - T_3)$$

as $T_1 = T_3$, $T_2 = T_4$

$$\boxed{W_{C_1} = W_{C_2}}$$

* Perfect inter cooling

1) $T_3 = T_1$
2) $P_i = \sqrt{P_2 \cdot P_1}$
3) $T_4 = T_2$
4) $W_{c_1} = W_{c_2}$

Reheating:

No effect of frequence relation on efficiency

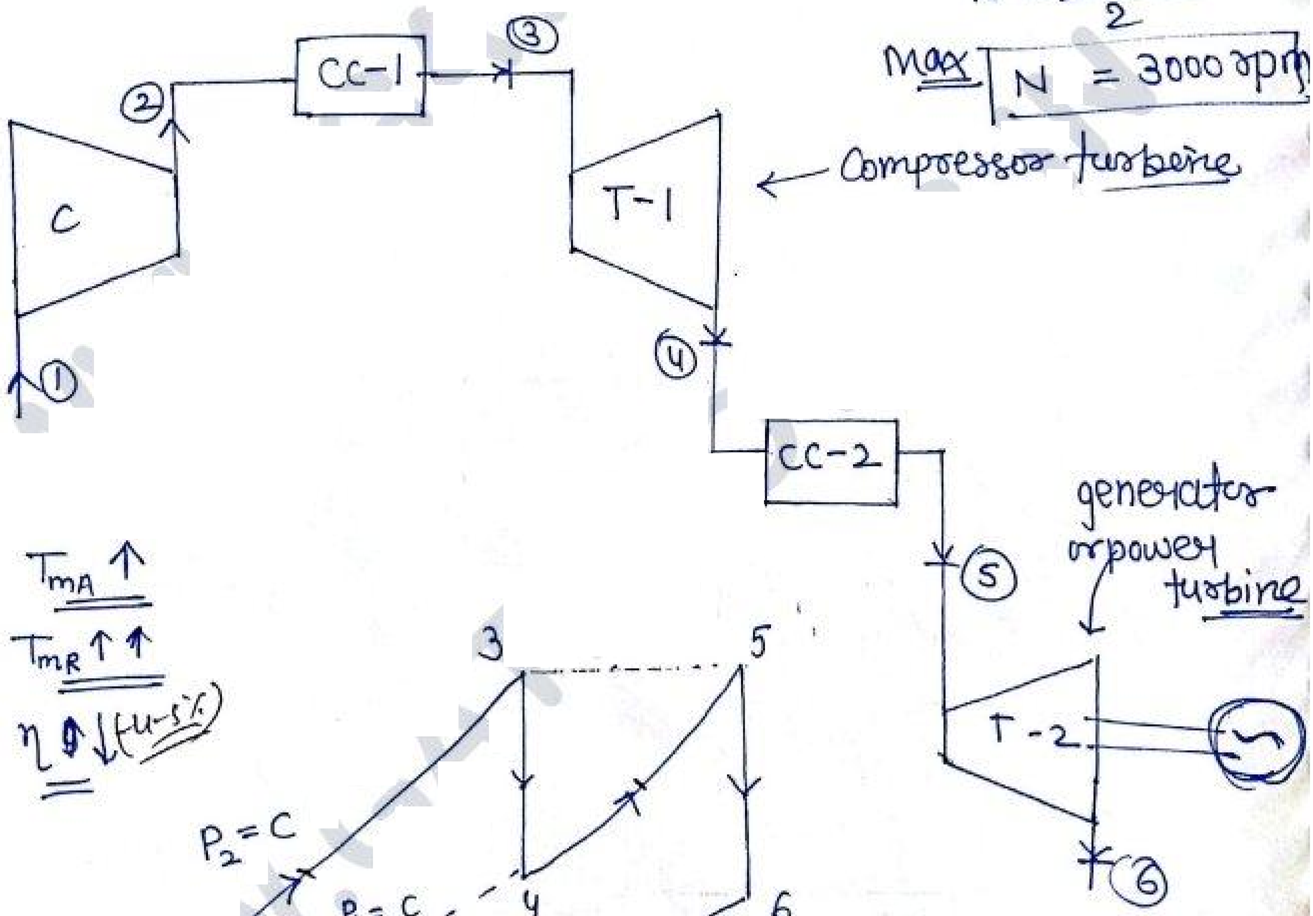
Generator max speed

$$\boxed{N = \frac{120 \cdot f}{P}}$$

P ← No. of poles

$$N = \frac{120 \times 50}{2}$$

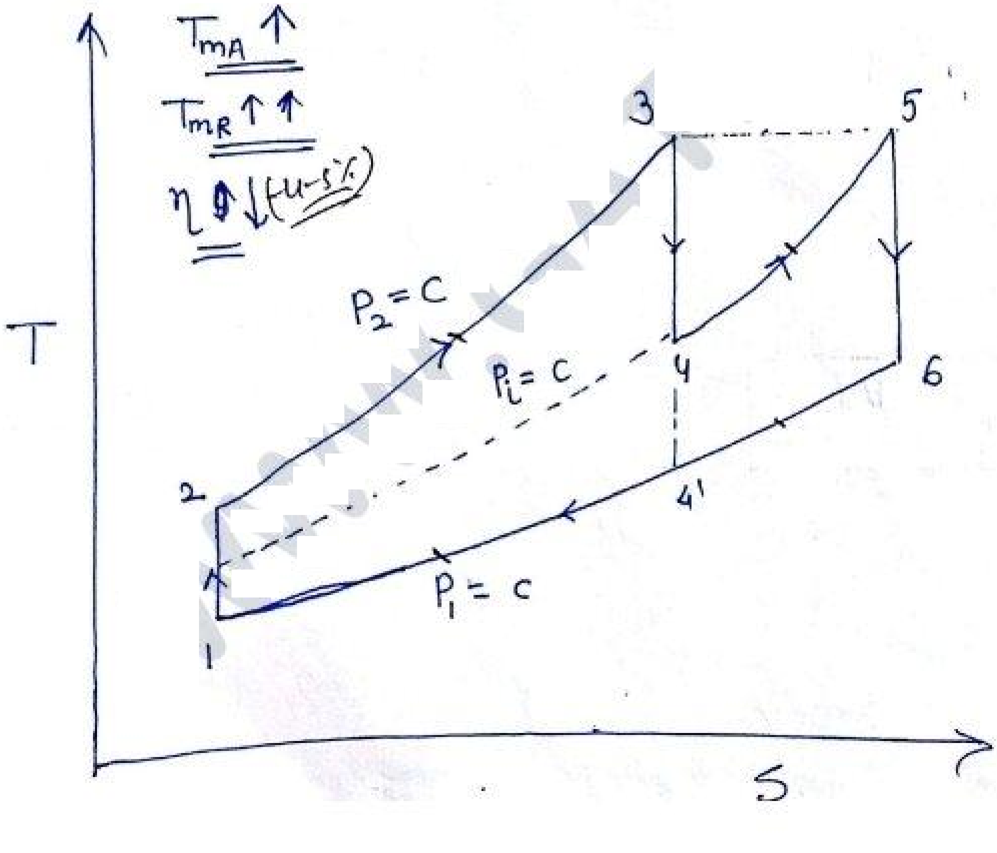
Max $\boxed{N = 3000 \text{ rpm}}$

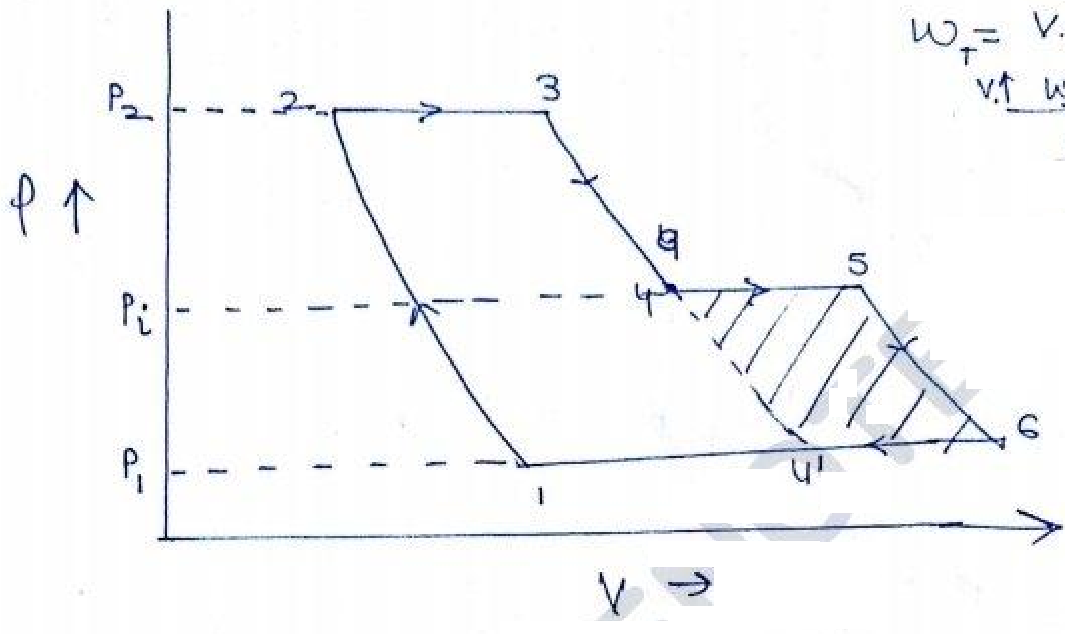


$T_{mA} \uparrow$

$T_{mR} \uparrow\uparrow$

$\eta \updownarrow \downarrow (4\text{-}5\%)$





flow process

$W_T = V.dp$

$V \uparrow \; W_T \uparrow$

$W = W_T - W_c$

$\uparrow \quad \uparrow$

