Modifications of Brayton Cycle

Generally, the thermal efficiency of brayton cycle is low. Thermal efficiency can be increased by incorporating thermal refinements in the simple cycle such as :-

- Intercooling between compressor stages
- Reheating between turbine stages
- Regeneration

The thermal refinements can raise the plant efficiency to over 30% and thereby obliterate the advantage of fuel possessed by diesel or steam power plants.

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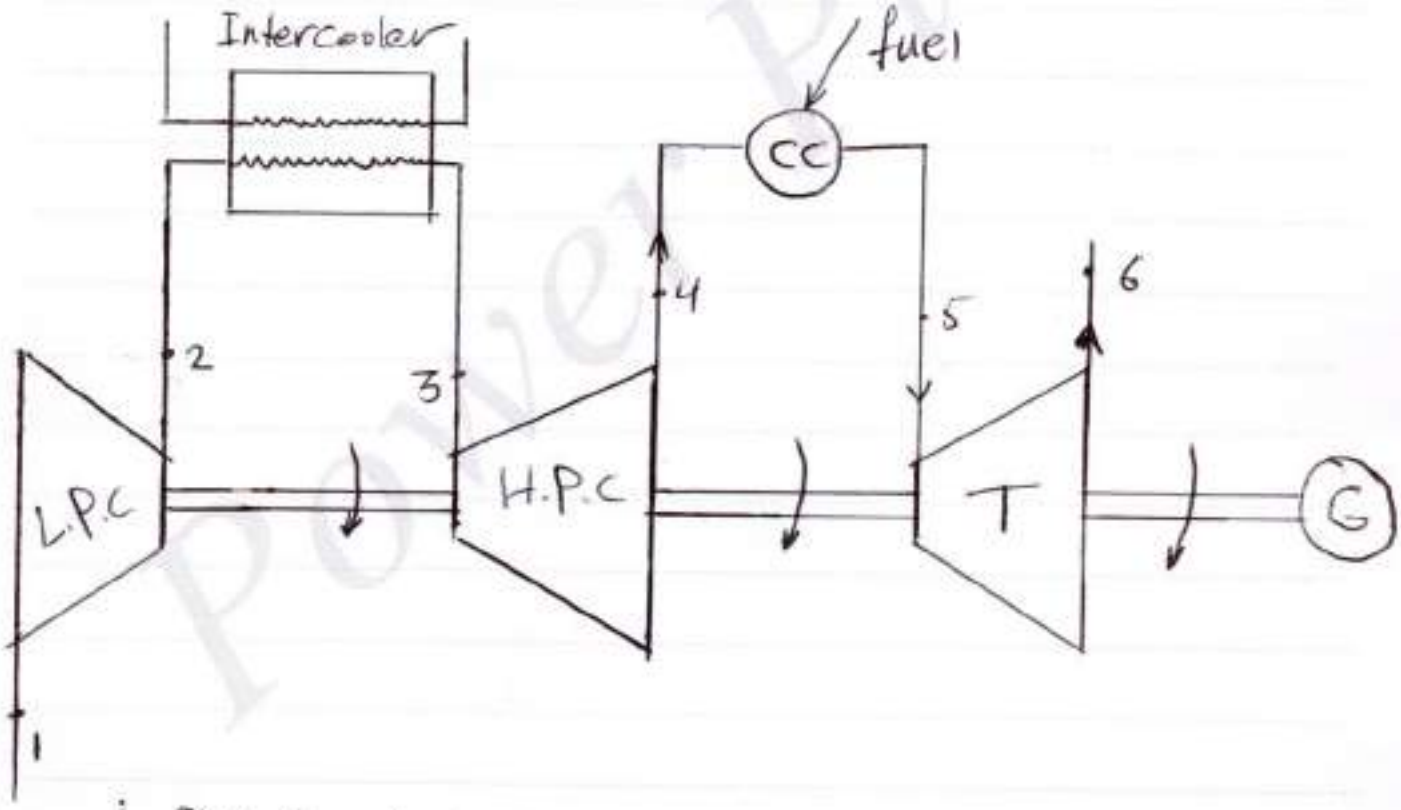
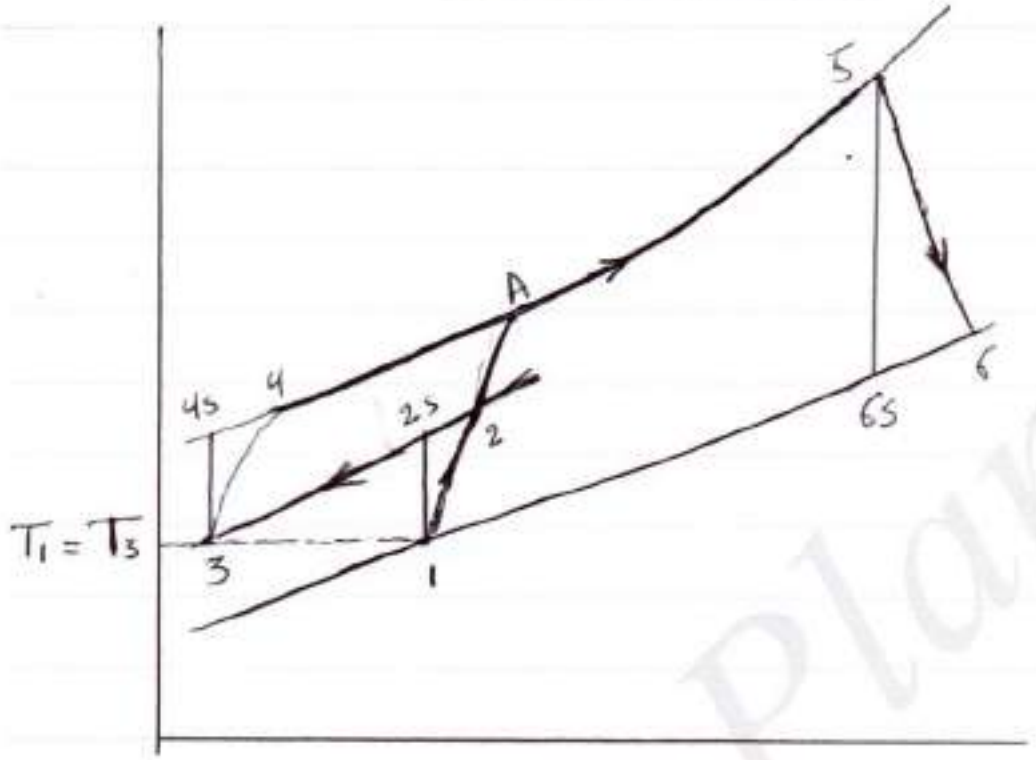
Intercooling

