Name :- Jutul Teron

Scholar Id :- 1916083

Sub :- Applied Thermodynamics

Sub code :- ME 206

Sec B :- Year II

Sem :- 4th

Branch :- Mechanical engineering

Assignment 1

Date

1) Air is drawn in a gas turbine unit at 15°C and 1.01 bar and pressure ratio is 7:1. The Compresser is driven by the HP Turbine and LP Turbine drives a separate power shaft. The Isentropic efficiences of the compressor and the HP and LP Turbine are 0.82, 0.85 & 0.85 respectively. If the maximum cycle temperature is 610°C calculate

I) The pressure and temperature of the gases entering the Power Turbine

II) The net power developed by unit per kg/s mass flow.

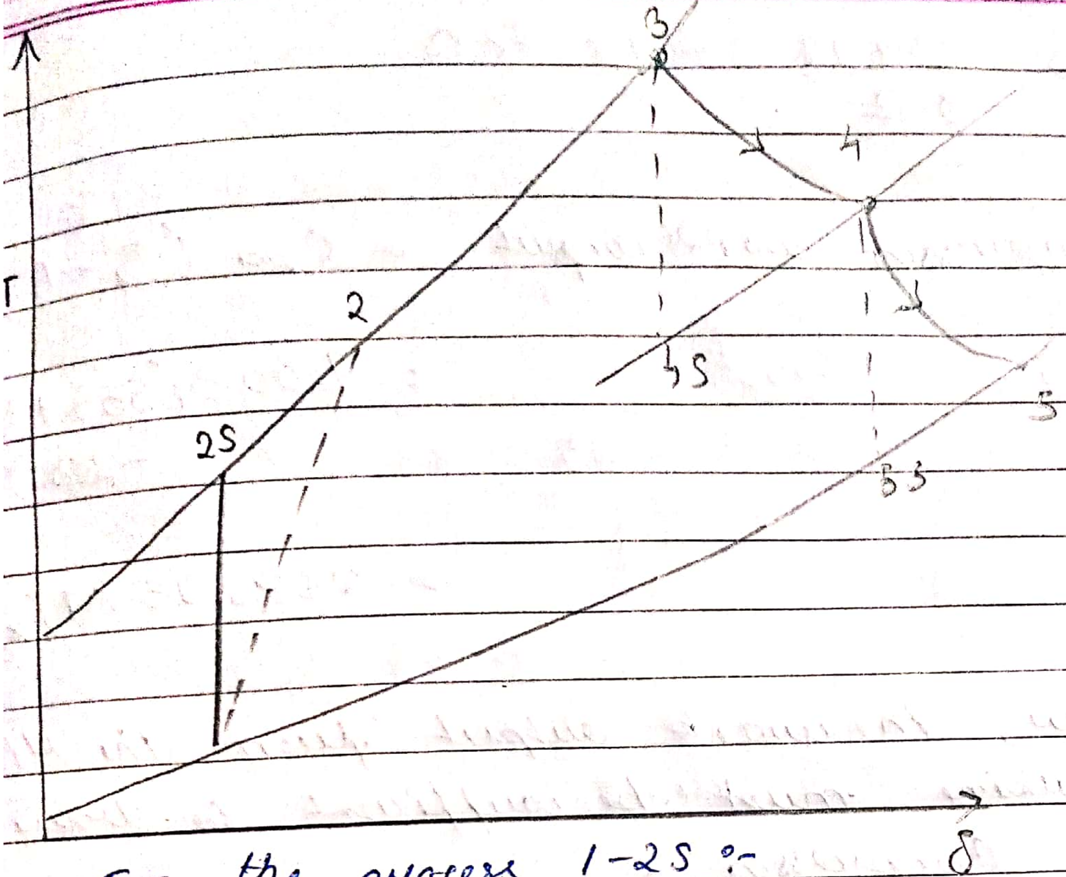
III) The work Ratio

IV) The thermal efficiency of unit.

For Compression process $C_{pa} = 1.005$ kJ/kg K
$\gamma = 1.4$.

For Combustion & expansion process,

$C_{pg} = 1.15$ kJ/kg K and $\gamma = 1.33$



For the process 1-2S :-

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

$$\therefore T_{2S} = (15+273)\left(\frac{7}{1}\right)^{(1.4-1)/1.4}$$

$$= 502.17K$$

Given,

$$\eta_{comp} = 0.82$$

$$\Rightarrow \frac{T_{2S}-T_1}{T_2-T_1} = 0.82$$

$$\Rightarrow \frac{502.17-288}{T_2-288} = 0.82$$

$$\Rightarrow \frac{214.17}{0.8} = T_2 - 288$$

Compresser work input $= C_{pa}(T_2 - T_1)$

$= 1.005(555.7 - 288)$

$= 269.05$ kJ/kg

Now, the work output from the HP Turbine must be sufficient to drive the Compressor,

Turbine work output from HP Turbine

$= C_p(T_3 - T_4)$

$= 269.05$ kJ/kg

$$\Rightarrow T_3 - T_4 = \frac{269.05}{1.15}$$

$$\rightarrow T_4 = 883 - \frac{269.05}{1.15}$$

$= 649.04$ K

$T_2 = 549.18$ K

Page No.
Date

Compressor work input $= C_{pa}(T_2 - T_1)$

$= 1.005(549.18 - 288)$

$= 262.49 \text{ kJ/kg}$

Now, the work output from the H.P. Turbine must be sufficient to drive the Compressor,

Turbine work output from H.P. Turbine.

