Name → JASWANT SINGH
Roll No. → 1904140409004
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Code → KME401

Section – (1)

Q1

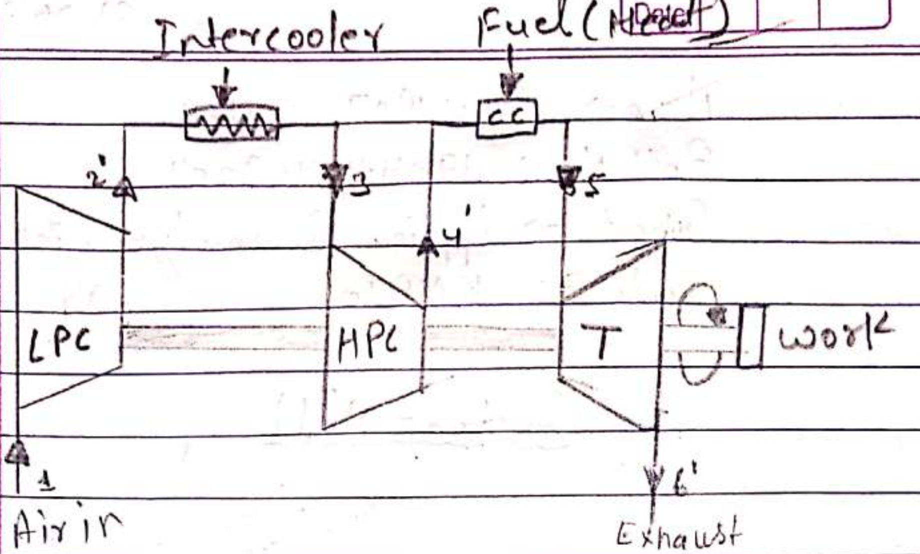
Ans. Thermal efficiency or specific output of an open cycle gas turbine can be improved by following three methods :-

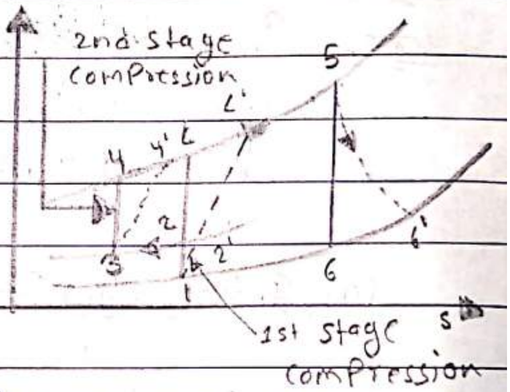
(a) Intercooling :-

- This is required to reduce the compressor work and to inc(res) the work ratio.

- The compression of air is to be done in two compressors.
- Firstly in low pressure compressure then in high pressure compressor, compression process is to be done as shown in fig.

- Fig. shows ideal and actual processes which occur in an open cycle gas turbine. The dotted lines show the actual curve & thicker one shows the ideal curve.





- From T-S diagram,

(i) The process with intercooling is 1-2-3-4-5-6 (Ideal process) or 1-2'-3-4'-5-6' (Actual Process)

(ii) The work required to run the compressor with intercooling is,

For ideal condition, $W_{CI} = C_p (T_2 - T_1) + C_p (T_4 - T_3)$
For actual condition, $W_{CI} = C_p (T_{2'} - T_1) + C_p (T_{4'} - T_3)$

(iii) The process 1-L-5-6 is ideal process without intercooling, whereas 1-L'-5-6' is actual process without intercooling.

(iv) The work required to run the compressor w/o intercooling is, For ideal condition,

$$W_C = C_p (T_L - T_1)$$
$$= C_p (T_L - T_2 + T_2 - T_1)$$
$$= C_p (T_L - T_2) + C_p (T_2 - T_1)$$

For actual condition,

$$W_C = C_p (T_{L'} - T_1)$$
$$= C_p (T_{L'} - T_{2'} + T_{2'} - T_1)$$
$$= C_p (T_{L'} - T_{2'}) + C_p (T_{2'} - T_1)$$

- As it is clear from the T-S curve that

$T_{L'} - T_2 > T_{4'} - T_3$ (For actual Process)
&
$T_L - T_2 > T_4 - T_3$ (For ideal Process)

- But the heat supplied inc(res) & this increase in heat supply leads to decrement in thermal efficiency.

