2019

RANK IMPROVEMENT WORKBOOK

## Mechanical Engineering

# Power Plant Engineering

Answer Key of Objective & Conventional Questions

MADE EASY Publications

# 1 Boilers, Condensors and Accessories

## LEVEL 1 Objective Questions

| | |
|---|---|
| 1. | (d) |
| 2. | (c) |
| 3. | (b) |
| 4. | (b) |
| 5. | (a) |
| 6. | (a) |
| 7. | (d) |
| 8. | (a) |
| 9. | (b) |
| 10. | (b) |
| 11. | (b) |
| 12. | (c) |
| 13. | (b) |
| 14. | (c) |
| 15. | (c) |
| 16. | (c) |
| 17. | (c) |
| 18. | (c) |
| 19. | (d) |
| 20. | (d) |
| 21. | (a) |
| 22. | (a) |
| 23. | (c) |
| 24. | (c) |
| 25. | (d) |
| 26. | (b) |

## LEVEL 2 Objective Questions

| | |
|---|---|
| 27. | (b) |
| 28. | (a) |
| 29. | (b) |
| 30. | (c) |
| 31. | (d) |
| 32. | (c) |
| 33. | (c) |
| 34. | (b) |
| 35. | (d) |
| 36. | (b) |
| 37. | (a) |

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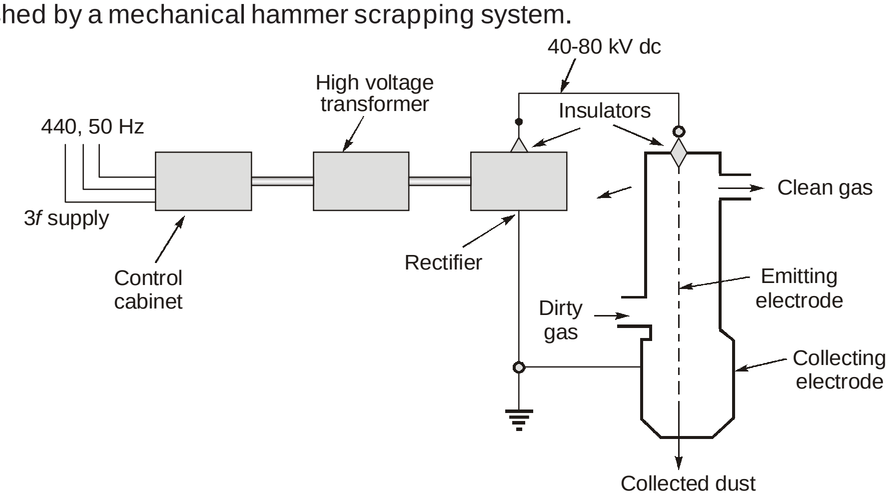
LEVEL 3 Conventional Questions

**Solution : 38**

**Electrostatic Precipitator**

The principal components of an electrostatic precipitator (ESP) are two sets of electrodes insulated from each other. The first set is composed of rows of electrically grounded vertical parallel plates, called the collection electrodes, between which the dust-laden gas flows. The second set of electrodes consists of wires, called the discharge or emitting electrodes that are centrally located between each pair of parallel plates. The wires carry a unidirectional negatively charged high-voltage current from an external dc source. The applied high voltage generates a unidirectional, non-uniform electrical field. When that voltage is high enough, a blue luminous glow called a corona, is produced around them. Electrical forces in the corona accelerate the free electrons present in the gas so that they ionize the gas molecules, thus forming more electrons and positive gas ions.

The positive ions travel to the negatively charged wire electrodes. The electrons follows the electrical field toward the grounded electrodes but their velocity decreases toward the plates. Gas molecules capture the low velocity electrons and become negative ions. As these ions move to the collecting electrode, the collide with the fly ash particles in the gas stream and give them negative charge. The negatively charged fly ash particles are driven to the collecting plate. Collected particulate matter must be removed from the collecting plates on a regular schedule to ensure efficient collector operation. Removal is usually accomplished by a mechanical hammer scrapping system.