$= C_p(T_3 - T_4) = 262.49 \text{ kJ/kg}$

$\Rightarrow T_3 - T_4 = \dfrac{262.49}{1.15}$

$\Rightarrow T_4 = 883 - \dfrac{262.49}{1.15}$

$\Rightarrow T_4 = 654.75 \text{K}$

Again,

η_{th} for H.P. Turbine $= 0.85$.

$\Rightarrow \dfrac{T_3 - T_4}{T_3 - T_{4S}} = \dfrac{883 - 654.75}{883 - T_{4S}} = 0.85$

$\Rightarrow \dfrac{228.25}{0.85} = 883 - T_{4S}$

$\Rightarrow T_{4S} = 883 - \dfrac{228.25}{0.85}$

Date

$\Rightarrow T_{4S} = 614.47k$

Again for Turbine we know,

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

$$\Rightarrow \frac{P_3}{P_{4S}} = \left(\frac{T_3}{T_{4S}}\right)^{\gamma/\gamma-1}$$

$$= \left(\frac{883}{614.47}\right)^{\frac{1.333}{0.333}}$$

$$= 4.27$$

$$\Rightarrow P_{4S} = \frac{P_3}{4.27}$$

$$= \frac{7 \times 1.01}{4.27}$$

$$= 1.66 \text{ bar}$$

(i) The Pressure and Temperature of gases entering the LP turbine are 1.66 bar & 657.75k

(ii) Also have,

$$\frac{P_4}{P_5} = \frac{P_4}{P_3} \times \frac{P_3}{P_5}$$

How, $P_2 = P_3$ & $P_5 = P_1$

$\therefore \frac{P_{4S}}{P_{5S}} = \frac{P_{4S}}{P_3} \times \frac{P_{2S}}{P_1}$

$\frac{P_{4S}}{P_{5S}} = \frac{7}{2.27} = 1.64$

Again, $\frac{T_4}{T_{5S}} = \left(\frac{P_{4S}}{P_{5S}}\right)^{\left(\frac{\gamma-1}{\gamma}\right)} = (1.64)^{0.33/1.33}$

