$\therefore \qquad T_7 = 898 - \left(\frac{898 - 650}{0.85}\right) = 606 \text{ K}$

Also, $\qquad \frac{T_6}{T_7} = \left(\frac{p_6}{p_7}\right)^{\frac{\gamma - 1}{\gamma}}$

or $\qquad \frac{p_6}{p_7} = \left(\frac{T_6}{T_7}\right)^{\frac{\gamma}{\gamma - 1}} = \left(\frac{898}{606}\right)^{\frac{1.333}{0.333}} = 4.82$

Then, $\qquad \frac{p_8}{p_9} = \frac{9}{4.82} = 1.86$

Again, $\qquad \frac{T_8}{T_9} = \left(\frac{p_8}{p_9}\right)^{\frac{\gamma - 1}{\gamma}} = (1.86)^{\frac{1.333 - 1}{1.333}} = 1.16$

$\therefore \qquad T_9 = \frac{T_8}{1.16} = \frac{898}{1.16} = 774 \text{ K}$

Also, $\qquad \eta_{\text{turbine (L.P.)}} = \frac{T_8 - T_9'}{T_8 - T_9}\ ; \quad 0.85 = \frac{898 - T_9'}{898 - 774}$

$\therefore \qquad T_9' = 898 - 0.85\ (898 - 774) = 792.6 \text{ K}$

$\therefore$ Net work output $= c_{pg}(T_8 - T_9') \times 0.95$

$= 1.15\ (898 - 792.6) \times 0.95 = 115.15$ kJ/kg

Thermal ratio or effectiveness of heat exchanger,

$$\varepsilon = \frac{T_5 - T_4'}{T_9' - T_4'} = \frac{T_5 - 428}{792.6 - 428}$$

*i.e.,* $\qquad 0.8 = \frac{T_5 - 428}{792.6 - 428}$

$\therefore \qquad T_5 = 0.8\ (792.6 - 428) + 428 = 719.7 \text{ K}$

Now, $\qquad$ Heat supplied $= c_{pg}(T_6 - T_5) + c_{pg}(T_8 - T_7')$

$= 1.15\ (898 - 719.7) + 1.15\ (898 - 650) = 490.2$ kJ/kg

$\therefore \qquad \eta_{\text{thermal}} = \frac{\text{Net work output}}{\text{Heat supplied}} = \frac{115.15}{490.2}$

$= 0.235$ or **23.5%.** **(Ans.)**

(*ii*) **Work ratio :**

Gross work of the plant $= W_{\text{turbine (H.P.)}} + W_{\text{turbine (L.P.)}}$

$= 285.5 + \frac{115.15}{0.95} = 406.7$ kJ/kg

$\therefore \qquad$ **Work ratio** $= \frac{\text{Net work output}}{\text{Gross work output}} = \frac{115.15}{406.7} =$ **0.283.** **(Ans.)**

(*iii*) **Mass flow rate, $\dot{m}$ :**

Let the mass flow be $\dot{m}$, then

$\dot{m} \times 115.15 = 4500$

$$\therefore \qquad \dot{m} = \frac{4500}{115.15} = 39.08 \text{ kg/s}$$

*i.e.,* **Mass flow** **= 39.08 kg/s. (Ans.)**

**Example 13.49.** *In a closed cycle gas turbine there is a two stage compressor and a two stage turbine. All the components are mounted on the same shaft. The pressure and temperature at the inlet of the first stage compressor are 1.5 bar and 20°C. The maximum cycle temperature and pressure are limited to 750°C and 6 bar. A perfect intercooler is used between the two stage compressors and a reheater is used between the two turbines. Gases are heated in the reheater to 750°C before entering into the L.P. turbine. Assuming the compressor and turbine efficiencies as 0.82, calculate :*

*(i) The efficiency of the cycle without regenerator.*

*(ii) The efficiency of the cycle with a regenerator whose effectiveness is 0.70.*

*(iii) The mass of the fluid circulated if the power developed by the plant is 350 kW.*

*The working fluid used in the cycle is air. For air :*

$$\gamma = 1.4 \text{ and } c_p = 1.005 \text{ kJ/kg K.}$$

**Solution.** *Given :* $T_1 = 20 + 273 = 293$ K, $T_5 = T_7 = 750 + 273 = 1023$ K, $p_1 = 1.5$ bar, $p_2 = 6$ bar, $\eta_{compressor} = \eta_{turbine} = 0.82$,

Effectiveness of regenerator, $\varepsilon = 0.70$, Power developed, $P = 350$ kW.