⇒ The net work output can be increased by increasing the work done by turbine and this is achieved by using several stages of expansion with reheating in between stages.

Effects of Reheating:-

1) W_c same
2) W_T increase
3) W_{net} increase
4) Q_S Increase (4-5)
5) Q_R Increase (6-4)
6) $T_{mA} \uparrow$
7) $T_{mR} \uparrow\uparrow$
8) $P_{mean} \downarrow$
9) $\boxed{\eta \downarrow}$
10) scope of regeration increases as turbine exit temp. increases.

* Intermediate Pressure for max. turbine output with perfect reheating

$(T_3 = T_5)$

$$W_T = W_{T_1} + W_{T_2}$$

$$= C_p \left[T_3 - T_4 + T_5 - T_6 \right]$$

$$W_T = C_p T_3 \left[1 - \frac{T_4}{T_3} + \frac{T_5}{T_3} - \frac{T_6}{T_3} \right]$$

$T_3 = T_5$

$$W_T = C_p . T_3 \left[2 - \frac{T_4}{T_3} - \frac{T_6}{T_5} \right]$$

$$\frac{T_4}{T_3} = \left(\frac{P_i}{P_2} \right)^x \qquad x = \frac{r-1}{r}$$

$$\frac{T_6}{T_5} = \left(\frac{P_1}{P_i} \right)^x$$

$$W_T = C_p . T_3 \left[2 - \left(\frac{P_i}{P_2} \right)^x - \left(\frac{P_1}{P_i} \right)^x \right]$$

$$\frac{dW_T}{dP_i} = 0 , \qquad - \frac{x P_i^{x-1}}{P_2^x} - \frac{(P_1)^x (-x)}{P_i^{x+1}} = 0$$

$$\frac{P_i^{x-1}}{P_2^x} = \frac{P_1^x}{P_i^{x+1}}$$

$$P_i^{2x} = P_1^x \cdot P_2^x$$

$$\boxed{P_i = \sqrt{P_1 P_2}} \qquad \frac{P_i}{P_2} = \frac{P_1}{P_i}$$

$$\frac{T_4}{T_3} = \left(\frac{P_i}{P_2}\right)^x , \quad \frac{T_6}{T_5} = \left(\frac{P_1}{P_i}\right)^x$$

$$\Rightarrow \quad T_3 = T_5 \quad \underline{\text{so}} \quad \boxed{T_4 = T_6}$$