$= 1.13$

$\therefore T_{5S} = \frac{654.75}{1.13} = 579.42k$

η_{turb} for the LP. turbine $= 0.85$

$\Rightarrow \frac{T_4 - T_5}{T_4 - T_{5S}} = 0.85$

$\Rightarrow \frac{T_4 - T_5}{654.75 - 579.42} = 0.85$

$\Rightarrow T_4 - T_5 = 64.03k$

$\therefore$ Work output from LP turbine

$= C_{pg}(T_4 - T_5)$

$= 73.63 \text{ kJ/kg}$

$\therefore$ Net power output

$= 73.63 \, kJ = 73.63 \, kW$

(iii) work ratio = $\dfrac{\text{Net work output}}{\text{Gross work output}}$

$= \dfrac{73.63}{73.63 + 262.49}$

$= 0.2191$

(iv) Now,

Heat supplied $= C_{pg}(T_3 - T_2)$

$= 1.15(883 - 549.18)$

$= 383.89 \, kJ/kg$

Hence the thermal efficiency of unit,

$\eta_{th} = \dfrac{\text{Net work output}}{\text{Heat supplied}}$

$= \dfrac{73.63}{383.89}$

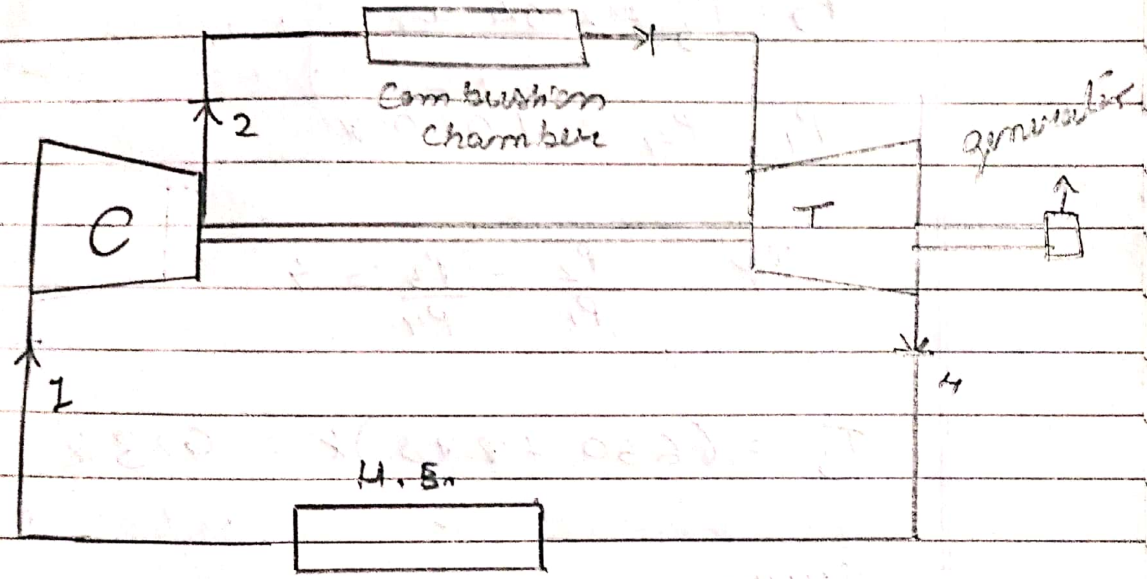
$\Rightarrow \eta_{th} = 0.1918$

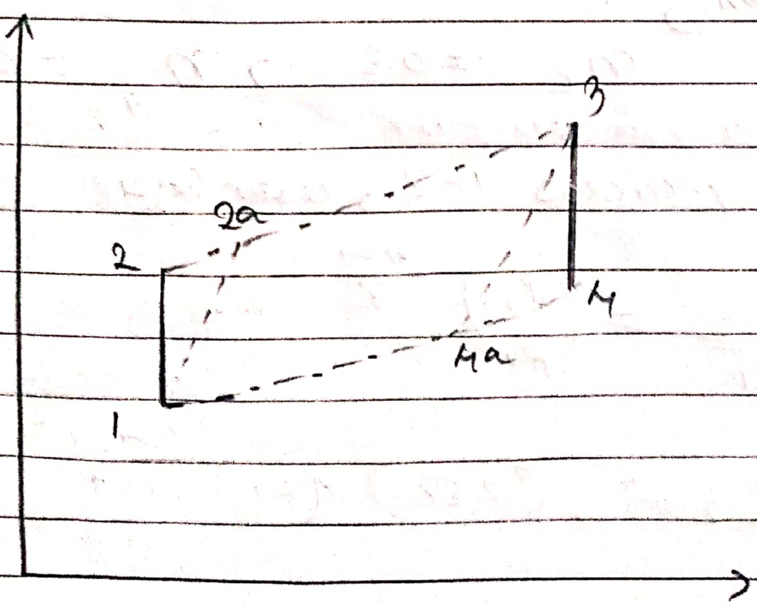
Scanned with CamScanner

Q2 In a gas turbine plant, air is compressed from 1.01 bar and 15°C through a pressure ratio of 4:1. It is then heated to 650°C in a combustion chamber and expanded back to original pressure of 1.01 bar.

Calculate the cycle efficiency and the specific power output if a perfect heat exchanger is employed. The Isentropic efficiency of the turbine and compressor are 0.85 & 0.8 respectively.

