PYQ.
3. Q. In a combined gas turbine-steam power plant the exhaust gas from open cycle gas turbine is the supply to the steam generator of the steam cycle at which additional fuel is burned in the gas. The pressure ratio for the gas turbine is 75. The air inlet temperature is 15°C and the maximum cycle temperature is 750°C. Combustion or additional fuel raises the gas temperature to ~~750°C~~ and the gas leave the steam generator at 100°C. The steam is supplied to the turbine at 50 bar and 600°C and the condenser pressure is 0.1 bar. The total power plant output is 200 MW. The calorific value of the fuel burned is 43.3 MJ/kg. Neglecting the effect of the mass flow rate of the fuel on the air flow, determine –

(a.) the flow rate of the air and steam required.

(b.) the power output of the gas turbine and the steam turbine

(c.) the thermal efficiency of the combined plant

Note. Assume that the combustion products and the air behave as ideal gases with the following properties

For the combustion products :

Specific heat c_p = 1.11 KJ/Kg-K

Specific heat ratio = K = 1.33 = γ

For the air

Specific heat, c_p = 1.005 KJ/Kg-K

Specific heat ratio , ~~K = 1.41~~ K = 1.4 = γ

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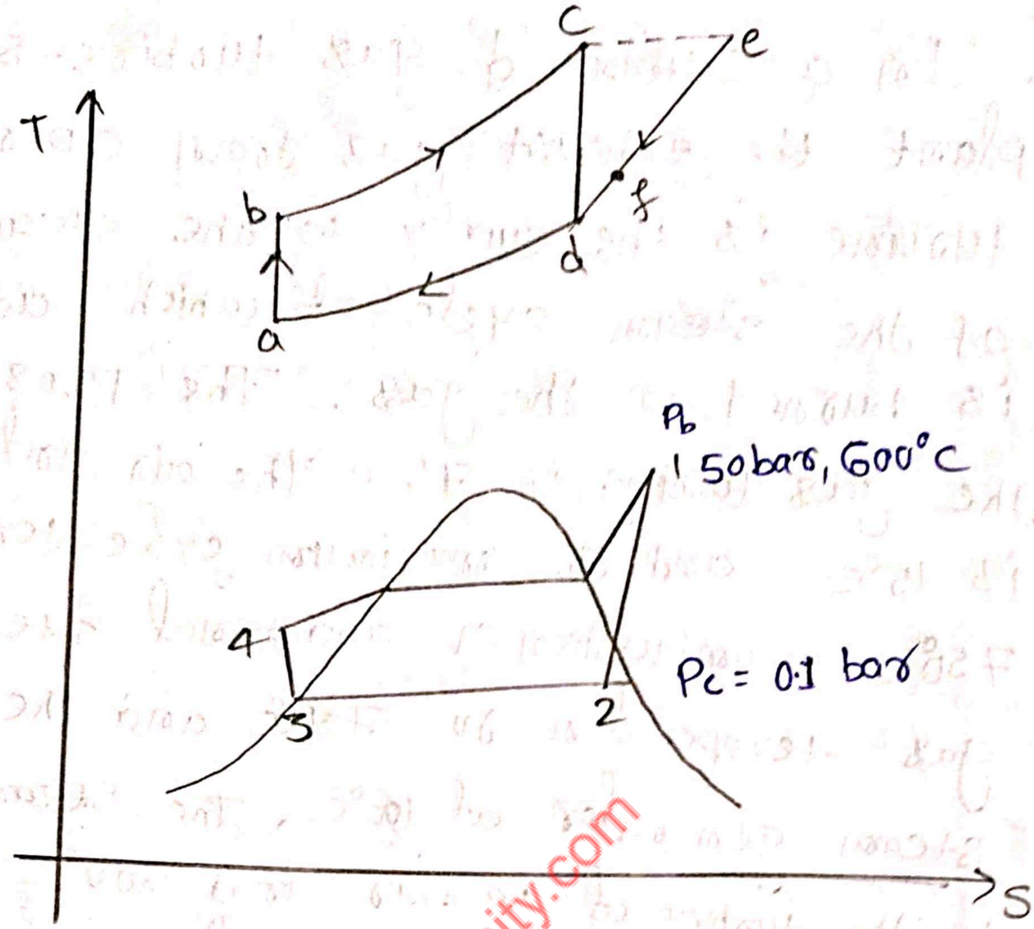
Soln :-