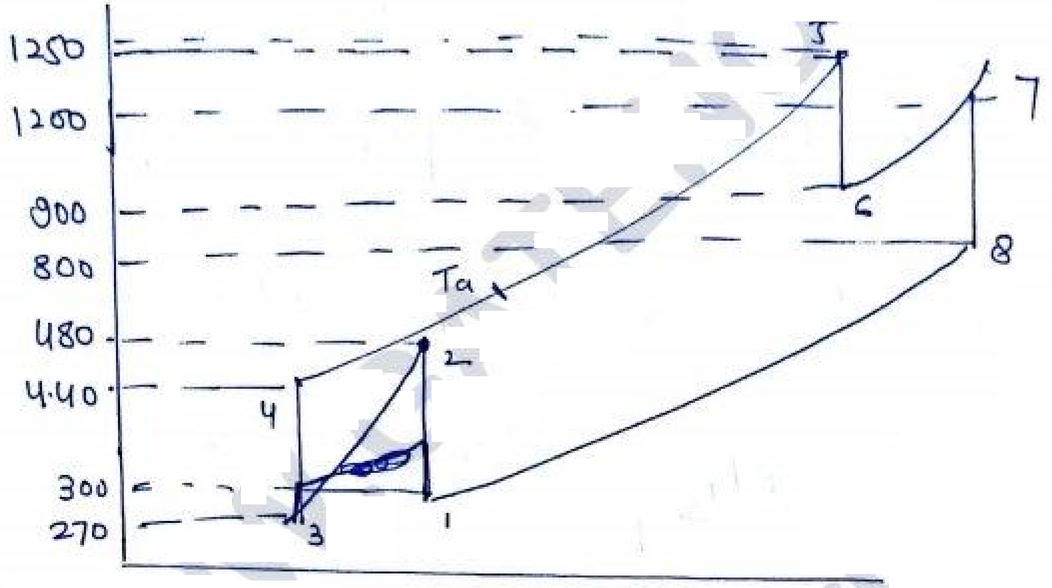
$$W_{T_1} = C_p(T_3 - T_4) , \quad W_{T_2} = C_p(T_5 - T_6)$$

$$\boxed{W_{T_1} = W_{T_2}}$$

* Prefect Reheating

1) $T_3 = T_5$
2) $P_i = \sqrt{P_2 \cdot P_1}$
3) $T_4 = T_6$
4) $W_{T_1} = W_{T_2}$

Ques For the actual gas turbine cycle as shown below find the eff. where the temp. are given in kelvin also find the eff. when a regenerator instal with an effectiveness of 0.7



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

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

$$\eta = \frac{(T_5 - T_6 + T_7 - T_8) - (T_2 - T_1 + T_4 - T_3)}{(T_5 - T_4) + (T_7 - T_6)}$$

$$\eta = \frac{(1250 - 900 + 1200 - 800 - 480 + 300 - 440 + 270)}{(1250 - 440 + 1200 - 900)} =$$

$$\eta = 36.036\ \%$$

$$\epsilon = \frac{T_a - T_4}{T_B - T_4} = 0.7$$

$$T_a - 440 = 0.7(1800 - 440)$$

$$T_a = 692$$

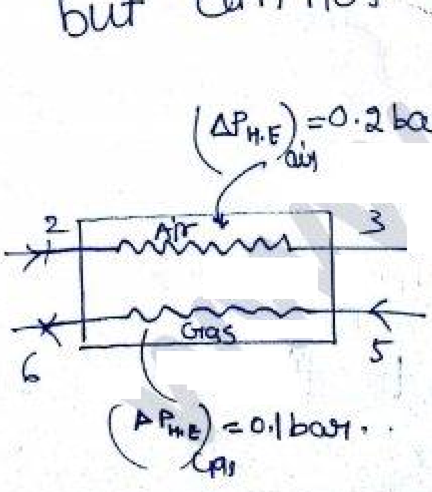
$$\eta = \frac{(1250-9\omega+12\omega-8\omega-480+3\omega-440+270)}{(1250-692+1200-9\omega)}$$