An electrostatic precipitator like a cyclone separator, has an overall collection efficiency, $\eta_o$ is defined by

$$\eta_o = \frac{\text{mass of all particles retained by collector (ESP)}}{\text{mass of all particles entering collector}}$$

$$= 1 - \exp\left(-\frac{AV_{mo}}{Q}\right)$$

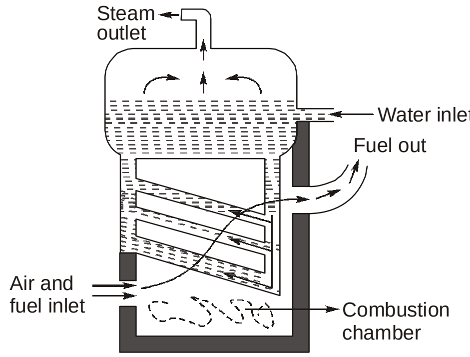
where $A$ = Area of collector plate ($m^2$)

$V_{mo}$ = effective migration velocity of particles (m/sec)

$Q$ = Flue gas volume flow rate for each plate ($m^3$/sec)

(i) With increase in collector area, collection efficiency increases.
(ii) With increase in migration velocity, collection efficiency increases.
(iii) With decrease in mass flow rate, collection efficiency increases.

**Solution : 39**




| Fire Tube Boilers | Water Tube Boilers |
|---|---|
| (i) Hot gases inside the tubes and water outside the tubes | (i) Water inside the tubes and hot gases outside the tubes |
| (ii) Generally internally fired | (ii) Externally fired |
| (iii) Operating pressure limited to 16 bar | (iii) Can work under as high pressure as 100 bar |
| (iv) Lower steam production rate | (iv) Higher rate of steam production |
| (v) Various parts not so easily accessible for cleaning, repair and inspection | (v) Various parts are more accessible |
| (vi) Difficult in construction | (vi) Simple in construction |

**Solution : 40**

**Essentials of a good steam boiler:**

1. It should produce maximum weight of steam of the desired quality at minimum expenses.
2. Steam production rate should be as per requirements.
3. It should have high reliability.
4. It should be light in weight and occupy minimum space.
5. It should be capable of easy starting.
6. There should be an easy access to the various parts of the boiler for maintenance, repair and inspection.
7. The boiler components should be transportable without difficulty.
8. Easy installation.
9. The tubes of the boiler should not accumulate soot or water deposits.
10. The tube material should have better wear and corrosion resistant.
11. The water and gas circuits should be such as to allow minimum fluid velocity (for low frictional losses).

**Factors considered while selecting a boiler.**

1. Working pressure and steam quality
2. Steam generation rate
3. Floor area available
4. Accessibility for repair and inspection
5. Comparative initial cost
6. Erection facilities
7. Plant load factor

8. Availability of fuel and water
9. Operation and maintenance cost

**Solution : 41**

Fire-tube boilers are relatively inexpensive. They have large water storage capacity and can thus meet relatively large and sudden load demands with only small pressure changes. Reduction in pressure leaves the stored water superheated and causes part of it to flash into steam. However, the large water storage increases the explosion hazard of the unit, and also because of it, a longer period of time is required to bring the unit of steaming from a cold condition.

The major shortcoming of a fire-tube boiler is that define size and pressure limitations are inherent in its basic design, i.e., the maximum size of the unit and the maximum operating pressure are limited. The tensile stress on the drum wall is a function of the drum diameter and the internal pressure given by

$$\sigma = pd/2t$$

The growing needs for increased quantities of steam at higher and higher pressures could not be met by fire-tube boilers, for as high pressures and large diameters lead to prohibitively thick shells, and the thicker the shell, the higher the cost.