(B) Reheating :-

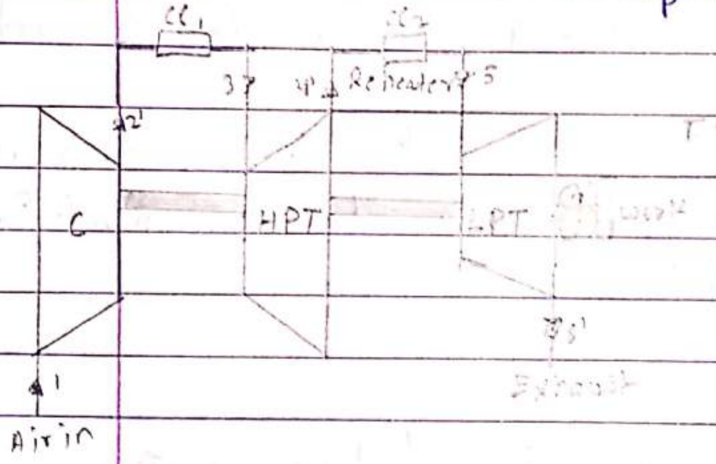
- This process uses two turbines a high press. turbine & a low press. turbine.
- There is a reheater present in b/w these two turbine.
- Here high press. turbine is used to drive the compressor & the low press. turbine provide useful work i.e. output.

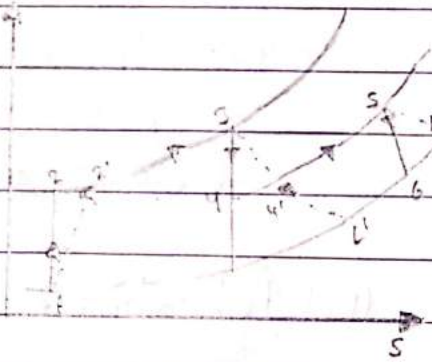
- Actual process is shown by 1-2'-3-4-5-6' (with reheating) & ideal process is shown by 1-2-3-4-5-6 (with reheating).

- Actual process without reheating is shown by 1-2'-3-L' & the ideal process without reheating is shown by 1-2-3-4-L

- The work output with reheating.
  $= C_p(T_5 - T_6)$

- The work output without reheating
  $= C_p(T_{4'} - T_{L'})$





- Hence the work output inc.(res) with reheating.
- This will also inc.(res) the work input & it may be result into reduction in thermal efficiency.

(c) Regeneration :-

- Regenerator is a heat exchanger which is used to preheat the air leaving compressor before entering the combustion chamber, thereby reducing the amount of fuel to be burnt inside combustion chamber (combustor).

- Under ideal conditions, no frictional press. drop occurs in either fluid stream while turbine exhaust gas gets cooled from 4 to 4' while compressed air is heated from 2 to 2'.

- Regenerator effectiveness, $\varepsilon = \dfrac{h_{2'} - h_2}{h_4 - h_2}$

- Thermodynamically the amount of heat added,

$$(Q_{add})_{regen} = m(h_3 - h_{2'})$$

Whereas without regenerator the heat added,

$$Q_{add} = m(h_3 - h_2)$$

- Here it is obvious that, $(Q_{add})_{regen} < Q_{add}$ this shows an obvious improved in cycle thermal efficiency.