Net work of gas turbine can be increased by reducing negative work i.e. compressor work.

Multistaging of compression process with intercooling in between is one of the approaches for reducing compression work.



L.P.C : low-pressure compressor
H.P.C : High-Pressure Compressor



1-2 : Air is compressed across the L.P.C
2-3 : Air is sent to intercooler where temperature is reduced from T_2 to T_3
3-4 : Air is compressed across the H.P.C
4-5 : Heat is added to the compressed air
5-6 : Air is expanded across the turbine to produce work.

In case of perfect intercooling,

$$T_1 = T_3 \quad \text{and} \quad \frac{P_2}{P_1} = \frac{P_4}{P_3}$$

T-S daigram shows that with absence of intercooling, the exiting tempreture would be T_A while with intercooling this state ia at 4

$$T_A > T_4$$

The reduced tempreture at compressor exit leads to lowering work of the compressor and thus increasing net work.

$$W_c = W_{L.P.C} + W_{H.P.C}$$
$$= C_{Pa}(T_2 - T_1) + C_{Pa}(T_4 - T_3)$$

$$W_t = C_{Pg}(T_5 - T_6)$$

$$W_{net} = W_t - W_c$$
$$= W_t - (W_{L.P.C} + W_{H.P.C})$$

$$Q_{add} = C_{Pg}(T_5 - T_4)$$

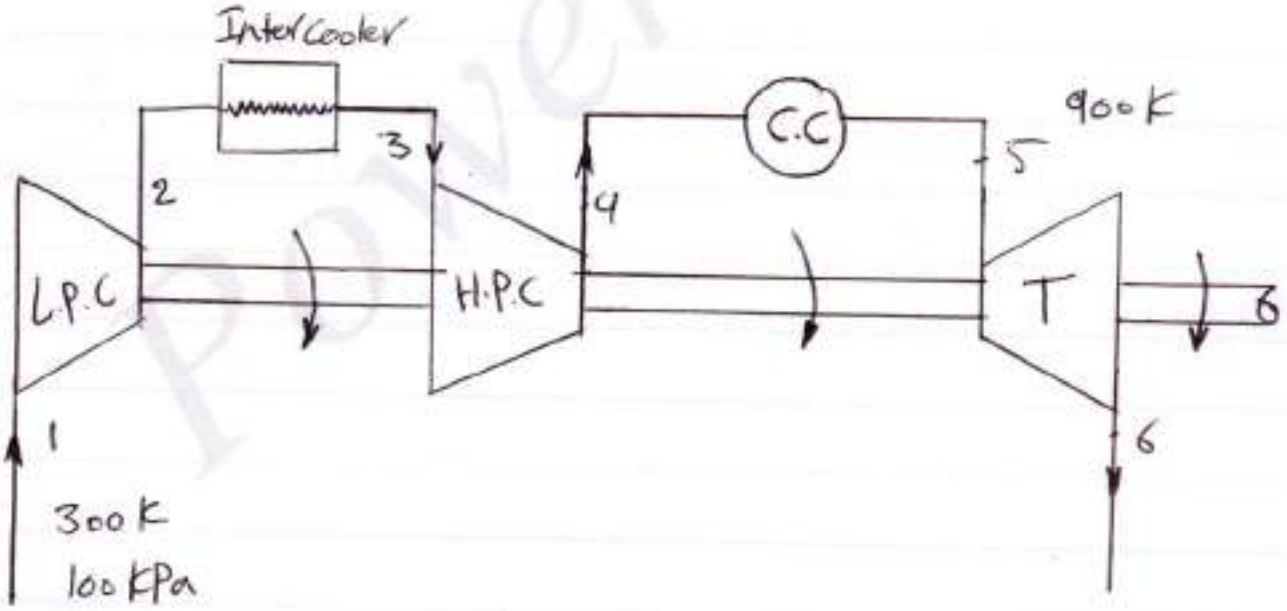
$$\eta = \frac{C_{Pg}(T_5 - T_6) - C_{Pa}[(T_2 - T_1) + (T_4 - T_3)]}{C_{Pg}(T_5 - T_4)}$$

