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SHAMBHUNATH INSTITUTE OF ENGINEERING AND TECHNOLOGY

Applied Thermodynamics(KME 401)

B. Tech.(IV-SEMESTER)

FIRST SESSIONAL EXAMINATION, EVEN SEMESTER,(2019-2020)

Branch: Mechanical Engineering

Time –1hr 30 min **Maximum Marks – 30**

SECTION – A

1. Attempt all questions in brief. **(1*5 = 5)**

Q N	QUESTION	Marks	CO	BL
a.	Define vacuum efficiency. **Ans-**The ratio of actual vacuum to ideal vacuum in the condenser is known as vacuum efficiency.	**1**	**3**	**1**
b.	Define Grate. **Ans-**The grate is the place where the fuel is burnt. it consist of cast iron bars with spacing between them so that the air for combustion may pass between the tubes ans ash may fall below.	**1**	**3**	**1**
c.	What is turboprop engine? **Ans-**In this engine 80 to 90 % of the total propulsive thrust is generated by the gas turbine and the remainder is developed by the expansion of gases in nozzles.due to this power generated in the gas turbine is used for driving the compressor and the propeller.	**1**	**5**	**1**
d.	Define propulsive efficiency. **Ans-**it is defined as the ratio of thrust power to propulsive power**.**	**1**	**5**	**1**
e.	State the requirements of modern condenser. **Ans-**(i) the steam should be evenly distributed over the whole cooling surface (ii)air leakages to the condenser should be avoided since it destroys the vacuum in the condenser.	**1**	**3**	**1**

SECTION - B

2. Attempt any TWO of the following. **(2*5 = 10)**

Q N	QUESTION	Marks	CO	BL
a.	How the boilers are classified? Compare the fire tube and water tube boilers. Boilers are of many types. **Depending upon their features they can be classified as given under:** (a) Based upon the orientation/axis of the shell: According to the axis of shell boiler can be classified as vertical boiler and horizontal boiler. (i) Vertical boiler has its shell vertical. (ii) Horizontal boiler has its shell horizontal. (iii) Inclined boiler has its shell inclined. (b**) Based upon utility of boiler: Boilers can be classified as** (i) Stationery boiler, such boilers are stationery and are extensively used in power plants, industrial processes, heating etc. (ii) Portable boiler, such boilers are portable and are of small size. These can be of the following types, Locomotive boiler, which are exclusively used in locomotives. Marine boiler, which are used for marine applications. (c**) Based on type of firing employed: According to the nature of heat addition process boilers can be classified as,** (i) Externally fired boilers, in which heat addition is done externally i.e. furnace is outside the boiler unit. Such as Lanchashire boiler, Locomotive boiler etc. (ii) Internally fired boilers, in which heat addition is done internally i.e. furnace is within the boiler	**5**	**3**	**2**

	unit. Such as Cochran boiler, Bobcock Wilcox boiler etc. (d) **Based upon the tube content: Based on the fluid inside the tubes, boilers can be,** (i) Fire tube boilers, such boilers have the hot gases inside the tube and water is outside surrounding them. Examples for these boilers are, Cornish boiler, Cochran boiler, Lancashire boiler, Locomotive boiler etc. (ii) Water tube boilers, such boilers have water flowing inside the tubes and hot gases surround them. Examples for such boilers are Babcock-Wilcox boiler, Stirling boiler, La-Mont boiler, Benson boiler etc. (e) **Based on type of fuel used: According to the type of fuel used the boilers can be,** (i) Solid fuel fired boilers, such as coal fired boilers etc. (ii) Liquid fuel fired boilers, such as oil fired boilers etc. (iii) Gas fired boilers, such as natural gas fired boilers etc. (f) **Based on circulation: According to the flow of water and steam within the boiler circuit the** boilers may be of following types, (i) Natural circulation boilers, in which the circulation of water/steam is caused by the density difference which is due to the temperature variation (ii) Forced circulation boilers, in which the circulation of water/steam is caused by a pump i.e. externally assisted circulation. (g) **Based on extent of firing: According to the extent of firing the boilers may be,** (i) Fired boilers, in which heat is provided by fuel firing. (ii) Unfired boilers, in which heat is provided by some other source except fuel firing such as hot flue gases etc. (iii) Supplementary fired boilers, in which a portion of heat is provided by fuel firing and remaining by some other source. Comparison between fire tube and water tube boiler **Fire tube boiler** 1-in this the hot flue gases flow in the tube surrounded outside by the water 2-it requires less floor area 3-these are usually made in smaller **Water tube boiler** **1-** in this the water flow in the tube surrounded outside by the hot gases. 2- it requires more floor area 3-these are bigger in size.			
b.	State the comparison between : **(i)** Jet and surface condenser **(ii)** Jet engine and propeller engine	**5**	**3**	**2**