For air : $c_p = 1.005$ kJ/kgK, $\gamma = 1.4$

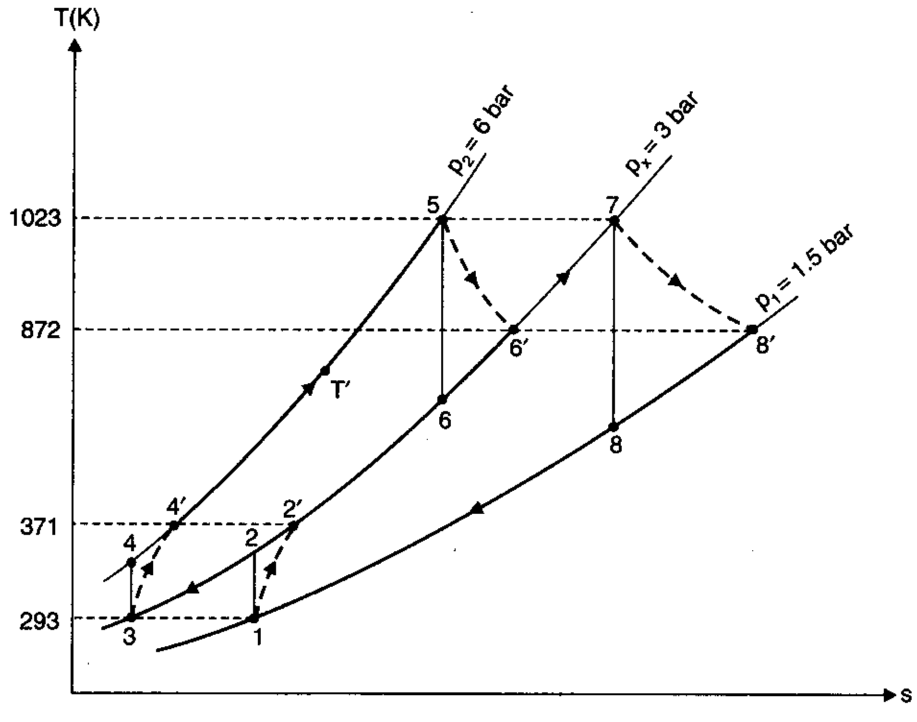


Fig. 13.68

As per given conditions : $T_1 = T_3$, $T_2' = T_4'$

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} \quad \text{and} \quad p_x = \sqrt{p_1 p_2} = \sqrt{1.5 \times 6} = 3 \text{ bar}$$

Now,
$$T_2 = T_1 \times \left(\frac{p_2}{T_1}\right)^{\frac{\gamma-1}{\gamma}} = 293 \times \left(\frac{3}{1.5}\right)^{\frac{1.4-1}{1.4}} = 357 \text{ K}$$

$$\eta_{\text{compressor (L.P.)}} = \frac{T_2 - T_1}{T_2' - T_1}$$

$$0.82 = \frac{357 - 293}{T_2' - 293}$$

$\therefore$
$$T_2' = \frac{357 - 293}{0.82} + 293 = 371 \text{ K}$$

*i.e.,*
$$T_2' = T_4' = 371 \text{ K}$$

Now,
$$\frac{T_5}{T_6} = \left(\frac{p_5}{p_6}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{p_2}{p_x}\right)^{\frac{1.4-1}{1.4}} \qquad \left[\because \begin{array}{l} p_5 = p_2 \\ p_6 = p_x \end{array}\right]$$

$$\frac{1023}{T_6} = \left(\frac{6}{3}\right)^{0.286} = 1.219$$

$\therefore$
$$T_6 = \frac{1023}{1.219} = 839 \text{ K}$$

$$\eta_{\text{turbine (H.P.)}} = \frac{T_5 - T_6'}{T_5 - T_6}$$

$$0.82 = \frac{1023 - T_6'}{1023 - 839}$$

$\therefore$
$$T_6' = 1023 - 0.82\,(1023 - 839) = 872 \text{ K}$$

$$T_8' = T_6' = 872 \text{ K} \quad \text{as} \quad \eta_{\text{turbine (H.P.)}} = \eta_{\text{turbine (L.P.)}}$$

and
$$T_7 = T_5 = 1023 \text{ K}$$

Effectiveness of regenerator, $\varepsilon = \dfrac{T' - T_4'}{T_8' - T_4'}$

where $T'$ is the temperature of air coming out of regenerator

$\therefore$
$$0.70 = \frac{T' - 371}{872 - 371} \quad \textit{i.e.,} \quad T' = 0.70\,(872 - 371) + 371 = 722 \text{ K}$$