Ex/ In a brayton cycle gas turbine power plant, the minumum and maximum tempretures are 300 K and 900 K respectively. Air is compressed from 100 kPa to 1000 kPa in a two-stage compressor with intercooling between. Consider that the inter-cooling tempreture is equal to the inlet temp. to the first compressor. Also, compression ratio between the two stages are equal.

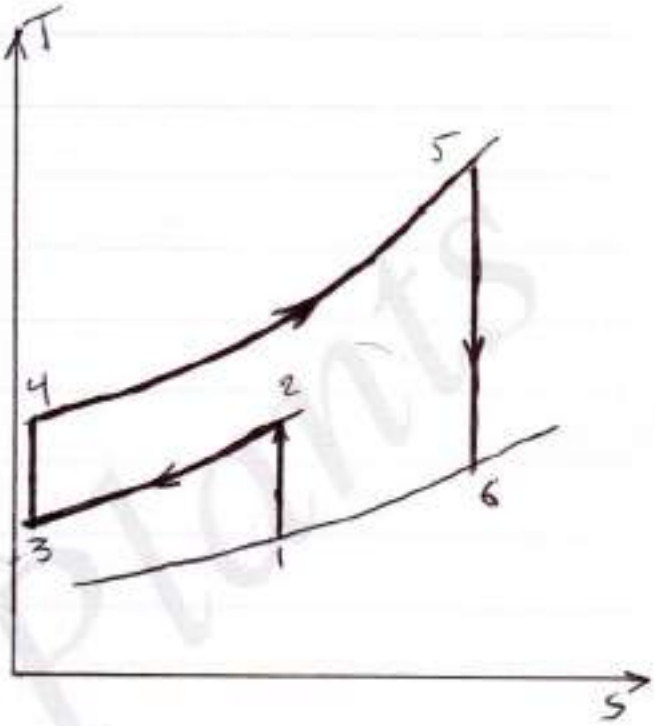
Take $C_{p_g} = 1.15$, $\gamma_g = 1.333$

$C_{p_a} = 1.005$, $\gamma_a = 1.4$

Calculate thermal efficiency of the plant?



Solution:—



It is given that

$$T_1 = T_3$$

$$\frac{P_2}{P_1} = \frac{P_4}{P_3}$$

$$\frac{P_4}{P_1} = \frac{1000}{100} = 10$$

$$\frac{P_4}{P_1} = \frac{P_4}{P_3} \cdot \frac{P_2}{P_1}$$

$$\therefore \frac{P_2}{P_1} = \sqrt{\frac{P_4}{P_1}} = \sqrt{10} = \frac{P_4}{P_3}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma} \Rightarrow T_2 = 300 \times \left(\sqrt{10}\right)^{\frac{0.4}{1.4}} = 416.8\ K$$

$$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}} = 300 \left(\sqrt{10}\right)^{\frac{0.4}{1.4}} = 416.8\ K$$

$$W_c = W_{L.P.C} + W_{H.P.C}$$

$$W_c = C_{pa}(T_2 - T_1) + C_{pa}(T_4 - T_3)$$
$$= 1.005(416.8 - 300) + 2$$
$$= 234.7 \text{ KJ/kg}$$

$T_5 = 900$ (Max temp.)

$$\frac{T_5}{T_6} = \left(\frac{P_5}{P_6}\right)^{\gamma-1/\gamma}$$

$$T_6 = \frac{900}{\left(\frac{1000}{100}\right)^{\frac{0.333}{1.333}}} = 506.3 \text{ K}$$

$$W_t = C_{pg}(T_5 - T_6)$$
$$= 1.15(900 - 506.3)$$
$$= 452.75 \text{ KJ/kg}$$

$$W_{net} = W_t - W_c$$
$$= 452.75 - 234.7$$
$$= 218 \text{ KJ/kg}$$

$$Q_{add} = C_{pg}(T_5 - T_4)$$
$$= 1.15(900 - 416.8) = 555.7 \text{ KJ/kg}$$

$$\eta_{cycle} = \frac{W_{net}}{Q_{add}} = \frac{218}{555.7} = 39.22\%$$