4.8.1 Jet Condensers :

Advantages of jet condensers :

(i) It requires less quantity of cooling water to condense the steam since both cooling water and steam are mixed intimately.

(ii) The system is simple in construction and it's cost is low.

(iii) It does not require cooling water pump.

(iv) Space requirement is less.

(v) It's maintenance cost is low.

Disadvantages of jet condensers :

(i) The condensate is a waste.

(ii) These are less suitable for high capacity plants.

(iii) The system requires large lengths of piping, therefore, the piping cost is high.

(iv) Due to leakage of air in long pipes, there is loss of vacuum of the order of 10 to 15 mm of Hg.

(v) More power is required to run the air extraction pump, it may be two times the power required for surface condensers.

Surface condensers:

(i)cooling water and steam are not mixed.

(ii) Any kind of feed water can be used. Since the make up water requirements are low (only 5 to 10%), the cost of water softening plant is reduced.

(iii) It can develop high vacuum, therefore, these are suitable for large capacity power plants.

(iv) It requires less power to run the air extraction pump.

(v) It requires less power for water pumping.

(vi) The system is more efficient.

Disadvantages :

(i) It requires large quantity of cooling water.

(ii) The system is complicated, costly and requires high maintenance cost.

(iii) It requires large floor space since it is bulky.

Sr. No.	Jet Engine	Propeller turbine Engine
1.	Compressed air is passed through the turbine.	A part of air drawn by propeller unit is passed around the ducts and reminder is passed to the turbine.
2.	Power developed by turbine is used to drive the compressor only. Thrust is developed by expansion of air in nozzles.	Power developed by the turbine is used to drive the compressor and propeller. The total thrust developed is both by the propeller and the nozzles.
3.	Pressure ratio for turbine is lower.	Pressure ratio for turbine is higher.

c.	A Lancashire boiler generates 2400kg of dry steam per hour at a pressure of 11 bar .The grate area is 3 m^2 and 90 kg of coal is burnt per m^2 of grate area per hour. The calorific value of the coal is 33180kJ/kg and the temperature of feed water is 17.5 ^{0}C. Determine : **(i)** Actual evaporation per kg of coal **(ii)** Equivalent evaporation from and at 100^{0}C . (**iii)** Efficiency of the boiler	**5**	**3**	**3**