Net work available, $W_{net} = [W_{T(L.P.)} + W_{T(L.P.)}] - [W_{C(H.P.)} + W_{C(L.P.)}]$

$= 2\,[W_{T(L.P.)} - W_{C(L.P.)}]$ as the *work developed by each turbine is same and work absorbed by each compressor is same.*

$\therefore$
$$W_{net} = 2c_p\,[(T_5 - T_6') - (T_2' - T_1)]$$
$$= 2 \times 1.005\,[(1023 - 872) - (371 - 293)] = 146.73 \text{ kJ/kg of air}$$

Heat supplied per kg of air *without regenerator*

$$= c_p(T_5 - T_4') + c_p(T_7 - T_6')$$
$$= 1.005\,[(1023 - 371) + (1023 - 872)] = 807 \text{ kJ/kg of air}$$

Heat supplied per kg of *air with regenerator*

$$= c_p(T_5 - T') + c_p(T_7 - T_6')$$
$$= 1.005\,[(1023 - 722) + (1023 - 872)]$$
$$= 454.3 \text{ kJ/kg}$$

(*i*) $\eta_{\text{thermal (without regenerator)}} = \dfrac{146.73}{807} = 0.182$ or **18.2%. (Ans.)**

(*ii*) $\eta_{\text{thermal (with regenerator)}} = \dfrac{146.73}{454.3} = 0.323$ or **32.3%. (Ans.)**

(*iii*) **Mass of fluid circulated,** $\dot{m}$ **:**

Power developed, $P = 146.73 \times \dot{m}$ kW

$\therefore \quad 350 = 146.73 \times \dot{m}$

*i.e.,* $\dot{m} = \dfrac{350}{146.73} = 2.38$ kg/s

*i.e.,* **Mass of fluid circulated = 2.38 kg/s. (Ans.)**

## HIGHLIGHTS

1. A cycle is defined as a repeated series of operations occurring in a certain order.
2. The efficiency of an engine using air as the working medium is known as an '**Air standard efficiency**'.
3. Relative efficiency, $\eta_{\text{relative}} = \dfrac{\text{Actual thermal efficiency}}{\text{Air standard efficiency}}$.
4. **Carnot cycle** efficiency, $\eta_{\text{Carnot}} = \dfrac{T_1 - T_2}{T_1}$.
5. **Otto cycle** efficiency, $\eta_{\text{Otto}} = 1 - \dfrac{1}{(r)^{\gamma - 1}}$.

   Mean effective pressure, $p_{m(\text{Otto})} = \dfrac{p_1 r[(r^{\gamma-1} - 1)(r_p - 1)]}{(\gamma - 1)(r - 1)}$.
6. **Diesel cycle** efficiency, $\eta_{\text{Diesel}} = 1 - \dfrac{1}{\gamma(r)^{\gamma-1}}\left[\dfrac{\rho^{\gamma} - 1}{\rho - 1}\right]$

   Mean effective pressure, $p_{m(\text{Diesel})} = \dfrac{p_1 r^{\gamma}[\gamma(\rho - 1) - r^{1-\gamma}(\rho^{\gamma} - 1)]}{(\gamma - 1)(r - 1)}$.
7. **Dual cycle** efficiency, $\eta_{\text{Dual}} = 1 - \dfrac{1}{(r)^{\gamma-1}}\left[\dfrac{(\beta.\rho^{\gamma} - 1)}{(\beta - 1) + \beta\gamma(\rho - 1)}\right]$

   Mean effective pressure, $p_{m(\text{Dual})} = \dfrac{p_1 r^{\gamma}[\beta(\rho - 1) + (\beta - 1) - r^{1-\gamma}(\beta\rho^{\gamma} - 1)]}{(\gamma - 1)(r - 1)}$.
8. Atkinson cycle efficiency, $\eta_{\text{Atkinson}} = 1 - \gamma \cdot \dfrac{(r - \alpha)}{r^{\gamma} - \alpha^{\gamma}}$

   where $\alpha$ = Compression ratio, $r$ = Expansion ratio.