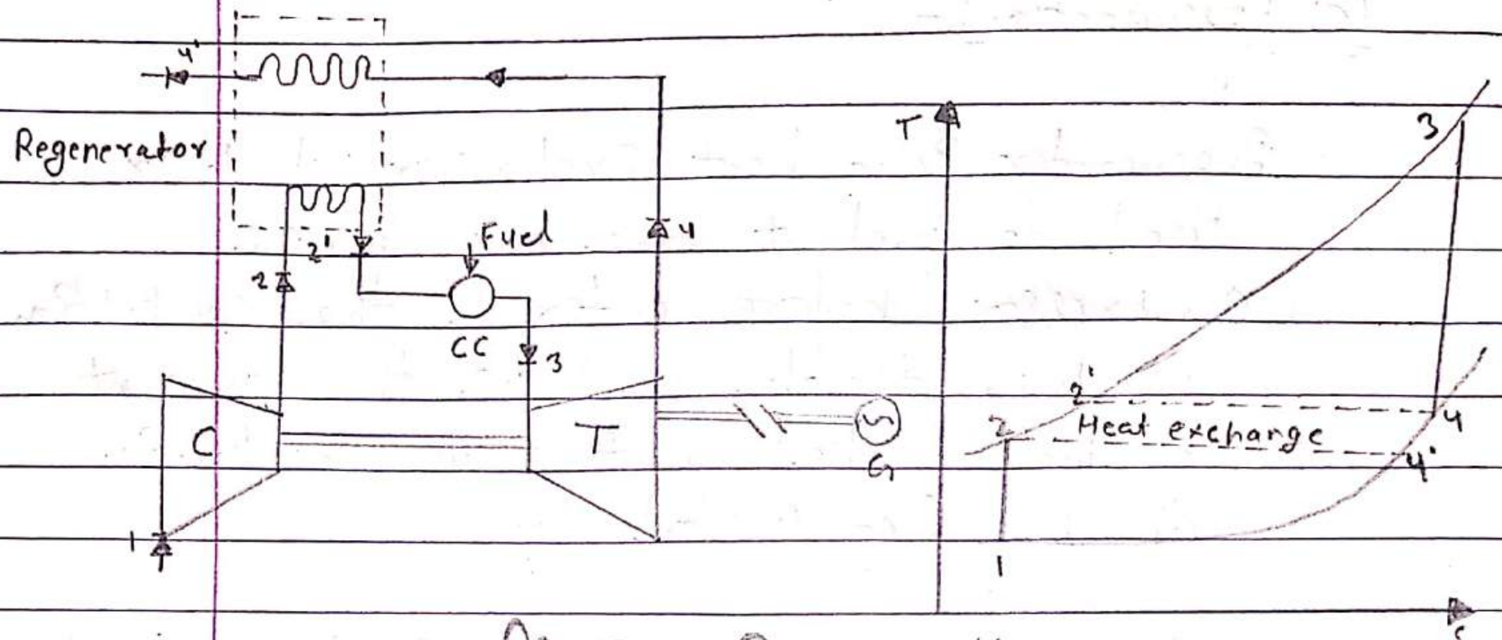


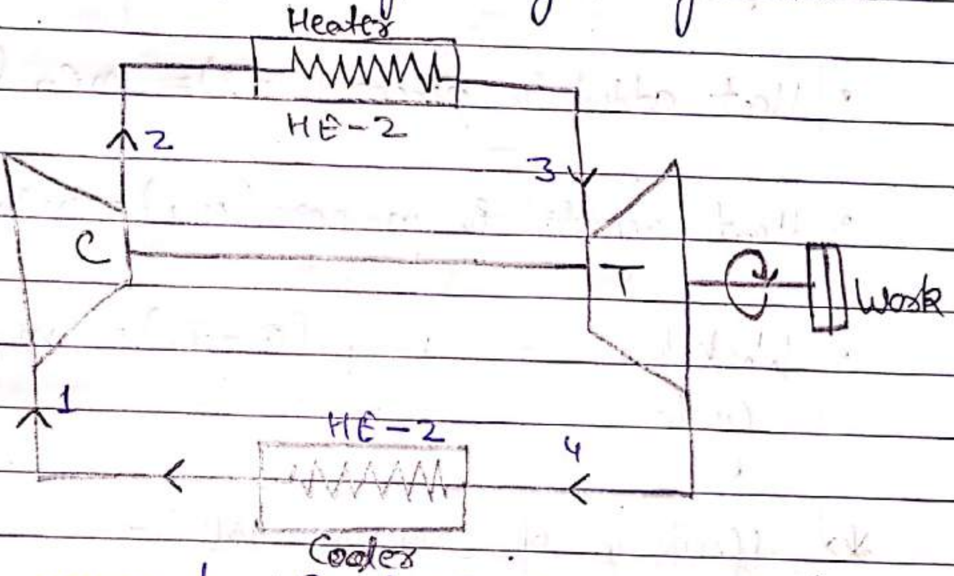
fig :- Regeneration

(2) Constant volume combustion gas turbine.