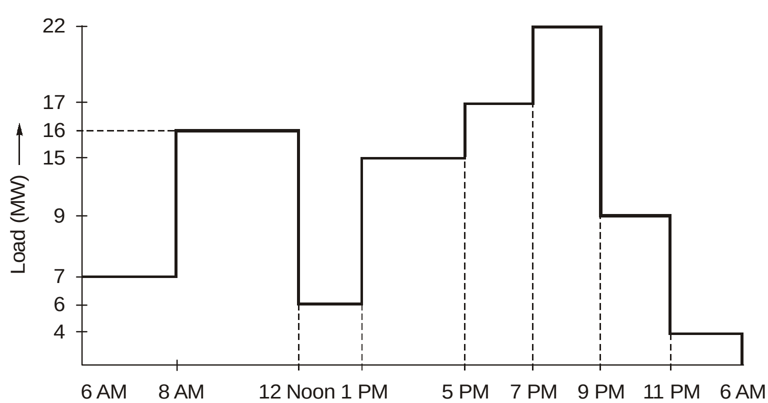
Water is adequately treated prior to feeding it to the boiler as make up water. Still, it has some impurities in the form of total dissolved solids (TDS). These solids are expressed in ppm (parts per million). Saturated water from the economiser is continuously entering the drum. Steam is separated in the drum and is taken to the superheater. So the solid content of water (TDS) in the drum goes on increasing. To maintain a certain ppm in the drum, blowdown is necessary to settledown. Trisodium phosphate is injected into the drum periodically in suitable doses to help precipitate salts to settledown at the drum bottom.

**Solution : 42**

$$n = 260$$

$$\text{Length of one coil} = 7.81 \text{ m}$$

**Solution : 43**




**Load Curve**

Total capacity of the plant = 5 MW × 5 = **25 MW**

**Operation Schedule**

| | |
|---|---|
| 11 PM to 6 AM | One unit of 5 MW |
| 6 AM to 8 AM | Two unit of 5 MW |
| 8 AM to 12 Noon | Four unit of 5 MW |
| 12 Noon to 1 PM | Two unit of 5 MW |
| 1 PM to 5 PM | Three unit of 5 MW |
| 5 PM to 7 PM | Four unit of 5 MW |
| 7 PM to 9 PM | Five unit of 5 MW |
| 9 PM to 11 PM | Two unit of 5 MW |

Number of units = 5

Load factor = 0.5076

Plant capacity factor = 0.4466

Plant use factor = 85.08%

**Solution : 44**

Revenue earned by the power plant per year = ` 63.773 crore

Capacity factor = 0.52

**Solution : 45**

Reserve capacity = 21 MW

Cost of power generation = 1.5/KWh

**Solution : 46**

Annual energy production = $78.84 \times 10^6$ kWh

Reserve capacity over and above the peak load = 7.5 MW

Hours not in service in a year = 973.33 hours

**Solution : 47**

$m_f$ = 0.572 kg/kWh Ans. (i)

cost of fuel (coal)/kWh = ` 28.6/kWh

**Solution : 48**

Mass of air = 0.02686 kg/m$^3$

$x$ = 0.94

Vacuum efficiency = 97.51%

Undercooling of condensate = 6°C

Condensate efficiency = 78.37%

**Solution : 49**

$\omega_{air}$ = 5.651 kg/s

$\omega_c$ = 5855.2 kg/s

$n$ = 7898

$l$ = 20.73 m

**Solution : 50**

Vacuum efficiency = 98.29%

Mass of air associated with 1 kg steam

= 0.467 kg air/kg steam

**Solution : 51**

$$\frac{\dot{m}_w}{\dot{m}_s} = 51.77 \text{ kg water/kg steam}$$

$$\text{Condenser efficiency} = 47.5\%$$

**Solution : 52**

$$m_a = 0.042 \text{ kg/m}^3$$

$$x = 0.835$$

$$\text{Vacuum efficiency} = \frac{\text{Actual vacuum}}{\text{Ideal vacuum}} = \frac{69}{76} \times 100 = 90.7\%$$

$$\text{Condensing effeciency5} = \left(\frac{32.5-20}{35-20}\right) \times 100 = 83.33\%$$

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# 2 Rankine Cycle

## LEVEL 1 Objective Questions

| | |
|---|---|
| 1. | (c) |
| 2. | (b) |
| 3. | (a) |
| 4. | (c) |
| 5. | (d) |
| 6. | (b) |
| 7. | (b) |
| 8. | (d) |
| 9. | (c) |
| 10. | (a) |
| 11. | (d) |
| 12. | (a) |