Sol^n





Date

$P_1 = 1.01$ bar , $T_1 = 15°C$

$= 15 + 273$

$= 288$ K

$r_p = \frac{P_2}{P_1} = 4$

$\Rightarrow P_2 = 4 \times P_1 = 4 \times 1.01$ bar $= 4.04$ bar

$\therefore r_p = 4$

$\therefore P_2 = 4.04$ bar

$P_2 = P_3 = 4.04$ bar

$P_1 = P_4 = 1.01$ bar

$r_p = \frac{P_2}{P_1} = \frac{P_3}{P_4} = 4$

$T_3 = (650 + 273)$ K $= 928$ K

Given,

$\eta_C = 0.8$, $\eta_T = 0.85$

For process 1-2, isentropic compression

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

$$\Rightarrow T_2 = (288) \times (4)^{\frac{1.4-1}{1.4}}$$

Page No. ______
Date

$\rightarrow T_2 = 427.96k$

$\eta_C = 0.8$

$$\rightarrow \frac{T_2 - T_1}{T_{2a} - T_1} = 0.8$$

$$\Rightarrow T_{2a} = \frac{427.96 - 288}{0.80} = 462.95k$$

For process 3-4,

Isentropic expansion,

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

$$T_4 = T_3\left(\frac{1}{4}\right)^{\frac{1.4-1}{1.4}}$$

$$= 923\left(\frac{1}{4}\right)^{\frac{0.4}{1.4}}$$

$$= 621.13k$$

$\eta_T = 0.85$

$$\frac{T_3 - T_{4a}}{T_3 - T_4} = 0.85$$

$\Rightarrow T_3 - T_{4a} = 0.85(923 - 621.13)$

$= 256.58$

$\rightarrow T_{4a} = 666.41 \quad [\because T_3 = 923K]$

$\therefore$ Cycle efficiency,

$$\eta_{th} = 1 - \left(\frac{1}{rp}\right)^{\frac{\gamma-1}{\gamma}}$$

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

$$= 0.32$$

$$\eta_{th} = 32\%$$

Now,

Network output $= Cp(T_3 - T_{4a}) - Cp(T_{2a} - T_1)$

$= 1.005(923 - 666.4 - 462.95 + 288)$

$= 82.05 \text{ kJ/kg}$

Scanned with CamScanner

Page No.
Date

$\therefore$ Net power output (or) the specific

power output $= 82.05 \times 1$
$= 82.05 kw$

Q3 In a gas turbine installation air is supplied at 1 bar, 25°c into compressor. The pressure after compression is 7.2 bar. The gas leaves the combustion chamber at 1100°c. A heat exchanger having effectiveness of 0.8 is fitted at exit of turbine for heating the air before its inlet into combustion chamber. Isentropic efficiency of the compressor and turbine are 0.8 and 0.85 respectively. The heat transfer rate to combustion chamber is 1.48 MW.

The adiabatic index is 1.4 for air and 1.33 for the gas produced by combustion. The specific heat Cp is 1.005 KJ/kgK for air and 1.5 KJ/kgK for the gas. Determine the following.

→ mass flow rate
→ net power output
→ Thermal efficiency of cycle.

Soln

Given,

adiabatic index, $\gamma = 1.4$

$\eta_{isoc} = 0.8$

$\eta_{isoT} = 0.85$

Let compression index be donate by n_C

$$\therefore \left(\frac{n_C - 1}{n_C}\right) = \left(\frac{\gamma - 1}{\gamma \cdot \eta_{iso,C}}\right)$$

$$\Rightarrow \frac{n_C - 1}{n_C} = \frac{(1.4 - 1)}{(1.4)(0.8)}$$

$$\rightarrow n_C - 1 = 0.36\, n_C$$

$$\rightarrow 0.64\, n_C = 1$$

$$\rightarrow n_C = 1.5625$$

Let the expansion index be n_T.

$$\therefore \left(\frac{n_T - 1}{n_T}\right) = \left(\frac{\eta_{iso,T} \cdot (\gamma - 1)}{\gamma}\right)$$