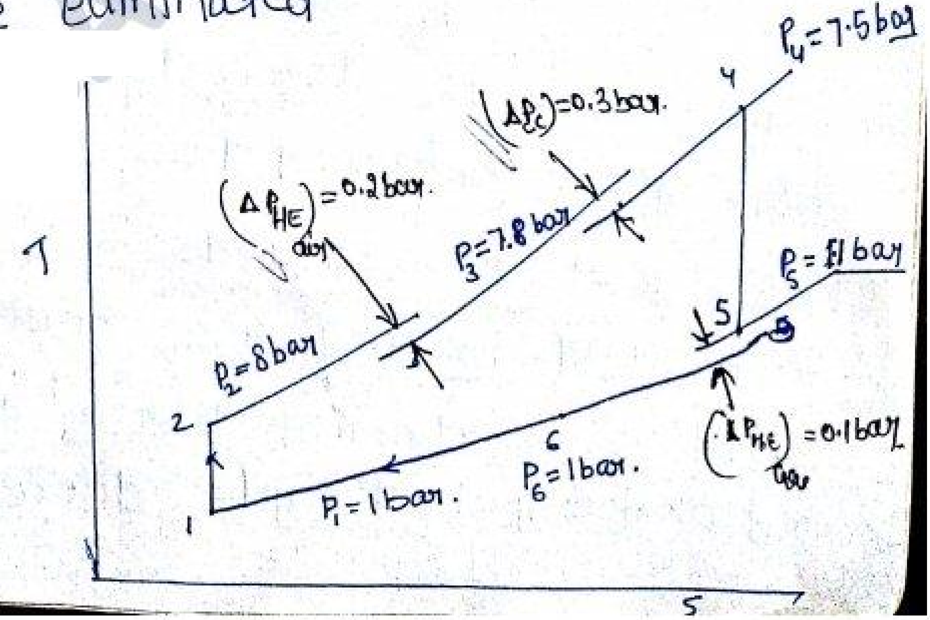
$$\eta = 46.6\%$$

21/01/16

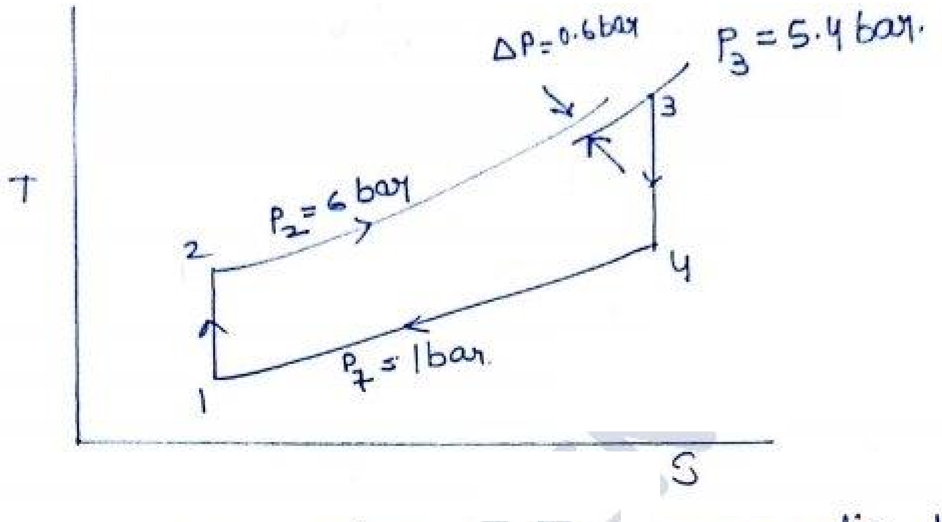
Actual Gas Turbine Cycle :-

Pressure losses :- There is always loss of pressure while flow takes place through Heat exchanger, combustion chamber, and duct connecting various combonent. by proper duct design these pressure losses can be minimised but can not be eliminated



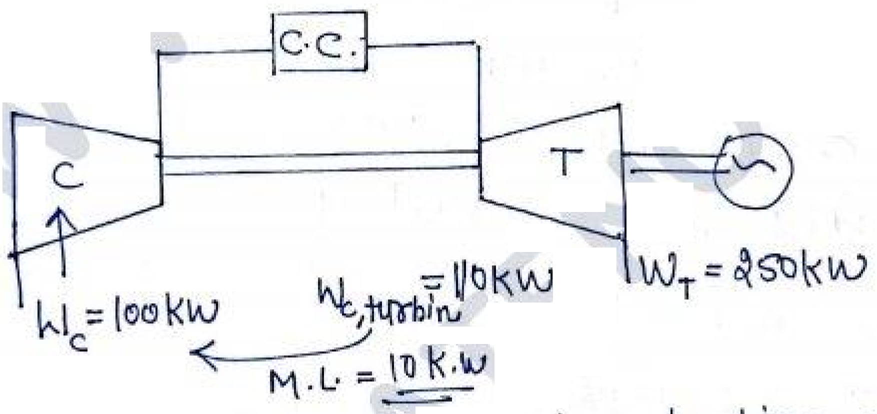


* let $(\Delta P)_{losses}$ = 10% of P_2 ⇒ Consider only at turbine intel.



