Q.1 Attempt any FIVE of the following: [10]
Q.1(a) Write uses of compressed air? [2]
Ans.: Industrial Use of compressed air:
(a) In sand blasting.
(b) In blasting furnace.
(c) In pneumatic tools.
(d) In ground water tube well.
(e) In manufacturing of acid and other chemical products

Commercial Use of compressed air:
(a) Filling air in the tubes of automobiles.
(b) For spray painting.
(c) For cleaning of automobiles.
(d) For supercharging of I.C Engines

Q.1(b) State the Unit of Refrigeration. [2]
Ans.: The capacity of mechanical equipment is generally given in H.P. and of electrical equipment in kW. Similarly the capacity of refrigeration unit is given in Tons of Refrigeration. Due to the fact that refrigeration was first produced by ice, the refrigerating effect of refrigeration machine is compared with refrigeration produced by ice.

A Ton of refrigeration is defined as 'the quantity of heat required to be removed to form one ton of ice at 0°C within 24 hours when initial condition of water is 0°C, because same cooling effect will be obtained by melting the same ice.'

In S.I. units, 1 Ton of refrigeration can be calculated by considering latent heat of fusion of ice = 335 kJ/kg.

\[
1 \text{ Ton of refrigeration} = \frac{\text{Latent heat of ice} \times \text{Mass of ice}}{\text{Time required for cooling}} = \frac{335 \times 1000}{24 \times 60 \times 60} = 3.517 \text{ kJ/s} = 3.517 \text{ kW}
\]

\[1 \text{ Ton} = 3.517 \text{ kW}\]
Thus, ton of refrigeration is not a unit of mass but a measurement of the rate of heat transfer from enclosed space.

Q.1(c) State the functions of Catalytic Converter. [2]
Ans.: Catalytic converters are widely used in car all over the world.

It is cylindrical canister placed between exhaust manifold and silencer. It contains plastic pallets coated with the catalyst.

Fig.: Catalytic converter
Catalytic converter is designed for the oxidation of pollutant gases escaping after primary combustion in the engine, within the exhaust system. The simplest type of catalytic converter is as shown in figure.

The temperature required for bulk gas oxidation and reduction of hydrocarbon gases (HC), carbon monoxide (CO) and oxides of nitrogen (NOx) is about 600 to 700°C. The temperature of exhaust gases in exhaust system is lower. The catalytic converter oxidizes and reduces all the three pollutant gases at lower temperature because of catalytic chemical reaction. A catalytic converter becomes effective in the temperature between 250 to 300°C.

Q.1(d) Define the term 'Compressor capacity'.
Ans.: Compressor capacity: It is the quantity of the free air, actually delivered by compressor in m³/min.

Q.1(e) Name the essential components used in Gas turbine.
Ans.: Compressor, Turbine, Combustion chamber heat exchanger, generator, starter.

Q.1(f) Classify gas turbines.
Ans.: 1. According to Path of Working Substance:
   (a) Closed cycle gas turbine
   (b) Open cycle gas turbine
   (c) Semi - closed cycle gas turbine
2. According to Process of Heat Absorption:
   (a) Constant pressure
   (b) Constant volume
3. According to Fuel Used:
   (a) Liquid Fuel gas turbine
   (b) Gaseous fuel gas turbine
   (c) Solid fuel gas turbine
4. According to cycle Operation:
   (a) Brayton cycle (For constant pressure gas turbine)
   (b) Atkinson cycle (For constant volume gas turbine)
5. According to Arrangement:
   (a) Simple
   (b) Intercooled
   (c) Reheat
   (d) Regenerative
6. According to Arrangement:
   (a) Axial flow
   (b) Radial flow

Q.1(g) State the any two advantages of 'Turbo Charging'.
Ans.: (i) Uses exhaust heat to run engine
      (ii) Better engine performance.

Q.2 Attempt any THREE of the following:
Q.2(a) Represent Diesel Cycle on P-V and T-S Diagram.
Ans.: Diesel cycle is a cycle on which diesel engine i.e. compression ignition engine works. It is an idealized cycle. In diesel cycle, addition of heat takes place at constant pressure and rejection of heat takes place at constant volume. Diesel cycle consists of four processes:
   Process 1-2 : Isentropic compression raising pressure and temperature.
   Process 2-3 : Addition of heat at constant pressure.
Process 3-4: Isentropic expansion from high pressure and temperature to low pressure and temperature.