## THEORETICAL QUESTIONS

1. What is a cycle ? What is the difference between an ideal and actual cycle ?
2. What is an air-standard efficiency ?
3. What is relative efficiency ?
4. Derive expressions of efficiency in the following cases :
   (*i*) Carnot cycle (*ii*) Diesel cycle (*iii*) Dual combustion cycle.
5. Explain "Air standard analysis" which has been adopted for I.C. engine cycles. State the assumptions made for air standard cycles.
6. Derive an expression for 'Atkinson cycle'.
7. Explain briefly Brayton cycle. Derive expression for optimum pressure ratio.
8. Describe with neat sketches the working of a simple constant pressure open cycle gas turbine.
9. Discuss briefly the methods employed for improvement of thermal efficiency of open cycle gas turbine plant.
10. Describe with neat diagram a closed cycle gas turbine. State also its merits and demerits.

## OBJECTIVE TYPE QUESTIONS

**Choose the Correct Answer :**

1. The air standard Otto cycle comprises
   (*a*) two constant pressure processes and two constant volume processes
   (*b*) two constant pressure and two constant entropy processes
   (*c*) two constant volume processes and two constant entropy processes
   (*d*) none of the above.
2. The air standard efficiency of Otto cycle is given by
   (*a*) $\eta = 1 + \frac{1}{(r)^{\gamma+1}}$ (*b*) $\eta = 1 - \frac{1}{(r)^{\gamma-1}}$
   (*c*) $\eta = 1 - \frac{1}{(r)^{\gamma+1}}$ (*d*) $\eta = 2 - \frac{1}{(r)^{\gamma-1}}$.
3. The thermal efficiency of theoretical Otto cycle
   (*a*) increases with increase in compression ratio (*b*) increases with increase in isentropic index $\gamma$
   (*c*) does not depend upon the pressure ratio (*d*) follows all the above.
4. The work output of theoretical Otto cycle
   (*a*) increases with increase in compression ratio (*b*) increases with increase in pressure ratio
   (*c*) increases with increase in adiabatic index $\gamma$ (*d*) follows all the above.
5. For same compression ratio
   (*a*) thermal efficiency of Otto cycle is greater than that of Diesel cycle
   (*b*) thermal efficiency of Otto cycle is less than that of Diesel cycle
   (*c*) thermal efficiency of Otto cycle is same as that for Diesel cycle
   (*d*) thermal efficiency of Otto cycle cannot be predicted.
6. In air standard Diesel cycle, at fixed compression ratio and fixed value of adiabatic index ($\gamma$)
   (*a*) thermal efficiency increases with increase in heat addition cut-off ratio
   (*b*) thermal efficiency decreases with increase in heat addition cut-off ratio
   (*c*) thermal efficiency remains same with increase in heat addition cut-off ratio
   (*d*) none of the above.