* Pressure loss also called parasatic losses.

Mechanical losses:-



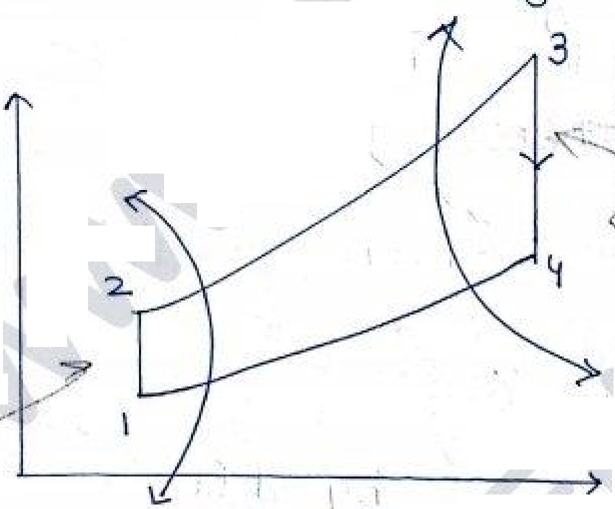
* Compressor is driven by turbine and during transmission of power from turbine to Compressor some part of energy is loss out in intermidiate ~~Gate~~ Gear, bearing and Connecting shaft know as Mechanical losses due to these losses net work output of Cycle decrease

$$* \boxed{\eta_{mech} = \frac{W_c}{W_{c,turbine}}}$$

$$W_{net} = W_T - W_{c,turbine}$$

$$* \boxed{W_{net} = W_T - \frac{W_c}{\eta_{mech}}}$$

<u>C_p, C_v & γ Value</u> :- C_p, C_v & γ doesnot remain constant with change in temp.



Gas
$C_{pg} = 1.147$
$\gamma_g = 1.33$
{1000 K}

<u>Turbine Side</u>

<u>Comp. Side</u>

Air
$C_{pa} = 1.005$
$\gamma_a = 1.4$
{300 K}

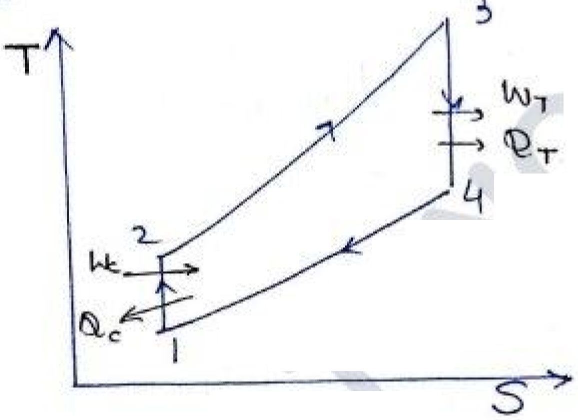
As temprature increases ($T\uparrow$) → $\underline{C_p}\uparrow$, $\underline{C_v}\uparrow$, $\underline{\gamma}\downarrow$

$$\boxed{C_p - C_v = R} \text{ (Remain constant)}$$

$$R = \frac{R_o}{M.W.}$$

Compression & expansion:

Compression & expansion process are not friction less and there is always increase in entropy due to internal reversibility.