## LEVEL 2 Objective Questions

| | |
|---|---|
| 13. | (a) |
| 14. | (c) |
| 15. | (d) |
| 16. | (3.6) |
| 17. | (2.83) |
| 18. | (a) |
| 19. | (b) |
| 20. | (a) |
| 21. | (c) |
| 22. | (26) |
| 23. | (b) |
| 24. | (b) |
| 25. | (b) |
| 26. | (c) |
| 27. | (c) |
| 28. | (c) |
| 29. | (b) |
| 30. | (d) |
| 31. | (b) |
| 32. | (a) |
| 33. | (b) |
| 34. | (c) |
| 35. | (a) |

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## LEVEL 3 Conventional Questions

**Solution : 36**

$$h_7 = 520.72 + 0.00106(40-2) \times 10^2$$
$$Q_1 = 15.1 \text{ mW}$$
$$\dot{m}_f = 2473.2 \text{ kg/hr} = 2.473 \text{ t/h}$$
$$Q_2 = 8.353 \text{ MW}$$
$$w_c = 332.5 \text{ kg/sec}$$

**Solution : 37**

Power output, $W_{net}$ = 32.68 MW

$$\dot{m}_w = 4352.63 \text{ kg/s}$$

**Solution : 38**

Reheat temperature $T_5$ = 741.4 K

power output = 6367.61 kW

Heat supplied in boiler = 14.574 MW

**Solution : 39**

$A$ = 182.38 $m^2$ Area

$\eta_{isentropic}$ = 76.69%

Network output = 15.53 kW

$\eta$ = 14.7%

**Solution : 40**

Mass flow rate of steam = 1118.7 kg/s

Heat generated, $Q_{gen}$ = 2902.33 MW

**Solution : 41**

$$\dot{m}_w = 297.46 \text{ kg/sec}$$

**Solution : 42**

$$\eta_{thermal} = 26\%$$

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# 3 Gas Power Plant

## LEVEL 1 Objective Questions

1. (a)
2. (b)
3. (b)
4. (c)
5. (b)
6. (c)
7. (b)
8. (b)
9. (b)
10. (c)
11. (d)
12. (d)
13. (236.794)
14. (402)
15. (a)
16. (725)
17. (1.74)
18. (c)
19. (d)
20. (38.18)
21. (c)
22. (4.26)
23. (b)
24. (d)

## LEVEL 2 Objective Questions

25. (97.3)
26. (361.48)
27. (c)
28. (d)
29. (c)
30. (322.566)
31. (0.5445)
32. (b)
33. (a)

■■■■

LEVEL 3 Conventional Questions

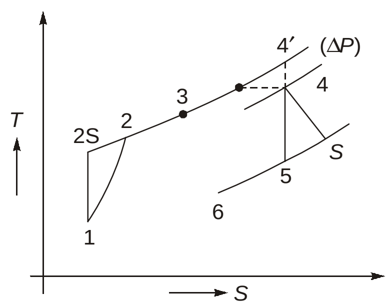
**Solution : 34**

$$T_3 = \text{Maximum temperature in cycle} = 1704.81\text{ K}$$
$$\eta = 29.04\%$$

**Solution : 35**

$$\eta_{th} = \frac{W}{Q} = 22.31\%$$

**Solution : 36**




$$\begin{pmatrix} \dot{m}_f = 10.55\text{ kg/sec} \\ \dot{m}_a = 1841.9\text{ kg/sec} \end{pmatrix}$$

$$\text{Work ratio} = 0.616$$
$$\eta_{thermal} = 50.2\%$$

**Solution : 37**

$$\eta = 41.19\%$$

**Solution : 38**

$$\dot{m}_a = 0.4244\text{ kg/s}$$

**Solution : 39**

Net power produced: $W_{net} = 3497.25$ kW

$\eta_{th} = 48.19\%$

Net power output: $W_{net} = 2142.34$ kW

Thermal efficiency: $\eta_{th} = 32.05\%$

Net power developed: $W_{net} = 2142.34$ kW

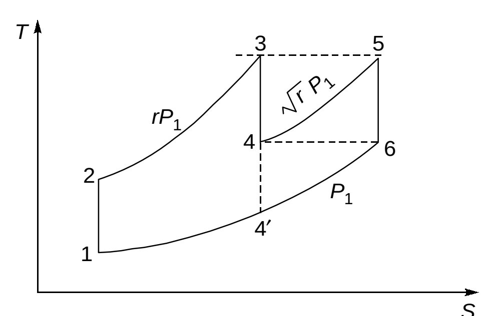
Thermal efficiency: $\eta_{th} = 36.18\%$