7. Thermal efficiency of a gas turbine plant as compared to Diesel engine plant is
   (a) higher (b) lower
   (c) same (d) may be higher or lower.
8. Mechanical efficiency of a gas turbine as compared to internal combustion reciprocating engine is
   (a) higher (b) lower
   (c) same (d) un-predictable.
9. For a gas turbine the pressure ratio may be in the range
   (a) 2 to 3 (b) 3 to 5
   (c) 16 to 18 (d) 18 to 22.
10. The air standard efficiency of closed gas turbine cycle is given by ($r_p$ = pressure ratio for the compressor and turbine)
   (a) $\eta = 1 - \dfrac{1}{(r_p)^{\gamma - 1}}$ (b) $\eta = 1 - (r_p)^{\gamma - 1}$
   (c) $\eta = 1 - \left(\dfrac{1}{r_p}\right)^{\frac{\gamma - 1}{\gamma}}$ (d) $\eta = (r_p)^{\frac{\gamma - 1}{\gamma}} - 1$.
11. The work ratio of closed cycle gas turbine plant depends upon
   (a) pressure ratio of the cycle and specific heat ratio
   (b) temperature ratio of the cycle and specific heat ratio
   (c) pressure ratio, temperature ratio and specific heat ratio
   (d) only on pressure ratio.
12. Thermal efficiency of closed cycle gas turbine plant increases by
   (a) reheating (b) intercooling
   (c) regenerator (d) all of the above.
13. With the increase in pressure ratio thermal efficiency of a simple gas turbine plant with fixed turbine inlet temperature
   (a) decreases (b) increases
   (c) first increases and then decreases (d) first decreases and then increases.
14. The thermal efficiency of a gas turbine cycle with ideal regenerative heat exchanger is
   (a) equal to work ratio (b) is less than work ratio
   (c) is more than work ratio (d) unpredictable.
15. In a two stage gas turbine plant reheating after first stage
   (a) decreases thermal efficiency (b) increases thermal efficiency
   (c) does not effect thermal efficiency (d) none of the above.
16. In a two stage gas turbine plant, reheating after first stage
   (a) increases work ratio (b) decreases work ratio
   (c) does not affect work ratio (d) none of the above.
17. In a two stage gas turbine plant, with intercooling and reheating
   (a) both work ratio and thermal efficiency improve
   (b) work ratio improves but thermal efficiency decreases
   (c) thermal efficiency improves but work ratio decreases
   (d) both work ratio and thermal efficiency decrease.
18. For a jet propulsion unit, ideally the compressor work and turbine work are
   (a) equal (b) unequal
   (c) not related to each other (d) unpredictable.

19. Greater the difference between jet velocity and aeroplane velocity
(a) greater the propulsive efficiency
(b) less the propulsive efficiency
(c) unaffected is the propulsive efficiency
(d) none of the above.

## ANSWERS

| | | | | | | |
|---|---|---|---|---|---|---|
| 1. (b) | 2. (b) | 3. (d) | 4. (d) | 5. (a) | 6. (b) | 7. (b) |
| 8. (b) | 9. (d) | 10. (d) | 11. (a) | 12. (b) | 13. (b) | 14. (b) |
| 15. (d) | 16. (d) | 17. (a) | 18. (a) | 19. (c). | | |

## UNSOLVED EXAMPLES

1. A Carnot engine working between 377°C and 37°C produces 120 kJ of work. Determine :
(i) The heat added in kJ.
(ii) The entropy change during heat rejection process.
(iii) The engine thermal efficiency. **[Ans.** (i) 229.5 kJ ; (ii) 0.353 kJ/K (iii) 52.3%]
2. Find the thermal efficiency of a Carnot engine whose hot and cold bodies have temperatures of 154°C and 15°C respectively. **[Ans.** 32.55%]
3. Derive an expression for change in efficiency for a change in compression ratio. If the compression ratio is increased from 6 to 8, what will be the percentage increase in efficiency ? **[Ans.** 8%]
4. The efficiency of an Otto cycle is 50% and $\gamma$ is 1.5. What is the compression ratio ? **[Ans.** 4]
5. An engine working on Otto cycle has a volume of 0.5 $m^3$, pressure 1 bar and temperature 27°C at the commencement of compression stroke. At the end of compression stroke, the pressure is 10 bar. Heat added during the constant volume process is 200 kJ. Determine :
(i) Percentage clearance
(ii) Air standard efficiency
(iii) Mean effective pressure
(iv) Ideal power developed by the engine if the engine runs at 400 r.p.m. so that there are 200 complete cycles per minutes. **[Ans.** (i) 23.76% ; (ii) 47.2% ; (iii) 2.37 bar (iv) 321 kW]
6. The compression ratio in an air-standard Otto cycle is 8. At the beginning of compression process, the pressure is 1 bar and the temperature is 300 K. The heat transfer to the air per cycle is 1900 kJ/kg of air. Calculate :
(i) Thermal efficiency
(ii) The mean effective pressure.
**[Ans.** (i) 56.47% ; (ii) 14.24 bar]
7. An engine 200 mm bore and 300 mm stroke works on Otto cycle. The clearance volume is 0.0016 $m^3$. The initial pressure and temperature are 1 bar and 60°C. If the maximum pressure is limited to 24 bar, find :
(i) The air-standard efficiency of the cycle
(ii) The mean effective pressure for the cycle.
Assume ideal conditions. **[Ans.** (i) 54.08% ; (ii) 1.972 bar]
8. Calculate the air standard efficiency of a four stroke Otto cycle engine with the following data :
Piston diameter (bore) = 137 mm ; Length of stroke = 130 mm ;
Clearance volume 0.00028 $m^3$.
Express clearance as a percentage of swept volume. **[Ans.** 56.1% ; 14.6%]
9. In an ideal Diesel cycle, the temperatures at the beginning of compression, at the end of compression and at the end of the heat addition are 97°C, 789°C and 1839°C. Find the efficiency of the cycle.
**[Ans.** 59.6%]
10. An air-standard Diesel cycle has a compression ratio of 18, and the heat transferred to the working fluid per cycle is 1800 kJ/kg. At the beginning of the compression stroke, the pressure is 1 bar and the temperature is 300 K. Calculate : (i) Thermal efficiency, (ii) The mean effective pressure.
**[Ans.** (i) 61% ; (ii) 13.58 bar]
11. 1 kg of air is taken through a Diesel cycle. Initially the air is at 15°C and 1 ata. The compression ratio is 15 and the heat added is 1850 kJ. Calculate : (i) The ideal cycle efficiency, (ii) The mean effective pressure. **[Ans.** (i) 55.1% ; (ii) 13.4 bar]