$$\frac{n_T - 1}{n_T} = \frac{(0.85)(1.33 - 1)}{1.33} = 0.21$$

$$\rightarrow n_T = 1.2658$$

Scanned with CamScanner

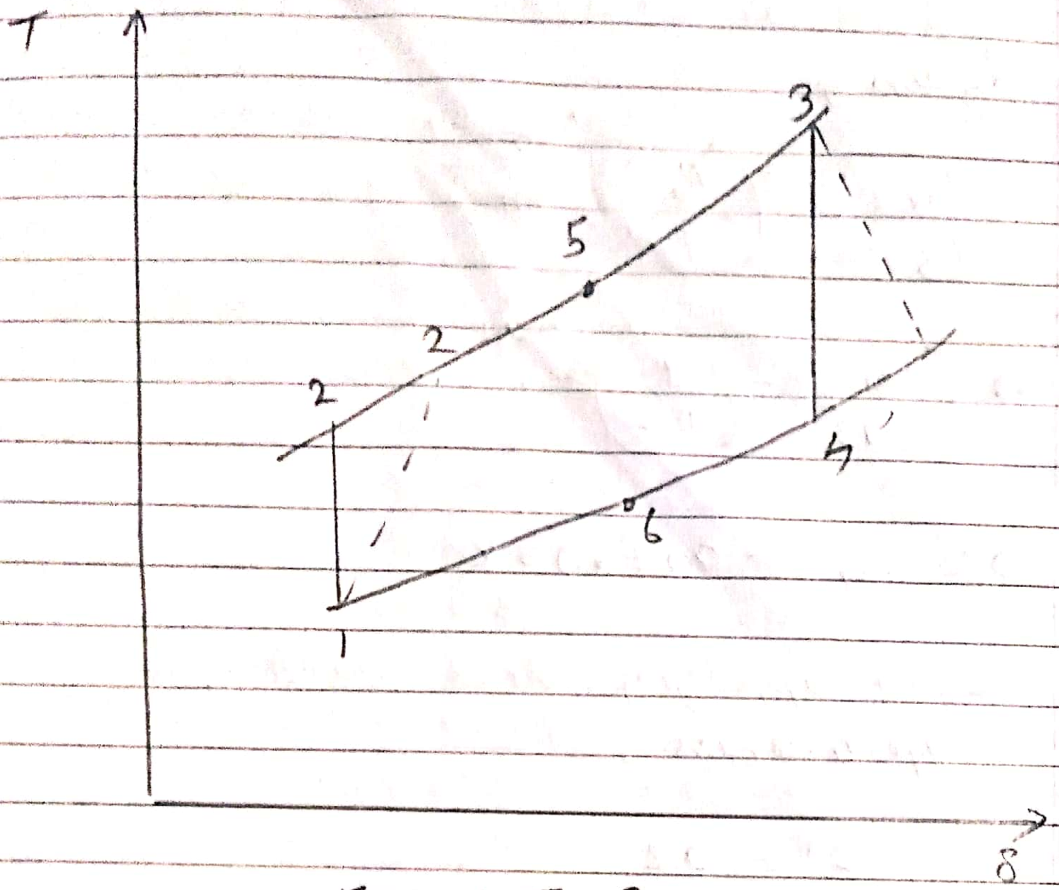


Fig : T − s plot

For process 1-2 :-

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

$$\Rightarrow \frac{T_2}{298} = \left(\frac{7.2}{1}\right)^{0.36}$$

$$\Rightarrow T_2 = 298 (7.2)^{0.36}$$

$$\Rightarrow T_2 = 606.54 K$$

$$\Rightarrow T_3 = 1100^\circ C = 1100 + 273 = 1373 K$$

Again,

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

$$\Rightarrow \frac{T_4}{1373} = \left(\frac{1}{7.2}\right)^{0.21}$$

$$\rightarrow T_4 = 907.05\,k$$

Now applying heat exchanger effectiveness,

$$\epsilon = 0.8$$

$$\left(\frac{T_5 - T_2}{T_4 - T_2}\right) \frac{c_p}{c_g} = 0.8$$

$$\Rightarrow \left(\frac{T_5 - 606.54}{907.05 - 606.54}\right) \frac{1.005}{1.15} = 0.8$$