Q_c = heat losses in compressor

Q_T = heat losses in turbine

There is always loss of energy during comp. & expansion process.

by SFEE ① & ②

$$h_1 - Q_c = h_2 - W_c$$

$$* \quad \boxed{W_c = (h_2 - h_1) + Q_c}$$

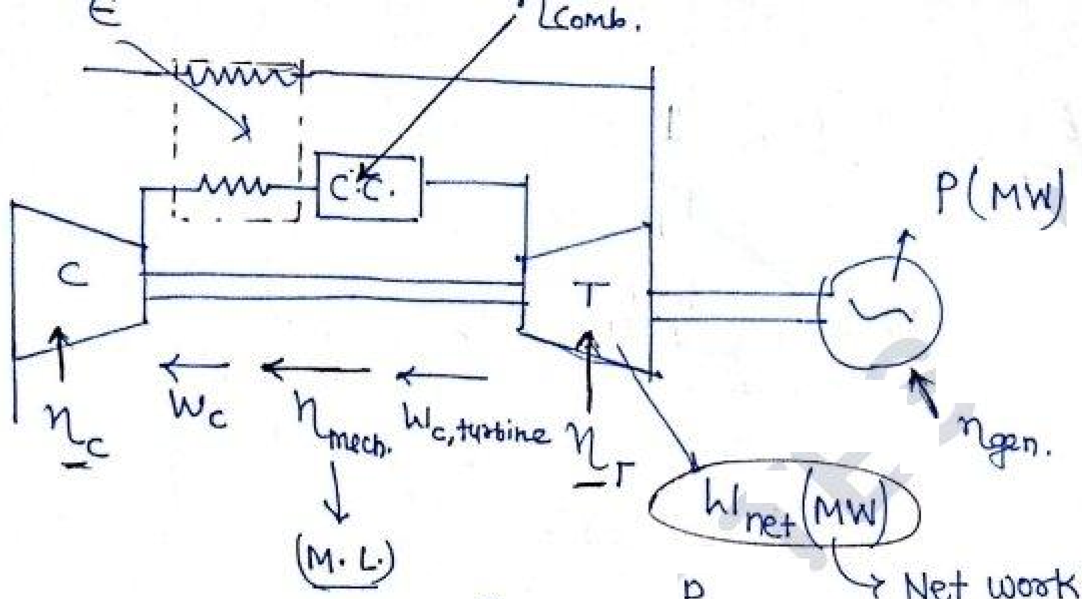
by SFEE ③ & ④

$$h_3 - Q_T = h_4 + W_T$$

$$* \quad \boxed{W_T = (h_3 - h_4) - Q_T}$$

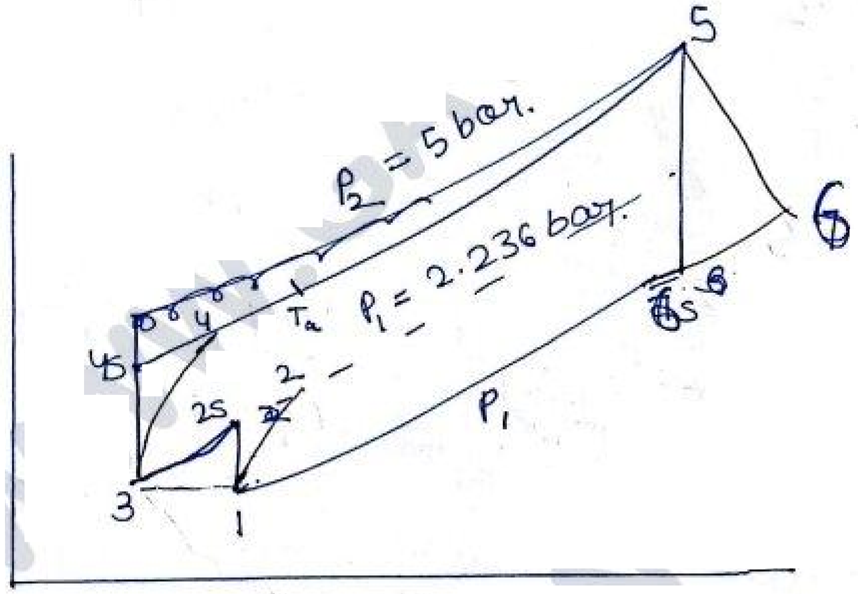
Incomplete combustion loss:-

* There is loss of energy in combustion chamber due to incomplete combustion in c.c. ($\eta_{combustion}$)



$$\eta_{gen} = \frac{P}{W_{net}}$$

Q.23
WB
Pg.37



$T_1 = 288$ K $P_2 = 5$ bar $r_p = 5$ bar.