Process 4-1: Rejection of heat at constant volume.

In case of diesel engine, compression ratio \( r = \frac{V_1}{V_2} \) and cut-off ratio \( \alpha_c = \frac{V_1}{V_4} \).

Consider for 1 kg of air:

- Heat supplied, \( q_A = C_p (T_3 - T_2) \)
- Heat rejected, \( q_R = C_v (T_4 - T_1) \)

Work done = \( q_A - q_R = C_p (T_3 - T_2) - C_v (T_4 - T_1) \)

Air standard efficiency of diesel cycle,

\[
\eta = \frac{\text{Net work done}}{\text{Heat addition}} = \frac{q_A - q_R}{q_A} = \frac{C_p (T_3 - T_2) - C_v (T_4 - T_1)}{C_p (T_3 - T_2)} \quad \text{...(1)}
\]

Consider process 1-2 : \( PV^\gamma = C \)

\[
\therefore \quad \frac{T_2}{T_1} = \left( \frac{V_1}{V_2} \right)^{\gamma - 1}
\]

\[
\therefore \quad T_2 = T_1 \left( \frac{V_1}{V_2} \right)^{\gamma - 1} = T_1 (r)^{\gamma - 1}
\]

Consider process 2-3 : \( P = \text{Constant} \)

From Charles' law :

\[
\frac{V}{T} = C
\]

\[
\therefore \quad \frac{V_3}{V_2} = \frac{T_3}{T_2}
\]

\[
\therefore \quad T_3 = \frac{V_3}{V_2} \times T_2 = \alpha_c \times T_2 (r)^{-1}
\]

Consider process 3-4 : \( PV^\gamma = C \)

\[
\therefore \quad \frac{T_4}{T_3} = \left( \frac{V_1}{V_4} \right)^{\gamma - 1}
\]

\[
\therefore \quad T_4 = T_3 \left( \frac{V_1}{V_2} \times \frac{V_3}{V_4} \right)^{\gamma - 1} \quad \text{[As } V_1 = V_4]\]

\[
\therefore \quad T_4 = T_3 \left( \frac{\alpha_c}{Y} \right)^{\gamma - 1} = \alpha_c T_1 (\gamma)^{-1} \left( \frac{\alpha_c}{Y} \right)^{\gamma - 1} = T_1 (\alpha c)^{\gamma - 1}
\]

Substitute the values of \( T_2, T_3 \) and \( T_4 \) in equation (1), we get
\[ \eta = 1 - \frac{T_4 - T_1}{\gamma(T_3 - T_2)} = 1 - \frac{1}{\gamma} \left[ \frac{T_3 \alpha_c^v - T_1}{\alpha_c T^v_r r^{-1} - T_P r^{-1}} \right] = 1 - \frac{1}{\gamma} \left[ \frac{T_i (\alpha_c^v - 1)}{r^{-1} T_r (\alpha_c - 1)} \right] \]

Conclusion:
(i) Efficiency of diesel cycle increases with the compression ratio \( r \).
(ii) Efficiency of diesel cycle decreases with increase in cut-off ratio \( \alpha_c \).

Q.2(b) State the effect of 'Air-Fuel Ratio' on exhaust emission. [4]
Ans.: Effect of 'Air-Fuel Ratio' on exhaust emission
- Effect of air-fuel ratio exhaust emissions can be also be observed with the help of a term, known as 'Equivalence ratio'.
- Equivalence ratio is also called as 'relative air-fuel ratio'.
- Equivalence ratio or Relative air-fuel ratio is defined as, "the ratio of actual fuel-air ratio to stoichiometric fuel-air ratio required to burn the fuel supplied."

Q.2(c) Explain the working of 'Lobe type Air Compressor' with neat sketch. [4]
Ans.: It consists of two rotors driven externally.
One of the rotor is connected to the drive and the second one is gear driven from the first.
The rotors have got two or three lobes having epicycloid, hypocycloid, involute profiles. The high pressure delivery side is sealed from the low pressure suction side at all angular positions.

A very small clearance is maintained between the surfaces to prevent wear. Air leakage through the clearance decreases the efficiency as pressure ratio increases.

Working:
During rotation, volume of air 'V' at atmospheric pressure 'P_1' is trapped between the left hand rotor and the casing. This air is positively displaced with change in volume until the space is open to high pressure region. At this instant some high pressure air rushes back from the receiver and mix irreversibly with blower air V until the pressure is equalized.