$$\Rightarrow T_5 = \cancel{0.05}\ 606.54 + \frac{276.4892}{1.005}$$

$$\Rightarrow T_5 = 881.63\,k$$

Heat added in combustion chamber,

$$q_{add} = c_p\,(T_3 - T_5)$$

$$= (1.005)\,(1373 - 881.63)$$

Page No.
Date

$= (493.83 \text{ KJ/kg})$

Compresser work, $W_C = C(T_2 - T_1)$

$= 310.08 \text{ KJ/kg}$

Turbine work, $W_T = C_{pg}(T_3 - T_4)$

$= 1.15(1.373 - 907.05)$

$= 535.84 \text{ kJ/kg}$

∴ Net work output,

$W = W_T - W_C$

$= 535.84 - 310.08$

$= 225.76 \text{ KJ/kg}$

Given,

heat transfer rate to the Combustion chamber, $W = 1.48 MW$

∴ Mass flow rate, $m = \frac{h}{W}$

$= \frac{1.48 \text{ MW}}{225.76 \text{ KJ/kg}}$

$= \frac{1.48 \times 1000 \text{ KJ}}{225.76 \text{ KJ/kg s}}$

$= 6.56 \text{ kg/s}$

Date

Net power output $= 225.76 \times 1$

$= 227.76$ kW

∴ The thermal efficiency of cycle is given by,

$$\eta_{th} = \frac{W_T - W_C}{q_{add}}$$

$$= \frac{W}{q_{add}}$$

$$= \frac{227.76}{493.83}$$

$$\eta_{th} = 0.4572$$

$$\eta_{th} = 45.72\%$$

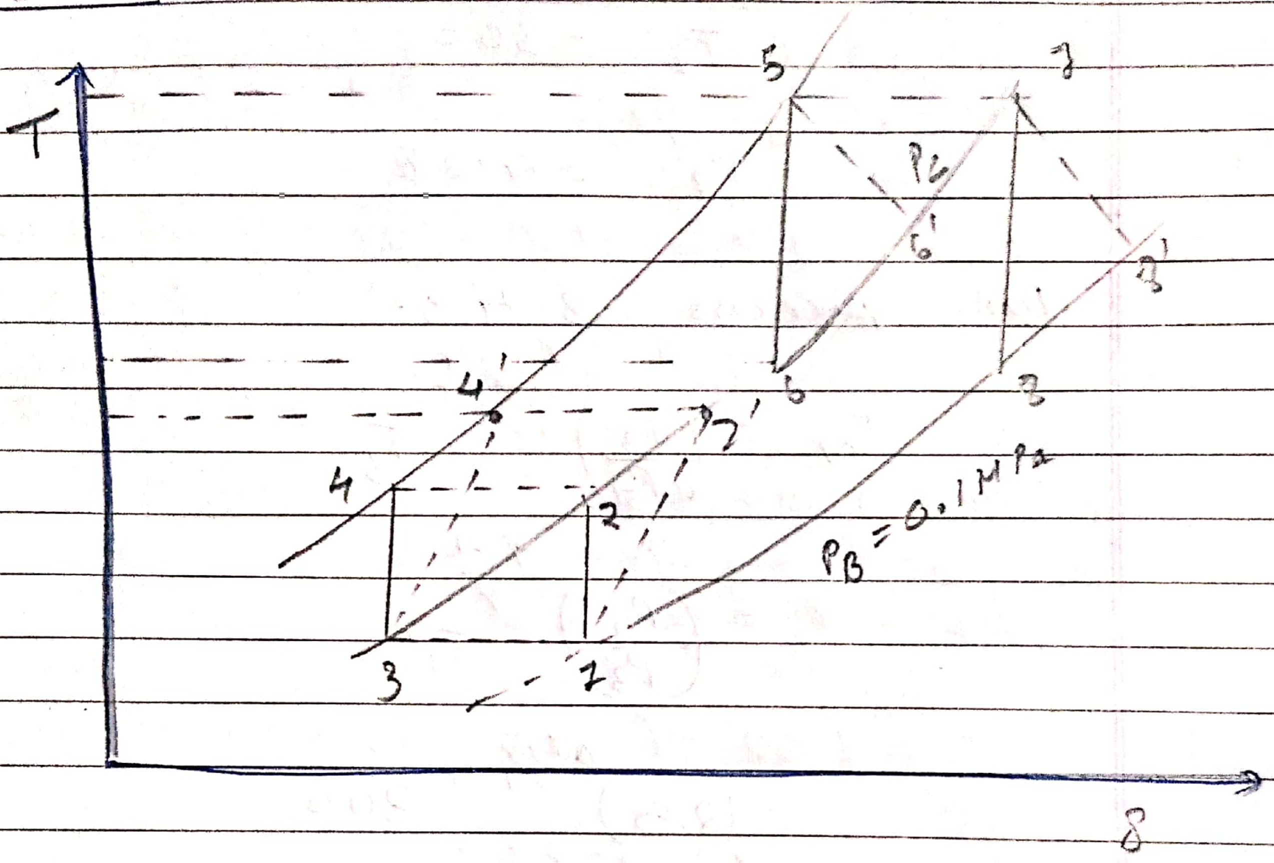
Q 4 In a gas turbine plant working on the Brayton cycle the air at inlet is at 27°C, 0.1 MPa. Compression is divided into two stage, each of pressure ratio 2.5 and efficiency 80% with inter cooling to 27°C and efficiency 80% with inter cooling to 27°C The maximum temperature of cycle is 800°C. Turbine isentropic efficiency is 80%

Find

The cycle efficiency

The turbine exhaust temperature

Soln :-



Given,

$T_1 = T_3 = 300k$

$\frac{P_C}{P_B} = 2.5$

For process 1-2:

$T_2 = (2.5)^{\frac{0.4}{1.4}} \times 300$

$T_2 = 389.77 K$

Again,

$$\eta = \frac{T_2 - T_1}{T_2' - T_1} = 0.8$$

$$\Rightarrow \frac{389.77 - 300}{T_2' - 300} = 0.8$$

$$\Rightarrow T_2' = 412k$$

For process 3-4 :-

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

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

$$= (2.5)^{0.4/1.4} \, 300$$

$$= 389.77k$$

Again,

$$\frac{T_4 - T_3}{T_4' - T_3} = 0.8$$

$$\rightarrow \frac{389.77 - 300}{T_4' - 300} = 0.8$$

Scanned with CamScanner

Page No.
Date

$\rightarrow T_4' = 412k$

For process 5-6:

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

$$= (2.5)^{\frac{-0.4}{1.4}} (1073)$$

$\rightarrow T_6 = 825.86k$

$\rightarrow T_7 = 1073k$

Again, $\frac{T_5 - T_6'}{T_5 - T_6} = 0.8$

$\rightarrow \frac{1073 - T_6'}{1073 - 825.86} = 0.8$

$\rightarrow T_6' = 875.29k$

For process 7-8:

$$T_8 = \left(\frac{P_7}{P_8}\right)^{\frac{1-\gamma}{\gamma}} \cdot T_7$$

$$= (2.5)^{\frac{-0.4}{1.4}} (1073)$$

$= 825.86k$

$\eta_T = 0.8$

$$\Rightarrow \frac{1073 - T_8'}{1073 - 823.86} = 0.8$$

$$\Rightarrow T_8' = 875.29\,k$$

→ Work done by Compressor,

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

$$= 1.005(412 - 300) + 1.005(412 - 300)$$

$$= 225.12 \text{ kJ/kg}$$

Turbine work,

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

$$= 1.005(1073 - 875.29) + 1.005(1073 - 875.29)$$

$$= 397.40 \text{ kJ/kg}$$

Effectiveness of re generator

$$e = \frac{T_a - T_4'}{T_8' - T_4'}$$

$$\Rightarrow 0.75 = \frac{T_a - 412}{875.29 - 42}$$

$$\Rightarrow T_a = 759.47\,k$$

Scanned with CamScanner

Page No.
Date

Heat supplied,

$$Q_s = C_p (T_5 - T_a) + C_p (T_7 - T_6')$$

$$= 1.005(1073 - 759.47) + 1.005(1073 - 875.29)$$

$$\Rightarrow Q_s = 513.80 \text{ kJ/kg}$$

Net work output,

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

$$= (397.40 - 225.12) \text{ kJ/kg}$$

$$W_{net} = 172.28 \text{ kJ/kg}$$

Efficiency of cycle,

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

$$= \frac{172.28}{519.80}$$

$$= 0.3353$$

$$\Rightarrow \eta_{cycle} = 33.53\%$$

Also, the turbine exhaust temperature

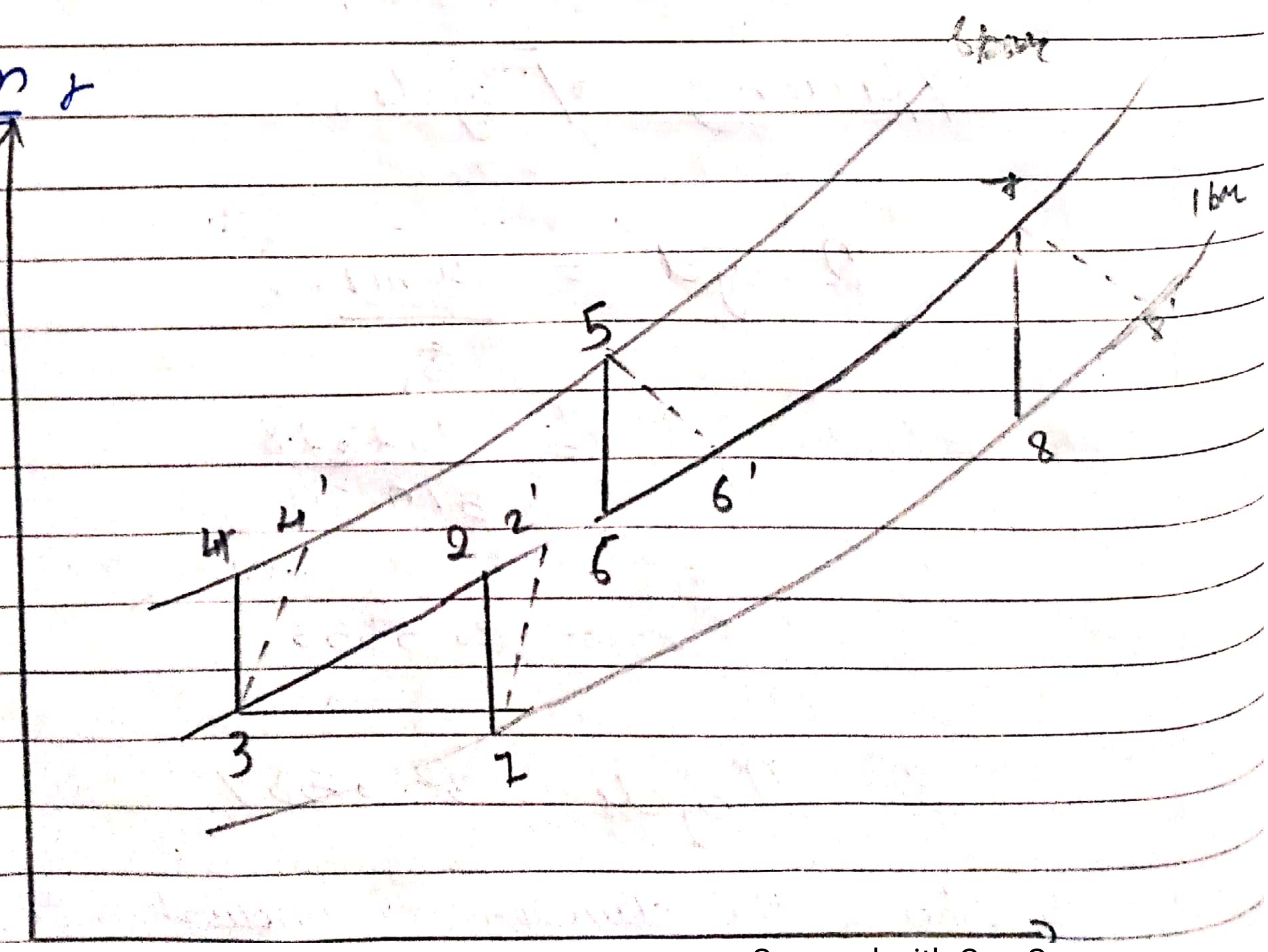
$$T_8' = 875.29 \text{ K}$$

Date

85 The air supplied to a gas turbine plant is 10kg/s. The pressure ratio is 6 and pressure at the inlet of the compressor is 1 bar. The compressor is two stage and provided with perfect intercooler. The inlet temperature is 300K & maximum temperature of cycle is limited to 1073 K.