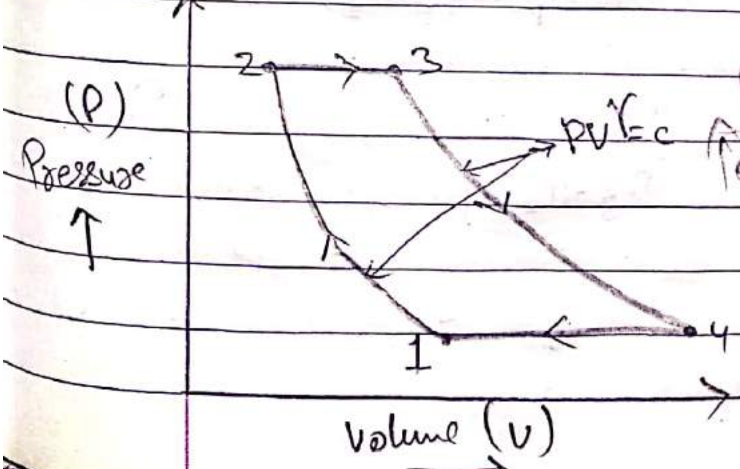
#) Brayton Cycle :-

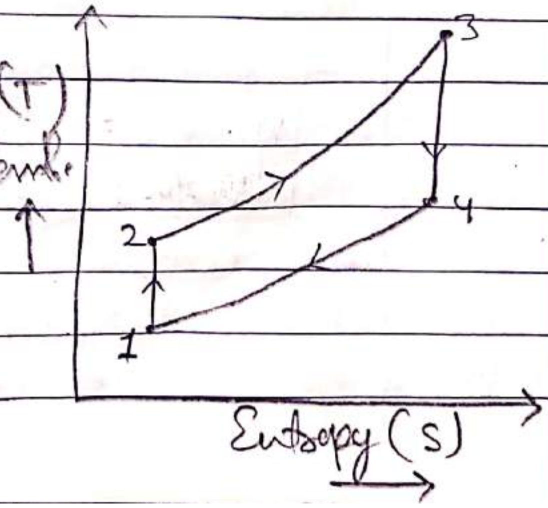
- It is a theoretical cycle for gas turbines and also known as constant pressure cycle for a perfect gas.

- The basic component of a Brayton cycle are :-



- There occur two isentropic processes & two constant pressure processes.
- Compression & expansion of working fluid is done by isentropic process while addition & rejection of heat is done at constant pressure.





Brayton cycle shows following processes:

(1 – 2) → Adiabatic Compression.
(2 – 3) → Constant pressure heat addition.
(3 – 4) → Adiabatic expansion.
(4 – 1) → Constant pressure heat rejection.

- $\frac{\text{Workdone}}{\text{Cycle}} = \frac{\text{Heat added}}{\text{Cycle}} - \frac{\text{Heat rejected}}{\text{Cycle}}$

- Heat added in process (2-3) = $mC_p(T_3 - T_4)$

- Heat rejected in process (4-1) = $mC_p(T_4 - T_1)$

- $\frac{\text{Workdone}}{\text{Cycle}} = mC_p(T_3 - T_2) - mC_p(T_4 - T_1)$

Efficiency of Brayton Cycle :-

- Efficiency, $\eta_{\text{air-std.}} = \frac{\text{Workdone / cycle}}{\text{Heat addition / cycle}}$

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

$$\boxed{\eta_{\text{air-std.}} = 1 - \frac{T_4 - T_1}{T_3 - T_2}} \quad — ①$$

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- From process (1-2) —

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \qquad \left(\because \frac{P_2}{P_1} = r_p = \text{Press. ratio}\right)$$

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

- Similarly, from process (3-4)

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

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

Now

- Putting the value of T_2 & T_3 in eqn ①, we get

$$\eta_{\text{air std.}} = 1 - \frac{T_4 - T_1}{T_4 (r_p)^{\frac{\gamma-1}{\gamma}} - T_1 (r_p)^{\frac{\gamma-1}{\gamma}}}$$

$$= 1 - \frac{\cancel{(T_4 - T_1)}}{(r_p)^{\frac{\gamma-1}{\gamma}} \cancel{(T_4 - T_1)}}$$

$$\boxed{\eta_{\text{air-standard}} = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}}$$