First, Considering gas turbine cycle:

$$\Rightarrow \frac{T_b}{T_a} = (R_p)^{\left(\frac{\gamma-1}{\gamma}\right)}$$

$$\Rightarrow T_b = \left[(7.5)^{\frac{1.4-1}{1.4}}\right] \times [15+273]$$

$$= 1.78 \times 288$$

$$= 512.64 \text{ K}$$

$$\frac{T_c}{T_d} = (R_p)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow \frac{T_c}{T_d} = (7.5)^{\frac{1.33-1}{1.33}} = 1.65$$

$$\Rightarrow T_d = \frac{750+273}{1.65} = \cancel{638.52}$$

$$= 620 \text{ K}$$

$T_a = 288K$, $T_c = 1023K$

$T_b = 512.64K$, $T_d = 620K$

~~SR~~ Second, Considering steam turbine cycle:-

Here, ~~let~~ pump work neglected,

At 50 bar, 600°C.

$$h_1 = 3664.5 \text{ KJ/Kg}$$

$$s_1 = s_2 = 7.258 \text{ KJ/Kg-K}$$

$$\Rightarrow s_2 = s_f + x \cdot s_{fg}$$

$$7.258 = 0.649 + x \cdot 7.502$$

$$x = \frac{7.258 - 0.649}{7.502} = 0.88$$

$$\therefore h_2 = h_f + x \cdot h_{fg}$$

$$= 191.8 + 0.88 + 2392.9$$

$$= 2297.55 \text{ KJ/Kg}$$

$$\& \; h_3 = h_4 = 191.8 \quad \text{(pump work neglected)}$$

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Now,

▶ power developed by gas turbine; mass of fuel neglected,

$$W_g = m_a[C_{pg}(T_c - T_d) - C_{pa}(T_b - T_a)]$$

$$= m_a[1.11(1023 - 620) - 1.005(512.64 - 288)]$$

$$= 221.56\, m_a \quad \text{—— (i)}$$

▶ power developed by steam turbine; pump work neglected.

$$W_s = m_s(h_1 - h_2)$$

$$= m_s \times (3664.5 - 2297.5)$$

$$= 1367\, m_s \quad \text{—— (ii)}$$

> Heat lost by gas = Heat gained by steam

$$m_g \times c_{pg}[T_e - T_f] = m_s(h_1 - h_4) \quad ; \; m_g = m_a$$

$$\Rightarrow m_a \times c_{pg}(T_e - T_f) = m_s(h_1 - h_4)$$

$$\Rightarrow m_a \times 1.11(750-100) = m_s(3664.5 - 191.8)$$

$$\Rightarrow \frac{m_a}{m_s} = \frac{3664.5-191.8}{1.11(650)} = 4.81$$

$$\therefore \frac{m_s}{m_a} = 0.207 \quad \text{— (iii)}$$

~~put the eqn (iii) in eqn (i)~~

> $W_{net} = W_g + W_s$

$$= 221.56\, m_a + 1367\, m_s \quad \text{— (iv)}$$

put the eqn (iii) in eqn (iv)

(a)

$$221.56 \times m_a + 1367 \times 0.207 \times m_a = 200\times10^3$$

$$\Rightarrow 504.53\, m_a = 200\times10^3$$

$$m_a = \frac{200\times10^3}{504.53} = 396.4 \text{ Kg/sec.}$$

Ans

$$m_s = \frac{200\times10^3}{221.56\times4.81+1367} = 82.2 \text{ Kg/sec}$$

Ans

(b) from eqn (i)

$$W_g = 221.56\times396.4 = 87.8\,2600\ W$$

from eqn (ii)

$$W_s = 1367\times82.2 = 112.3\ MW$$

Ans

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(c) $\eta = \frac{W_{net}}{Q_{in}}$

$Q_{in} = \cancel{m_g \times c_{pg}}\ m_a \times c_{pa}(T_c - T_b) + m_g \times c_{pg}(T_e - T_d)$

$\because m_g \simeq m_a$

$= 396.4 \times [1.005(1023 - 512.64) + 1.11(1023 - 620)]$

$= 396.4 \times 960.24$

$= 377.758$ MJ/sec

$\cancel{W_{net} = 87.8 + 112.}$

$\therefore \eta_{cycle} = \frac{200}{377.758} \times 100$

$= 52.9\%$ Ans

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