12. What will be loss in the ideal efficiency of a Diesel engine with compression ratio 14 if the fuel cut-off is delayed from 6% to 9% ? [**Ans.** 2.1%]

13. The pressures on the compression curve of a diesel engine are at $\frac{1}{8}$ th stroke 1.4 bar and at $\frac{7}{8}$ th stroke 14 bar. Estimate the compression ratio. Calculate the air standard efficiency of the engine if the cut-off occurs at $\frac{1}{15}$th of the stroke. [**Ans.** 18.54 ; 63.7%]

14. A compression ignition engine has a stroke 270 mm, and a cylinder diameter of 165 mm. The clearance volume is 0.000434 $m^3$ and the fuel ignition takes place at constant pressure for 4.5 per cent of the stroke. Find the efficiency of the engine assuming it works on the Diesel cycle. [**Ans.** 61.7%]

15. The following data belong to a Diesel cycle :

    Compression ratio = 16 : 1 ; Heat added = 2500 kJ/kg ; Lowest pressure in the cycle = 1 bar ; Lowest temperature in the cycle = 27°C.

    Determine :

    (*i*) Thermal efficiency of the cycle. (*ii*) Mean effective pressure.

    [**Ans.** (*i*) 45% ; (*ii*) 16.8 bar]

16. The compression ratio of an air-standard Dual cycle is 12 and the maximum pressure in the cycle is limited to 70 bar. The pressure and temperature of cycle at the beginning of compression process are 1 bar and 300 K. Calculate : (*i*) Thermal efficiency, (*ii*) Mean effective pressure.

    Assume : cylinder bore = 250 mm, stroke length = 300 mm, $c_p$ = 1.005, $c_v$ = 0.718 and $\gamma$ = 1.4.

    [**Ans.** (*i*) 61.92% ; (*ii*) 9.847 bar]

17. The compression ratio of a Dual cycle is 10. The temperature and pressure at the beginning of the cycle are 1 bar and 27°C. The maximum pressure of the cycle is limited to 70 bar and heat supplied is limited to 675 kJ/kg of air. Find the thermal efficiency of the cycle. [**Ans.** 59.5%]

18. An air standard Dual cycle has a compression ratio of 16, and compression begins at 1 bar, 50°C. The maximum pressure is 70 bar. The heat transferred to air at constant pressure is equal to that at constant volume. Determine :

    (*i*) The cycle efficiency. (*ii*) The mean effective pressure of the cycle.

    Take : $c_p$ = 1.005 kJ/kg-K, $c_v$ = 0.718 kJ/kg-K. [**Ans.** (*i*) 66.5% ; (*ii*) 4.76 bar]

19. In an air standard gas turbine engine, air at a temperature of 15°C and a pressure of 1.01 bar enters the compressor, where it is compressed through a pressure ratio of 5. Air enters the turbine at a temperature of 815°C and expands to original pressure of 1.01 bar. Determine the ratio of turbine work to compressor work and the thermal efficiency when the engine operates on ideal Brayton cycle.