	Solution. Given : $m_s = 2400$ kg/h ; $p = 11$ bar ; Grate area = 3 m^2 ; Coal burnt = 90 kg/m^2 /h =33 180 kJ/kg ; $t_1 = 17.5°$ C *Actual evaporation per kg of coal* We know that mass of coal burnt per hour, $m_f = 90 \times 3 = 270$ kg/h ∴ Actual evaporation per kg of coal, $m_e = m_s / m_f = 2400 / 270 = 8.89$ kg / h **Ans.** 2. *Equivalent evaporation 'from and at 100° C'* From steam tables, corresponding to a feed water temperature of 17.5° C, we find that $h_{f1} = 73.4$ kJ/kg 17.5 → hf = and corresponding to a steam pressure of 11 bar, we find that pressure $h = h_g = 2779.7$ kJ/kg . . . (For dry steam) We know that equivalent evaporation 'from and at 100° C' $E = \frac{m_e (h - h_{f1})}{2257} = \frac{8.89\,(2779.7 - 73.4)}{2257} = 10.66$ kg/h **Ans.** 3. *Efficiency of the boiler* We know that efficiency of the boiler, $\eta = \frac{m_e (h - h_{f1})}{C} = \frac{8.89\,(2779.7 - 73.4)}{33\,180} = 0.725$ or 72.5 % **Ans.**			
d.	In a boiler ,the following observation made: Pressure of steam=10 bar Steam condensed=540kg/h Fuel used=65kg/h Moisture in fuel=2%by mass Mass of dry flue gases=9 kg/kg of fuel Lower calorific value of fuel= 32000kJ/kg Temperature of the flue gases= 325^{0}C Temperature of the boiler house= 28^{0}C Feed water temperature= 50^{0}C Mean specific heat of flue gases=1 kJ/kg K Dryness fraction of steam=0.95 Draw up a heat balance sheet for the boiler **Solution.** Given : $p = 10$ bar ; $m_s = 540$ kg/h ; $m_f = 65$ kg/h ; $m_m = 0.02$ kg/kg of fuel ; m_g = 9 kg/kg of fuel ; $C = 32\,000$ kJ/kg ; $t_g = 325°$ C ; $t_b = 28°$ C ; $t_1 = 50°$ C ; $c_{pg} = 1$ kJ/kg K ; $x = 0.95$ First of all, let us find the heat supplied by 1 kg of fuel. Since the moisture in fuel is 0.02 kg, therefore heat supplied by 1 kg of fuel $= (1 - 0.02)\, 32\,000 = 31\,360$ kJ . . (i) 1. *Heat utilised in raising steam per kg of fuel* We know that the mass of water actually evaporated per kg of fuel, $m_e = m_s / m_f = 540 / 65 = 8.31$ kg From steam tables, corresponding to a feed water temperature of 50° C, we find that $h_{f1} = 209.3$ kJ/kg	**5**	**3**	**3**

and corresponding to a steam pressure of 10 bar, we find that

$$h_f = 762.6 \text{ kJ/kg} ; \; h_{fg} = 2013.6 \text{ kJ/kg}$$

$\therefore$ Heat utilised in raising steam per kg of fuel

$$= m_e (h - h_{f1}) = m_e (h_f + x\, h_{fg} - h_{f1})$$

$$= 8.31 (762.6 + 0.95 \times 2013.6 - 209.3) = 20\,495 \text{ kJ} \quad \ldots (ii)$$

2. Heat carried away by dry flue gas

We know that heat carried away by dry flue gas

$$= m_g\, c_{pg} (t_g - t_b) = 9 \times 1\, (325 - 28) = 2673 \text{ kJ} \quad \ldots (iii)$$

3. Heat carried away by moisture in fuel per kg of fuel

From steam tables, corresponding to a temperature of 28° C, we find that

$$h_b = 117.3 \text{ kJ/kg}$$

We know that heat carried away by moisture in fuel

$$= m_m [2676 + c_p (t_g - 100) - h_b]$$

$$= 0.02 [2676 + 2.1 (325 - 100) - 117.3] = 60.6 \text{ kJ} \quad \ldots (iv)$$

... (Taking c_p for superheated steam = 2.1 kJ/kg K)

4. Heat lost by radiation etc.

We know that heat lost by radiation etc. (by difference)

$$= 31\,360 - (20\,495 + 2673 + 60.6) = 8131.4 \text{ kJ} \quad \ldots (v)$$

Now complete heat balance sheet per kg of fuel is given below :

Heat supplied	*kJ*	*Heat expenditure*	*kJ*	%
Heat supplied by 1 kg of fuel	31 360	1. Heat utilised in raising steam	20 495	65.35
		2. Heat carried away by dry flue gases	2673	8.53
		3. Heat carried away by moisture in fuel	60.6	0.19
		4. Heat lost by radiation etc. (by difference).	8131.4	25.93
Total	31 360	Total	31 360	100