$T_5 = 1073$ K $P_1 = 1$ bar $\gamma_a = 1.4$

$T_2 = \cancel{288}\ 2.$ $T_{2S} = T_{4S} = \cancel{456.14k}\ \cancel{368.05k}$ 362.44

$\cancel{T_6 = \frac{1073}{(5)^{\frac{1.33-1}{1.33}}} = 719.73}$ K

$$0.\ \epsilon = \frac{T_a - T_4}{T_6 - T_4}$$

$$0.7 = \frac{T_a - 456.14}{719.73 - 456.14} = T_a = 640.65\ K$$

$$\eta_{c_1} = \frac{T_{2s} - T_1}{T_2 - T_1} = 0.8$$

$$\cancel{\frac{368.07 - 288}{T_2 - 288} = 0.8}$$

$$\frac{362.44 - 288}{T_2 - 288} = 0.8$$

$$T_2 = 381.05\ \underline{\underline{K}} = T_4$$

$$\cancel{\frac{T_4}{T_3} = \frac{T_5}{T_6}} \qquad \cancel{T_7 = \frac{(1073)(288)}{381.05}}$$

$$T_6 = \frac{T_5}{(r_p)^{\frac{1.33-1}{1.33}}} = \frac{1073}{(5)^{1/4}} = 717.55\ \underline{K}$$

$$\cancel{\eta_T = \frac{T_5 - T_6}{T_5 - T_{6s}} = 0.9}$$

$$\eta_t = \frac{T_5 - T_6}{T_5 - T_{6s}} = 0.9$$

$$\cancel{\frac{1073 - 717.55}{1073 - T_6} = 0.9}$$

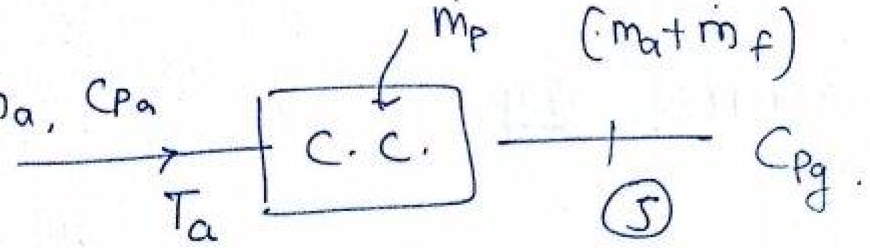
$$T_6 = 755.07$$

$$\cancel{T_6 = 755.08}$$

$$\epsilon = 0.7 = \frac{T_a - T_4}{T_6 - T_4}$$

$$T_a = \underline{\underline{642.85}}$$

①



$$\dot{m}_f \cdot CV \cdot \eta_{comb} = (\dot{m}_a + \dot{m}_P)\, C_{pg} \cdot T_5 - \dot{m}_a\, C_{pa} \cdot T_a$$

$$\dot{m}_f = \frac{\dot{m}_a\left(C_{pg} \cdot T_5 - C_{pa}\, T_a \right)}{\left(CV \cdot \eta_{com} - C_{pg} \cdot T_5 \right)}$$

$$\frac{\dot{m}_a}{\dot{m}_f} = 75.51$$

$$\dot{m}_f = 3.308 \text{ kg/s}$$

② $W_c = 2 W_{c_1} = 2\, \dot{m}_a \cdot C_{pa} (T_2 - T_1)$

$$W_c = 46.7 \text{ MW}$$

$$W_T = (\dot{m}_a + \dot{m}_f)\, C_{pg} \cdot (T_6 - T_7)$$

$$W_T = 8\cancel{8}6.99 \text{ MW}$$

$$W_{net} = W_T - \frac{W_c}{\eta_{mech}} = 38.31 \text{ MW}$$

$$Q_s = \dot{m}_f \cdot CV \cdot \eta_{comb.} = 131.98$$

$$\eta = \frac{W_{nt}}{Q_s} = 29.02\%$$

③ $\eta_{gen} = \frac{P}{W_{net}} \Rightarrow P = \underline{\underline{28.732 \text{ MW}}}$

④ $SFC = \frac{\dot{m}_f}{W_{net}(kW)} = \frac{3.308 \times 3600}{38.31 \times 10^3}$

$SFC = 0.311$ kg/kWh