    Take : $\gamma$ = 1.4, $c_p$ = 1.005 kJ/kg K. [**Ans.** 2.393 ; 37.03%]

20. In an open cycle constant pressure gas turbine air enters the compressor at 1 bar and 300 K. The pressure of air after the compression is 4 bar. The isentropic efficiencies of compressor and turbine are 78% and 85% respectively. The air-fuel ratio is 80 : 1. Calculate the power developed and thermal efficiency of the cycle if the flow rate of air is 2.5 kg/s.

    Take $c_p$ = 1.005 kJ/kg K and $\gamma$ = 1.4 for air and $c_{pg}$ = 1.147 kJ/kg K and $\gamma$ = 1.33 for gases. $R$ = 0.287 kJ/kg K. Calorific value of fuel = 42000 kJ/kg. [**Ans.** 204.03 kW/kg of air ; 15.54%]

21. A gas turbine has a pressure ratio of 6/1 and a maximum cycle temperature of 600°C. The isentropic efficiencies of the compressor and turbine are 0.82 and 0.85 respectively. Calculate the power output in kilowatts of an electric generator geared to the turbine when the air enters the compressor at 15°C at the rate of 15 kg/s.

    Take : $c_p$ = 1.005 kJ/kg K and $\gamma$ = 1.4 for the compression process, and take $c_p$ = 1.11 kJ/kg K and $\gamma$ = 1.333 for the expansion process. [**Ans.** 920 kW]

22. Calculate the thermal efficiency and the work ratio of the plant in example 3 (above), assuming that $c_p$ for the combustion process is 1.11 kJ/kg K. [**Ans.** 15.8% ; 0.206]

23. The gas turbine has an overall pressure ratio of 5 : 1 and a maximum cycle temperature of 550°C. The turbine drives the compressor and an electric generator, the mechanical efficiency of the drive being 97%. The ambient temperature is 20°C and the isentropic efficiencies for the compressor and turbine are 0.8 and

0.83 respectively. Calculate the power output in kilowatts for an air flow of 15 kg/s. Calculate also the thermal efficiency and the work ratio.

Neglect changes is kinetic energy, and the loss of pressure in combustion chamber.

[**Ans.** 655 kW ; 12% ; 0.168]

**24.** Air is drawn in a gas turbine unit at 17°C and 1.01 bar and the pressure ratio is 8 : 1. The compressor is driven by the H.P. turbine and the L.P. turbine drives a separate power shaft. The isentropic efficiencies of the compressor, and the H.P. and L.P. turbines are 0.8, 0.85 and 0.83, respectively. Calculate the pressure and temperature of the gases entering the power turbine, the net power developed by the unit per kg/s of mass flow, the work ratio and the thermal efficiency of the unit. The maximum cycle temperature is 650°C.

For the compression process take $c_p$ = 1.005 kJ/kg K and $\gamma$ = 1.4

For the combustion process and expansion process, take

$$c_p = 1.15 \text{ kJ/kg K and } \gamma = 1.333$$

Neglect the mass of fuel. [**Ans.** 1.65 bar, 393°C ; 74.5 kW ; 0.201 ; 19.1%]

**25.** In a gas turbine plant, air is compressed through a pressure ratio of 6 : 1 from 15°C. It is then heated to the maximum permissible temperature of 750°C and expanded in two stages each of expansion ratio $\sqrt{6}$, the air being reheated between the stages to 750°C. A heat exchanger allows the heating of the compressed gases through 75 per cent of the maximum range possible. Calculate : (*i*) The cycle efficiency (*ii*) The work ratio (*iii*) The work per kg of air.

The isentropic efficiencies of the compressor and turbine are 0.8 and 0.85 respectively.

[**Ans.** (*i*) 32.75% (*ii*) 0.3852 (*iii*) 152 kJ/kg]

**26.** At the design speed the following data apply to a gas turbine set employing the heat exchanger : Isentropic efficiency of compressor = 75%, isentropic efficiency of the turbine = 85%, mechanical transmission efficiency = 99%, combustion efficiency = 98%, mass flow = 22.7 kg/s, pressure ratio = 6 : 1, heat exchanger effectiveness = 75%, maximum cycle temperature = 1000 K.