![Roots Blower](image)

Q.2(d) Represent Brayton Cycle on P- V and T- S diagram. [4]
Ans.: Working Cycle: Joule or Brayton cycle
The air standard Brayton cycle or constant pressure cycle is an idealized cycle for simple gas turbine, i.e. In Brayton cycle the heat added and heat rejected is at constant pressure. The cycle consists of compressor, combustion chamber and turbine. The cycle can be shown on P-V and T-S diagram as shown in figure.
The various processes in Brayton cycle are:

Process 1-2: Isentropic compression in the compressor raising pressure and temperature from $P_1$, $T_1$ to $P_2$, $T_2$.

Process 2-3: Addition of heat at constant pressure raising temperature from $T_2$ to $T_3$.

Process 3-4: Isentropic expansion of air from high pressure and temperature to low pressure and temperature to give work of expansion.

Process 4-1: Rejection of heat at constant pressure to restore the original state.

Q.3 Attempt any THREE of the following: [12]

Q.3(a) List the pollutants in exhaust gases of I.C engines and state their effects on the environment and human-being.

Ans.: Effects of Pollutants of Human Beings

(i) SOOT
- Soot contains solid particles of carbon containing up to 99% of pure carbon.
- They get suspended in air and are breathed in by human beings and animals and become mechanical pollutant of lungs.
- It is an active carrier of cancer producing substances

(ii) CO
- This is formed, when the fuel burns with insufficient amount of oxygen. Carbon monoxide is colorless, odorless and tasteless.
- It causes head-ache, nausea, breathing problem. It also causes heart diseases.

(iii) HC
- The content of hydrocarbon in the exhaust promotes the formation of petrochemical smog with NOx and sunlight.
- They may reduce the visibility, which leads to eye irritation. It gives peculiar odour and may damage vegetation.
- Hydrocarbon can cause throat and lung irritation.

(iv) NOx
- It is a poisonous gas with penetrating odour, which destroys lung tissue.
- NOx irritates the eyes, nose and throat. It causes coughing, headache etc.
- It damages the food crops, vegetation and also affects the animal life.

(v) SO2
- It is toxic and corrosive.
- It reacts with water and forms sulphuric acid, which is harmful to plant and in animals.
- Its presence in atmosphere causes cardiac, respiratory diseases, eye irritation and throat infections.

(vi) CO2
- It leads to respiratory problems, suffocation and eye irritation.
- It also damages the food crops, vegetation and plant life.
- Increased percentage of CO2 in the atmosphere is leading to global warming.
Effects of Pollutants on Environment:

(i) Acid Rain
- They fall in rainy season in the form of acid rain and acid snow.
- If affects the life of plants, fishes in lakes and rivers.

(ii) Green house effect
- Green house emissions lead to increase in temperature of earth. Even a small increase in earth’s temperature causes change in climate, such as wind patterns, duration of seasons, precipitation, cyclones, storms etc.

(iii) Global warming
- The solar heat enters the layers formed by the gases emitted from earth’s surface, but does not get radiated back to the space due to different wavelengths.
- This tends to increase the earth’s temperature leading to global warming. CO₂ is the main cause of global warming.

(iv) Ozone layer depletion
- Ozone layer protects the human beings against harmful effects like cancer by absorbing ultraviolet rays coming from sun and allow only the heat rays and light to reach earth’s surface.
- Some of the gases such as fluorine and chlorine released from refrigerants and pollutants from vehicles react with ozone to form different compounds. It leads to depletion of ozone layer.

Q.3(b) Explain the term

(i) Octane Number
(ii) Knock Resistance

Ans.: (i) Octane Number:
The octane number (ON) is a measure of the knock resistance of gasoline. It defines a numerical value from 0 to 100, and describes the behavior of the fuel in the engine during combustion. In determining the octane number, a distinction is primarily made between the research octane number (RON) and the motor octane number (MON).

A high octane number can help increase the efficiency and thus performance of an engine. However, the octane number is not a measure of energy content or better combustion. More performance can only be achieved by adjusting the engine parameters to the fuel, not simply by fuelling with higher-octane fuel.

(ii) Knock Resistance:
Knock resistance is a fuel’s ability not to self-ignite and burn in an uncontrolled way while the fuel is being compressed. This means that the air-fuel mixture in engine is not ignited only by the ignition spark, but also by compression. An octane number describes this phenomenon under defined conditions.

Q.3(c) Explain with neat sketch the working of Household Refrigerator.