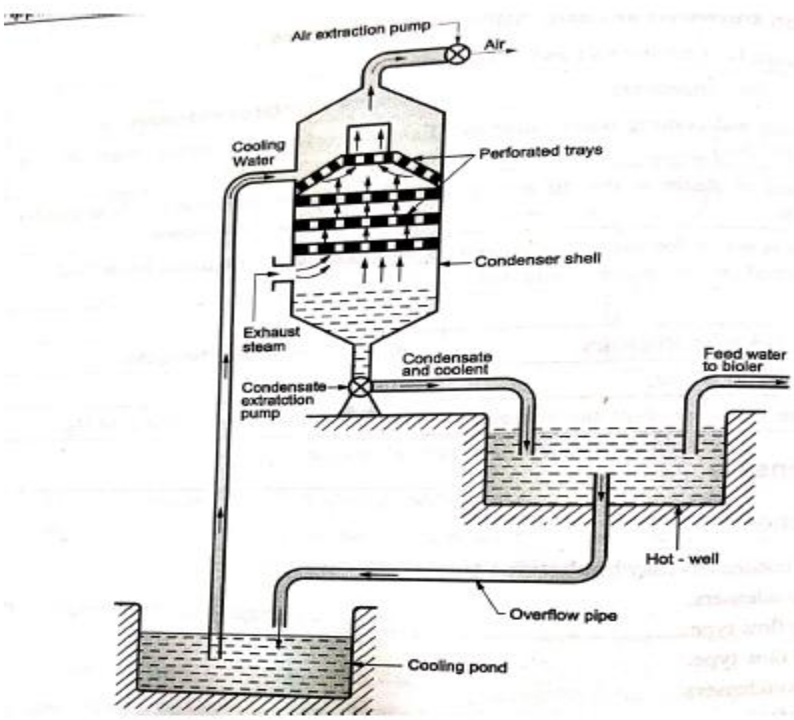
SECTION - C

3. Attempt any ONE part of the following: **(1*5 = 5)**

Q N	QUESTION	Marks	CO	BL
a.	The following observations were made on a steam condensing plant : Barometer reading =760 mm of Hg Recorded vacuum =700mm of Hg Mean temperature of condensation = 34^0C Hot well temperature =27^0C Mass of condensate =2120 kg/hr Mass of cooling water =66000kg/hr Rise in temperature of cooling water = 16^0C,Find: **(i)** The state of steam entering the condenser **(ii)** Mass of air present in kg/m^3 of condenser **(iii)** Vacuum efficiency **(i) The state of steam entering condenser :** Heat lost by steam = heat gained by cooling water. $m_s(h_f + x \cdot h_{fg}) - h_c) = m_w(t_o - t_i)s_w$ From steam tables at saturation temperature of 34° C, we get, $p_s = 0.05318$ bar ; $h_f = 142.4$ kJ/kg ; $h_{fg} = 2421.2$ kJ/kg $\therefore\ 2120(142.4 + x \times 2421.2 - 4.187 \times 27) = 66000 \times 16 \times 4.187$ $\therefore$ State of steam entering the condenser, $x = \mathbf{0.8492}$ ...Ans. **(ii) Mass of air present :** Total absolute pressure of condenser, p_t = Barometer reading – Vacuum gauge reading $= 760 - 700 = 60$ mm of Hg $= 60 \times \frac{1.013}{760} = 0.07991$ bar $\therefore$ Partial pressure of air, $p_a = p_t - p_s = 0.07997 - 0.05318 = 0.02679$ bar $p_a V_a = m_a R T_a$ $(0.02679 \times 10^5) \times 1 = m_a \times 287 \times (273 + 34)$ $\therefore\ m_a = \mathbf{0.304\ kg/m^3}$ **of condenser** ...Ans. **(iii) Vacuum efficiency :** $p_s = 0.05318$ bar $= 0.05318 \times \frac{760}{1.013} = 39.898$ mm of Hg Vacuum efficiency $= \frac{\text{Actual vacuum}}{\text{Barometer} - p_s} = \frac{700}{760 - 39.898} = \mathbf{0.972\ or\ 97.2\%}$ ...Ans.	5	3	3

b.	With a neat sketch explain the working of low level counter flow jet condenser.	**5**	**3**	**2**