The ambient air temperature and pressure are 15°C and 1.013 bar respectively. Calculate :

(*i*) The net power output (*ii*) Specific fuel consumption

(*iii*) Thermal efficiency of the cycle.

Take the lower calorific value of fuel as 43125 kJ/kg and assume no pressure-loss in heat exchanger and combustion chamber. [**Ans.** (*i*) 2019 kW (*ii*) 0.4799 kg/kWh (*iii*) 16.7%]

**27.** In a gas turbine plant air at 10°C and 1.01 bar is compressed through a pressure ratio of 4 : 1. In a heat exchanger and combustion chamber the air is heated to 700°C while its pressure drops 0.14 bar. After expansion through the turbine the air passes through a heat exchanger which cools the air through 75% of maximum range possible, while the pressure drops 0.14 bar, and the air is finally exhausted to atmosphere. The isentropic efficiency of the compressor is 0.80 and that of turbine 0.85.

Calculate the efficiency of the plant. [**Ans.** 22.76%]

**28.** In a marine gas turbine unit a high-pressure stage turbine drives the compressor, and a low-pressure stage turbine drives the propeller through suitable gearing. The overall pressure ratio is 4 : 1, and the maximum temperature is 650°C. The isentropic efficiencies of the compressor, H.P. turbine, and L.P. turbine are 0.8, 0.83, and 0.85 respectively, and the mechanical efficiency of both shafts is 98%. Calculate the pressure between turbine stages when the air intake conditions are 1.01 bar and 25°C. Calculate also the thermal efficiency and the shaft power when the mass flow is 60 kg/s. Neglect kinetic energy changes, and pressure loss in combustion. [**Ans.** 1.57 bar ; 14.9% ; 4560 kW]

**29.** In a gas turbine unit comprising L.P. and H.P. compressors, air is taken at 1.01 bar 27°C. Compression in L.P. stage is upto 3.03 bar followed by intercooling to 30°C. The pressure of air after H.P. compressor is 58.7 bar. Loss in pressure during intercooling is 0.13 bar. Air from H.P. compressor is transferred to heat exchanger of effectiveness 0.60 where it is heated by gases from L.P. turbine. The temperature of gases supplied to H.P. turbine is 750°C. The gases expand in H.P. turbine to 3.25 bar and are then reheated to 700°C before expanding in L.P. turbine. The loss of pressure in reheater is 0.1 bar. If isentropic efficiency of compression in both stages is 0.80 and isentropic efficiency of expansion in turbine is 0.85, calculate : (*i*) Overall efficiency (*ii*) Work ratio (*iii*) Mass flow rate when the gas power generated is 6500 kW. Neglect the mass of fuel.

Take, for air : $c_p$ = 1.005 kJ/kg K, $\gamma$ = 1.4

for gases : $c_{pg}$ = 1.15 kJ/kg K, $\gamma$ = 1.3. [**Ans.** (*i*) 16.17% (*ii*) 0.2215 (*iii*) 69.33 kg of air/sec.]

**30.** In a gas turbine installation, air is taken in L.P. compressor at 15°C 1.1 bar and after compression it is passed through intercooler where its temperature is reduced to 22°C. The cooled air is further compressed in H.P. unit and then passed in the combustion chamber where its temperature is increased to 677°C by burning the fuel. The combustion products expand in H.P. turbine which runs the compressor and further expansion is continued in the L.P. turbine which runs the alternator. The gases coming out from L.P. turbine are used for heating the incoming air from H.P. compressor and then exhausted to atmosphere.

Taking the following data determine : (*i*) power output (*ii*) specific fuel consumption (*iii*) Thermal efficiency :

Pressure ratio of each compressor = 2, isentropic efficiency of each compressor stage = 85%, isentropic efficiency of each turbine stage = 85%, effectiveness of heat exchanger = 0.75, air flow = 15 kg/sec., calorific value of fuel = 45000 kJ/kg, $c_p$(for gas) = 1 kJ/kg K, $c_p$ (for gas) = 1.15 kJ/kg K, $\gamma$ (for air) = 1.4, $\gamma$ (for gas) = 1.33.

Neglect the mechanical, pressure and heat losses of the system and fuel mass also.

[**Ans.** (*i*) 1849.2 kW (*ii*) 0.241 kg/kWh (*iii*) 33.17%]