**Solution : 40**

$$\frac{T_2}{T_1} = \left(\frac{rP_1}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = r^a = C$$

$$\frac{T_3}{T_4} = \frac{T_5}{T_6}$$

$$\frac{T_3}{T_4} = r_a^{\frac{\gamma-1}{\gamma}},\ \frac{T_5}{T_6} = r_a^{\frac{\gamma-1}{\gamma}}$$



$r \rightarrow$ compression ratio
$r_a \rightarrow$ expansion ratio

$$\frac{T_3}{T_4} = \frac{T_5}{T_6} = (\sqrt{r})^a = \sqrt{C}$$

$$W_T = C_P(T_3 - T_4) + C_P(T_5 - T_6) = C_P(T_3 - T_4) + C_P(T_3 - T_6)$$

or
$$W_T = 2\,C_P(T_3 - T_4)$$

or
$$W_T = 2C_P T_3\left(1 - \frac{1}{\sqrt{C}}\right)$$

$$W_C = C_P(T_2 - T_1) = C_P T_1\left(\frac{T_2}{T_1} - 1\right) = C_P T_1(C - 1)$$

Net work output,
$$W_N = W_T - W_C = 2C_P T_3\left(1 - \frac{1}{\sqrt{C}}\right) - C_P T_1(C - 1)$$

$$W_N = \left\{2\frac{T_3}{T_1}\left(1 - \frac{1}{\sqrt{C}}\right) - (C - 1)\right\} C_P T_1$$

$\therefore$
$$\frac{W_N}{C_P T_1} = 2\frac{T_3}{T_1}\left(1 - \frac{1}{\sqrt{C}}\right) - (C - 1) = 2t(1 - C^{-1/2}) - (C - 1) \quad \text{...(i)}$$

Here c is the variable, for maximum work output, $\frac{d}{dc}\left(\frac{W_N}{C_P T_1}\right) = 0$

$$2t\left[-1 \times \frac{-1}{2} \times C^{-3/2}\right] - 1 = 0$$

or
$$t\,C^{-3/2} = 1$$

$$C = (t^{-1})^{-2/3} = t^{2/3}$$

as
$$C = r^a = t^{2/3}$$

or $\boxed{r = t^{(2/3a)}}$ Proved

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# 4 Turbine

## LEVEL 1 Objective Questions

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



## LEVEL 2 Objective Questions

| | |
|---|---|
| 18. | (c) |
| 19. | (c) |
| 20. | (a) |
| 21. | (1.72) |
| 22. | (a) |
| 23. | (d) |
| 24. | (b) |
| 25. | (c) |
| 26. | (b) |
| 27. | (3.43) |
| 28. | (86.35) |
| 29. | (c) |
| 30. | (d) |

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## LEVEL 3 Conventional Questions

**Solution : 31**

Tangential thrust, = 810.05 N

Diagram power, $W_D$ = 324.02 kW

Diagram efficiency, $\eta_D$ = 86.4%

Axial thrust = 0

**Solution : 32**

$D_m$ = 0.95 m

Height of blades $H_b$ = 0.115 m

**Solution : 33**

$T_2$ = 390.43 K

$T_4$ = 417.12 K

Compressor power = 1850.385 kW

**Solution : 34**

$\beta_1$ = 24.92°

$\beta_2$ = 41.77°

Power output, $P$ = 86.78 kW

Diagram efficiency, $\eta_D$ = 62.59 %

**Solution : 35**

tangential force on the blades = 809.55 N

Diagram power = 323.82 kW

Axial trust = 0

Diagram efficiency = 86.352%

**Solution : 36**

enthalpy drop per kg = 124.46 kJ/kg

$h$ = 5.28 cm

Drum diameter, $D_m$ = 5.28 × 12 = 63.36 cm

percentage increase in relative velocity in blade passage = 46.2%

**Solution : 37**

$D_m$ = 3.5174 meter

$D_m$ = 4.974 meter

$D_m$ = 1.7586 meter

$D_m$ = 1.573 meter

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# 5 Compressor

## LEVEL 1 Objective Questions

| | |
|---|---|
| 1. | (c) |
| 2. | (b) |
| 3. | (a) |
| 4. | (c) |
| 5. | (155.59) |
| 6. | (c) |
| 7. | (c) |
| 8. | (b) |
| 9 | (d) |
| 10. | (a) |
| 11. | (b) |
| 12. | (c) |
| 13. | (d) |
| 14. | (b) |
| 15. | (d) |
| 16. | (b) |
| 17. | (c) |