- Schematic diagram of a low level counter flow jet condenser is shown in Fig. 4.3.
- Exhaust steam is supplied from the bottom side of condenser and it flows upwards while the cooling water is supplied from the top of the condenser.
- The water flows in downward direction through a series of perforated trays. The steam gets condensed while it comes in contact with the falling water.
- The air extraction pump is situated at the top of condenser which draws the air and any uncondensed vapour.
- The air pump always maintains the required vacuum in the condenser and induces the cooling water to be lifted into the condenser upto a height of 5.5 m approximately.
- The mixture of condensate and the coolant is extracted with the help of condensate extraction pump and it is discharged into a hot well.
- The excess amounts of condensate from hotwell flows into the cooling pond by an overflow pipe as shown and the remainder is pumped to the boiler as feed water.
- The capacity of air pump required is small since it is required to extract cooled air and water vapour. These condensers can be installed directly below the steam turbine. Such condensers have a disadvantage of flooding the steam turbine if the condensate extraction pump fails.



4. Attempt any ONE part of the following : (1*5 = 5)

Q N	QUESTION	Marks	CO	BL
a.	Discuss the working of turbojet engine with T-S diagram.	5	5	2

The schematic diagram of a turbojet engine is shown in Fig. 10.2. The basic components of the turbojet are diffuser, compressor, combustor, gas turbine and the set of nozzles.

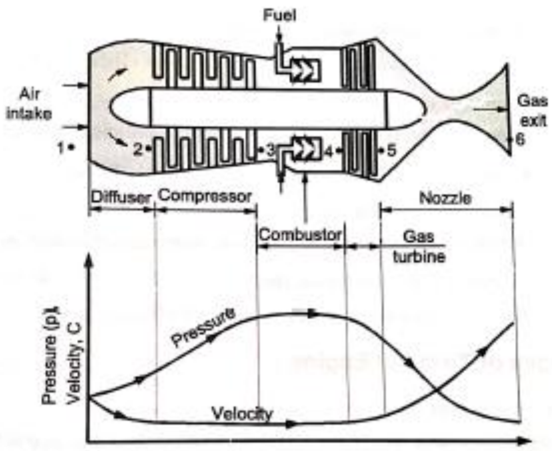


Fig. 10.2 : Schematic diagram of a turbojet engine

The atmospheric air at the aircraft velocity at point 1 enters into the **diffuser** which converts the kinetic energy into pressure energy. Such a compression is called **ram compression.**

This air is further compressed in an axial flow compressor. The pressurised air then passes to a combustion chamber called **combustor** where the fuel is added and burnt. The combustion process is at constant pressure and during the process it raises the temperature of the gases.

The products of combustion are now expanded in the gas turbine upto a pressure such that the power produced by the turbine is just sufficient to drive the compressor and any other auxiliary equipment like fuel and lubricating oil pumps. The pressure at the exit of the gas turbine is much above the atmospheric pressure. These gases finally expands in the nozzles upto surrounding pressure.

The velocity of the gases at the exit of the nozzle are much above the inlet velocity of air to the diffuser section. The rate of change of momentum produces the required thrust and its reaction provides the necessary propulsive force to propel the jet engine in the forward direction.

At higher speeds the turbojet has higher propulsive efficiency and these have been found suitable to aircrafts travelling at speeds higher than 800 kmph.

The pressure and velocity variation of air and gases along the section of turbojet is also shown in Fig. 10.2 and the processes on (T-S) diagram are represented in Fig. 10.3. The various processes involved in turbojet are :