Isentropic efficiency of compressor stage is 80% and turbine stage is 85%. A regenerator having effectiveness of 0.7 is included. Neglecting the mass of fuel determine the power output and the thermal efficiency of the plant

Soln :



Scanned with CamScanner

Page No. ____
Date

For perfect inter cooling the pressure ratio of each compression stage $= \sqrt{6}$

$= 2.45$

Hence, $T_1 = T_3 = 300K$, $T_5 = 1073K$

For process 1-2:

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

$$\Rightarrow T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 300\,(2.45)^{\frac{1.4-1}{1.4}}$$

$= 387.54K$

Again, $\eta_c = \dfrac{T_2 - T_1}{T_2' - T_1} = 0.8$

$$\Rightarrow \frac{387.54 - 300}{T_2' - 300} = 0.8$$

$$\Rightarrow T_2^2 = 300 + \left(\frac{387.54 - 300}{0.8}\right)$$

$= 409.425$

$= 409.43K$ (Approx)

Scanned with CamScanner

For process 3-4r

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

$$\Rightarrow T_4 = 300 \, (2.45)^{\frac{0.4}{1.4}}$$

$$= 387.54 \, k$$

Again,

$$\frac{T_4 - T_3}{T_4' - T_3} = 0.8$$

$$\Rightarrow \frac{387.54 - 300}{T_4' - 300} = 0.8$$

$$\Rightarrow T_4' = 300 + \left(\frac{387.54 - 300}{0.8}\right)$$

$$= 409.43 \, k$$

For process 5-6:-

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

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

Scanned with CamScanner

Page No.
Date

$T_6 = (1073)(2.45)^{\frac{1-1.4}{1.4}}$ $(\because T_5 = 1073k)$

$\Rightarrow T_6 = 830.63k$

Also,

$T_7 = T_5 = 1073k$

Now,

$$\frac{T_5 - T_6'}{T_5 - T_6} = 0.85$$

$$\Rightarrow \frac{1073 - T_6'}{1073 - 830.63} = 0.85$$

$\Rightarrow (1073 - T_6') = (0.85)(1073 - 830.63)$

$\Rightarrow T_6' = 1073 - (0.85)(1073 - 830.63)$

$\Rightarrow T_6' = 866.99k$

for process 7-8

$$\frac{T_8}{T_7} = \left(\frac{P_7}{P_8}\right)^{\frac{1-8}{\gamma}}$$

$\Rightarrow T_8 = (1073)(2.45)^{\frac{(-0.4)}{1.4}}$

$\Rightarrow T_8 = 830.63k$

$$\eta_T = \frac{T_7 - T_8'}{T_7 - T_8} = 0.85$$

$$\Rightarrow \frac{1073 - T_8'}{1073 - 830.63} = 0.85$$

$$\Rightarrow T_8' = -(0.85)(1073 - 830.63) + 1073$$

$$\Rightarrow T_8' = 1073 - (0.85)(1073 - 830.63)$$

$$= 866.994$$

Work done by Compressor

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

$$= (1.005)[409.43 - 300 + 409.43 - 300]$$

$$= 219.95 \text{ kJ/kg}$$

Turbine work,

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

$$= 1.005[1073 - 866.99 + 1073 - 866.99]$$

$$= 414.08 \text{ kJ/kg}$$

Scanned with CamScanner

Date

Effectiveness of regenerator

$$\varepsilon = \frac{T_a - T_4'}{T_8' - T_4'}$$

$$0.7 = \frac{T_a - 409.43}{866.99 - 409.43}$$

$$\Rightarrow T_a = (409.43) + (0.7)(866.99 - 409.43)$$

$$\Rightarrow T_a = 729.72\,K$$

Heat supplied,

$$Q_S = C_p (T_5 - T_a) + C_p (T_7 - T_6')$$

$$= 1.005(1073 - 729.72) + 1.005(1073 - 866.99)$$

$$= 552.04\ kJ/kg.$$

∴ Net work output,

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

$$= (414.08 - 219.95)$$

$$= 194.13\ kJ/kg.$$

∴ Power output,

Page No.
Date

$P = m \times W_{net}$

$= 10 kg/s \times 194.13 kJ/kg$

$= 1941.3 kJ/s$

$= 19413 kW$

efficiency of the gas turbine plant,

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

$$= \frac{194.13}{552.04}$$

$$\eta = 0.3517$$

$\therefore \eta = 35.17\%$