## LEVEL 2 Objective Questions

| | |
|---|---|
| 18. | (300) |
| 19. | (b) |
| 20. | (c) |
| 21. | (a) |
| 22. | (d) |
| 23. | (b) |
| 24. | (a) |
| 25. | (c) |
| 26. | (c) |
| 27. | (c) |
| 28. | (b) |

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## LEVEL 3 Conventional Questions

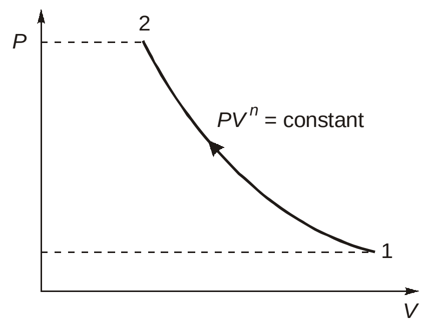
**Solution : 29**

$$\text{Tip diameter } (D_2) = 548.8 \text{ mm}$$

**Solution : 30**

Work done during polytropic compression is given by,

$$W = \int_1^2 pdV$$




We have,

$$PV^n = C$$

$$P = \frac{C}{V^n} = CV^{-n}$$

$$W = \int_1^2 V^{-n}dV = C\left(\frac{V^{-n+1}}{-n+1}\right)\Bigg|_1^2$$

$$W = \left|PV^n \frac{V^{1-n}}{1-n}\right|_1^2 = \frac{(PV)}{1-n}\Bigg|_1^2 = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{R(T_2 - T_1)}{1-n} \quad \text{... (i)}$$

Heat transfer for a polytropic process is given by

$$dQ = du + PdV = C_V(T_2 - T_1) + \frac{R(T_2 - T_1)}{1-n}$$

$$= C_V(T_2 - T_1) - \frac{C_V(\gamma - 1)(T_2 - T_1)}{1-n} = C_V(T_2 - T_1)\left[1 - \frac{\gamma - 1}{n - 1}\right]$$

$$Q = C_V \frac{n-\gamma}{n-1}(T_2 - T_1) \quad \text{... (ii)}$$

$$\Delta T = \frac{200(n-1)}{(\gamma - 1)C_V} = \frac{200(1.3-1)}{0.75(1.4-1)} = \mathbf{200\ K}$$

**Solution : 31**

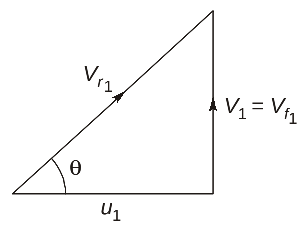
$$\text{Power given to the air, } W = 783.82 \text{ kW}$$

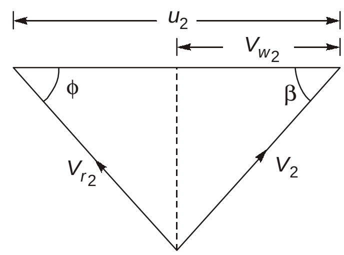
$$\beta_1 = 52.47°$$

$$\beta_2 = 20.19°$$

**Solution : 32**

Velocity triangle




$\beta = 24.22°$

Blade angle at outlet ($\phi$) = 18.37°

Breadth of impeller blade at inlet = 0.176 m

Breadth of impeller blade at outlet = 0.088 m

**Solution : 33**

Power of compressor = 102.14 kw

Pressure coefficient, $\Psi_P = 0.8415$

$P_2 = 1.0352$ bar

**Solution : 34**

$D_2 = 48.93$ cm = 489.3 mm

**Solution : 35**

$B_r = 57.33°$

$B_t = 37.32°$

$M_t = 0.744$

**Solution : 36**

$\mu = 0.86$

**Solution : 37**

$V_a = 142$ m/sec

No. of stages $n = 11$

**Solution : 38**

$\eta_c = 88.5\%$

$\dot{m}_a = 15.1244$ kg/sec.