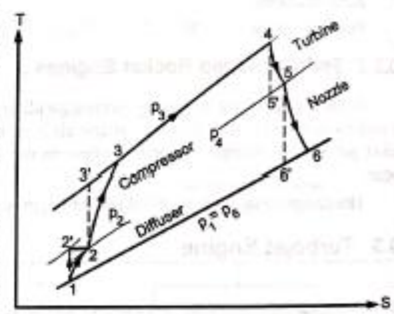


Fig. 10.3 : (T-S) diagram for turbojet engine

Process (1-2')	:	Isentropic compression in diffuser.
Process (1-2)	:	Actual compression in diffuser with diffuser efficiency, η_d.
Process (2-3')	:	Isentropic compression in compressor.
Process (2-3)	:	Actual compression in compressor with isentropic efficiency, η_c of compressor.
Process (3-4)	:	Constant pressure heat addition process in combustor.
Process (4-5')	:	Isentropic expansion in gas turbine
Process (4-5)	:	Actual expansion in gas turbine with isentropic efficiency η_t of turbine
Process (5-6')	:	Isentropic expansion in nozzles.
Process (5-6)	:	Actual expansion in nozzles with nozzle efficiency, η_n.

b.

A turbojet engine draws air at the rate of 1 kg/s while flying at a speed of 900 kmph. The velocity of gases at the exit of the nozzle is 620 m/s. The engine uses fuel at the rate of 0.0125 kg/s of calorific value 45000 kJ/kg. Find

(i) Fuel air ratio

(ii) Fuel consumption in kg/hr

(iii) Thrust power

(iv) TSFC

(v) Overall efficiency

Solution :

Given : Mass flow rate of air, $\dot{m}_a = 1$ kg/s

Mass flow rate of fuel, $\dot{m}_f = 0.0125$ kg/s

Turbojet speed, $C_a = 900 \text{ kmph} = \frac{900 \times 1000}{3600} = 250$ m/s

Gas velocity, $C_g = 620$ m/s

Calorific value (C.V.) of fuel $= 45000$ kJ/kg

(i) Fuel-air ratio, $f = \frac{\dot{m}_f}{\dot{m}_a} = \frac{0.0125}{1} = \mathbf{0.0125 : 1}$

(ii) Fuel consumption in kg/hr $= \dot{m}_f \times 3600 = 0.0125 \times 3600 = \mathbf{45 \text{ kg/hr}}$

(iii) Thrust, $F = \dot{m}_a (1 + f)(C_g - C_a)$

$= 1(1 + 0.0125)(620 - 250) = \mathbf{374.625 \text{ N}}$

Thrust power, $P_t = F \times C_a$

$= 374.625 \times 250 = \mathbf{93656.25 \text{ Nm/s or W}}$

Thrust specific fuel consumption (TSFC)

$= \frac{\text{Fuel consumption in kg/hr}}{\text{Thrust}}$

$= \frac{45}{374.625} = \mathbf{0.12012 \text{ kg/hr N}}$

(iv) Propulsive power, $P_p = \frac{\dot{m}_a}{2}(1 + f)(C_g^2 - C_a^2)$

$= \frac{1}{2}(1 + 0.0125)(620^2 - 250^2) = \mathbf{162961.9 \text{ W}}$

Propulsive efficiency, $\eta_p = \frac{2C_a}{C_g + C_a} = \frac{2 \times 250}{(620 + 250)} = \mathbf{0.5747 \text{ or } 57.47 \%}$

(v) Thermal efficiency, $\eta_t = \frac{P_p}{\dot{m}_f \times \text{C. V.}} = \frac{162961.9}{0.0125 \times 45000 \times 1000}$

$= \mathbf{0.2897 \text{ or } 28.97 \%}$

Overall efficiency, $\eta_o = \eta_p \times \eta_t = 0.5747 \times 0.2897 = \mathbf{0.1665 \text{ or } 16.65\%}$

5 | **5** | **3**

5. Attempt any ONE part of the following : (1*5 = 5)

Q N	QUESTION	Marks	CO	BL
a.	In a gas turbine cycle, air at 27^0C and 0.98 bar is compressed to 6 bar .the temperature of air is increased to 750 ^{0}C as it passes through the combustion chamber. The isentropic efficiencies of compressor and turbine are 0.8 and 0.85 respectively .Determine the efficiency of the plant.	5	5	3

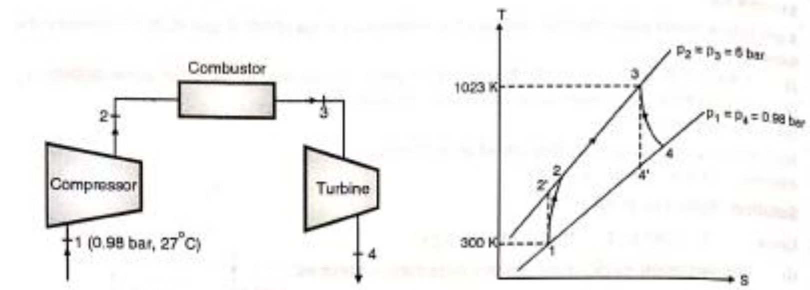
Solution :

Schematic and (T-S) diagrams for the cycle are shown in Fig. P. 9.6(a) and P. 9.6(b) respectively.

Given : At inlet to compressor, $p_1 = 0.98$ bar, $T_1 = 27°C = 300$ K

At exit of compressor, $p_2 = 6$ bar

At exit of combustor, $p_3 = p_2$ and $T_3 = 750°C = 750 + 273 = 1023$ K



(a) Schematic diagram (b) (T-S) diagram

Fig. P. 9.6

Assuming for air as : $\gamma = 1.4$, $C_p = 1.005$ kJ/kgK

For compressor :

For isentropic process (1-2'), $T_2' = T_1\left(\frac{p_2}{p_1}\right)^{(\gamma-1)/\gamma} = 300\left(\frac{6}{0.98}\right)^{(1.4-1)/1.4} = 503.45$ K

Isentropic efficiency of compressor, $\eta_c = \frac{T_2' - T_1}{T_2 - T_1}$; i.e. $0.8 = \frac{503.45 - 300}{T_2 - 300}$

$\therefore$ $T_2 = 554.31$ K

Compressor work/kg of air, $W_C = C_p(T_2 - T_1) = 1.005\,(554.31 - 300) = 255.58$ kJ/kg

Combustor :

Heat supplied $q_s = C_p\,(T_3 - T_2) = 1.005\,(1023 - 554.31) = 471.03$ kJ/kg

Gas Turbine :

For isentropic process, (3,4'), $\frac{T_3}{T_4'} = \left(\frac{p_3}{p_4}\right)^{(\gamma-1)/\gamma}$ $\frac{1023}{T_4'} = \left(\frac{6}{0.98}\right)^{(1.4-1)/1.4}$

$T_4' = 609.59$ K

Isentropic efficiency of the turbine, $\eta_t = \frac{T_3 - T_4}{T_3 - T_4'}$; i.e. $0.85 = \frac{1023 - T_4}{1023 - 609.59}$

$T_4 = 671.6$ K

Turbine work per kg of air, $W_T = C_p\,(T_3 - T_4) = 1.005\,(1023 - 671.6) = 353.16$ kJ/kg

Shaft work output, $W_S = W_T - W_C = 353.16 - 255.58 = 97.58$ kJ/kg

Efficiency of the plant;

$$\eta = \frac{\text{Shaft work } W_s}{\text{Heat supplied } q_s} = \frac{97.58}{471.03} = \mathbf{0.2072 \text{ or } 20.72\ \%}$$ ...Ans.

b.

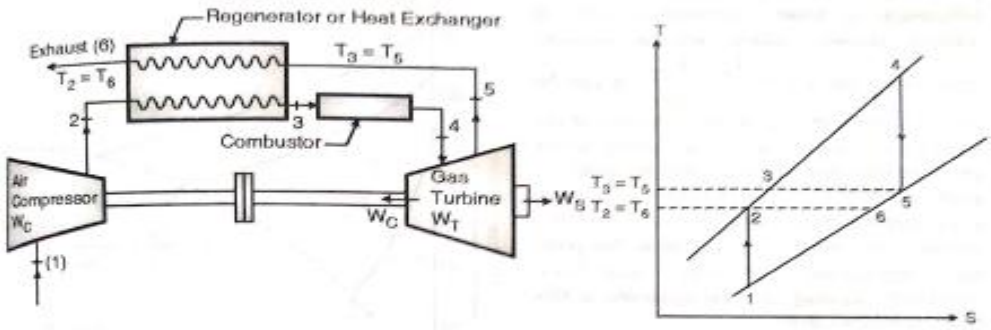
Write a short note on reheat and regeneration in gas turbine plan.