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# 6 Jet Propulsion

## LEVEL 1 Objective Questions

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

## LEVEL 2 Objective Questions

| | |
|---|---|
| 15. | (d) |
| 16. | (b) |
| 17. | (d) |
| 18. | (d) |
| 19. | (b) |
| 20. | (c) |
| 21. | (b) |
| 22. | (a) |
| 23. | (b) |
| 24. | (c) |
| 25. | (d) |
| 26. | (a) |
| 27. | (b) |
| 28. | (b) |

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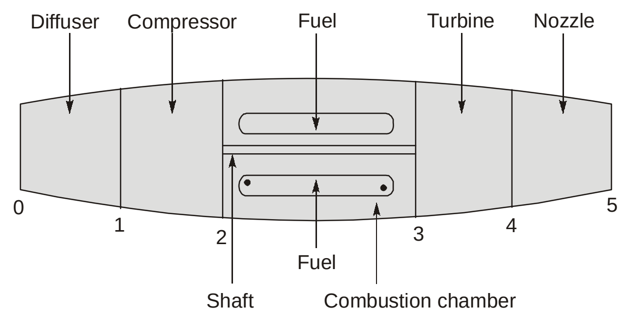
LEVEL 3 Conventional Questions

**Solution : 29**

The turbojet engines are most common type air breathing engine.

The engine consists of the following components:

1. A diffuser
2. A mechanical compressor
3. A combustion chamber
4. A mechanical turbine and
5. An exhaust nozzle




**The turbojet engine**

The function of the diffuser is to convert the kinetic energy of the entering air into a static pressure rise which is achieved by the ram effect. After this air enters the mechanical compressor.

The compressor used in a turbojet can be either centrifugal type or axial flow type. The use of a particular type of compressor gives the turbojet typical characteristics. The centrifugal compressor produces a high pressure ratio of about 4 : 1 to 5 : 1 in a single stage and usually a double sided rotor is used to reduce the engine diameter. The turbojet using a centrifugal compressor has a short and sturdy appearance. The advantages of centrifugal compressor are high durability, ease of manufacture and low cost, and good operation under adverse circumstances such as icing and when sand and small foreign particles are inhaled in inlet duct.

The axial flow compressor is more efficient than the centrifugal type and gives the turbojet a long, slim, streamlined appearance. The engine diameter is reduced which results in low aircraft drag. A multistage axial flow compressor can develop a pressure ratio as high as 6 : 1 or more. The air handled by it is more than that handled by a centrifugal compressor of the same diameter.

After the compressor air enters to the combustion chamber, the fuel nozzles feed fuel continuously and continuous combustion takes place at constant pressure. The high pressure, high temperature gases then enter the turbine, where they expand to provide enough power output from the turbine.

The turbine is directly connected to the compressor and all the power developed by the turbine is absorbed by the compressor and the auxiliaries. The main function of the turbine is to provide power, to drive the compressor. After the gases leaves the turbine they expand further in the exhaust nozzle, and are ejected into the atmosphere with a velocity greater than the flight velocity thereby producing thrust for propulsion.

Current turbojet engines operate with compressor pressure ratios between 6 and 16, and with turbine inlet temperatures of the order of 1200 K. The corresponding speed of the exhaust jet when propelling an aircraft at 900 km per hour (250 m/s) is of the order of 500 m/s.

**Solution : 30**

$$\text{Thrust Power } (TD) = 4402.37 \text{ kW}$$
$$\text{Propulsive Power} = 7.764 \text{ MW}$$
$$\text{Propulsive efficiency } \eta_p = 56.7\%$$
$$\text{Thermal efficiency} = 31\%$$
$$\text{Overall efficiency} = 17.6\%$$

**Solution : 31**

$$\text{AFR} = \frac{1}{f} = 36.409 \text{ kg of air/kg of fuel}$$

$$\text{Specific thrust from (ii)} = 378.93 \text{ m/sec}$$
$$\text{Propulsive efficiency} = 60.54\%$$

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