Gas turbine cycle with regenerations

We have observed that the temperature T_4 of the exhaust from the gas turbine is higher than th temperature of air, T_2 at the exit of the compressor. We may think to utilise the heat energy of th exhaust of the turbine, which is a waste to the atmosphere, to heat the compressed air in a hea exchanger called ***regenerator***.

In a counter flow heat exchanger, theoretically, it is possible to heat the air discharged by the compressor reversibly to the temperature of the exhaust leaving the turbine and to cool the turbine exhaust gases equal to the temperature of the discharge of the compressor air so that ($T_3 = T_5$) and ($T_2 = T_6$). The system and processes are shown in Fig. 9.10(a) and (b) respectively.

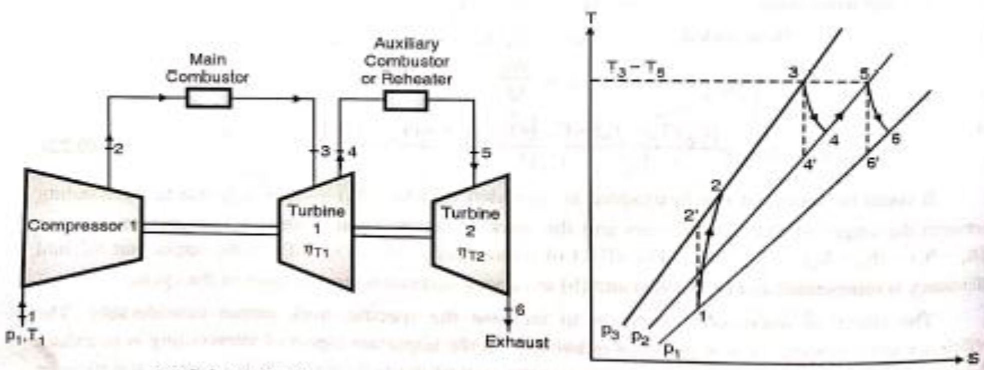
The advantage of introducing such a regenerator is to reduce the mass of fuel supplied in the combustor because it is now necessary to add only the heat equal to ($h_4 - h_3$) instead of ($h_4 - h_2$). If the closed cycle is used, it would also reduce the capacity of the sink consequently reducing its size.



(a) Schematic diagram **(b) (T-S) diagram Ideal regeneration cycle**

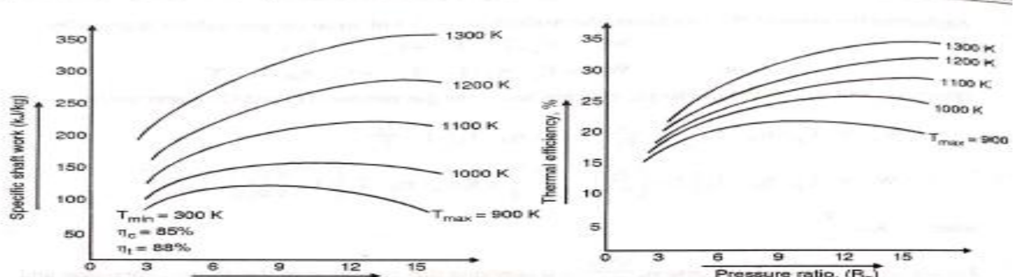
Gas turbine cycle with reheating

Increase in the output of the turbine can be achieved by reheating the gas in between the expansion process in two or three stages. The heat is added in an auxiliary combustor or reheater between the turbine stages by adding more fuel as shown in schematic diagram in Fig. 9.15(a) and the corresponding (T - S) diagram is shown in Fig. 9.15(b).



(a) Schematic diagram **(b) (T - S) diagram**

Fig. 9.15 : Gas turbine cycle with reheating



(a) **(b)**

5 | 5 | 1