Ans.: Cycle Used: Vapour compression refrigeration cycle.
Refrigerant: R-134a, R-11, R-12
Working:
- Low pressure liquid refrigerant enters into the evaporator, absorbs heat from the refrigerated space and gets converted into low pressure, low temperature vapour refrigerant. It creates cooling effect in the space to be refrigerated.
- This low pressure vapour is sucked by the compressor, where its pressure and temperature are increased by compression.
- High pressure and high temperature vapour delivered by compressor is cooled and condensed to liquid state in the condenser. Thus, heat is rejected by the refrigerant in the condenser.
- Then, this high pressure liquid refrigerant is passed through capillary tube, where its pressure is reduced.
- Low pressure and low temperature liquid refrigerant is supplied to evaporator and the cycle is repeated.
- Capacity of household refrigerator is expressed in terms of litres.
- Standard refrigerators of capacity 90, 165, 210, 300, 420 etc. Litres are available in market.

Q.3(d) Differentiate between Two Stroke and Four Stroke I. C. Engine (any four points).

Ans.:

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Four Stroke Engine</th>
<th>Two Stroke Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>The cycle is completed in two revolutions of crankshaft.</td>
<td>The cycle is completed in one revolution of crankshaft.</td>
</tr>
<tr>
<td>2.</td>
<td>One power stroke is obtained in every two revolutions of crankshaft.</td>
<td>One power stroke is obtained in every revolution of crankshaft.</td>
</tr>
<tr>
<td>3.</td>
<td>Because of one power stroke for two revolutions, power produced for same size engine is small or for same power engine is bulky.</td>
<td>Because of one power stroke for one revolution, power produced for same size engine is more. Theoretically twice but in actual practice 1.5 times or for same power engine is light and compact.</td>
</tr>
</tbody>
</table>
4. The turning effort on crankshaft is not uniform so heavier flywheel is required. | The turning effort on the crankshaft is much more uniform so that lighter flywheel can be used.
---
5. Four-stroke engine contains valves and valve mechanism. | Two-stroke engine do not have valves but only ports are present.
---
6. Because of heavy weight and complication of valve mechanism higher in initial cost. | Because of light weight and simplicity due to absence of valve, less initial cost.
---
7. The crown of the piston is flat or dome shaped. | The crown of piston is provided with deflector for efficient scavenging.
---
8. Thermal efficiency is more. | Thermal efficiency is less.
---
9. Used where efficiency is important. E.g. bus, truck, tractor etc. | Used where light and compact engine is required. E.g. scooters, lawn movers.

Q.4 Attempt any THREE of the following: [12]

Q.4(a) Explain the term "Exhaust Gas Recirculation" with neat sketch. [4]

Ans.: EGR is a technique used to reduce emissions in diesel engine. Diesel engines tend to emit higher Nitrogen Oxide (NO\textsubscript{x}) which is harmful to human. This is because of high temperatures in the engine cylinders due to higher compression ratio of diesel engine. To control and decrease the NO\textsubscript{x}, EGR technology is used in diesel engines. EGR works by recirculating a portion of an engine's exhaust gas back to the engine cylinders. This dilutes the O\textsubscript{2} present in incoming air stream and reduce peak cylinder temperature, which reduces formation of NO\textsubscript{x}.

If EGR is used in spark ignition engine, it increases the efficiency of engine, as charge dilution allows a larger throttle position and reduces pumping losses.

**Advantages of EGR:**
- EGR reduces the harmful emission of NO\textsubscript{x}.
- It improves the efficiency of engine.
- It reduces the fuel consumption of engine.
Q.4(b) Draw the labeled Valve Timing Diagram of typical 4-stroke Diesel Engine.

Ans.:

![Valve Timing Diagram](image)

**Fig. 1:** Valve timing diagram of 4-stroke diesel engine

---

Q.4(c) Explain the concept of following terms with respect to refrigerants

(i) GWP  
(ii) ODP

Ans.:

(i) **GWP**

Global warming Potential (GWP) is perhaps the most commonly used environmental metric. GWP is the index, which compares the global warming impact of an emission of a greenhouse gas in relation to the impact from the emission of similar amount of CO₂. The impact is estimated during a time horizon. A time horizon of 100 years is most adopted and normally assumed.

The smaller the GWP, lower is the contribution of a substance to the global warming. Based on GWP criteria the R290 (Propane) and R1270 (Propene) can be considered as the most environmentally friendly refrigerants while the R1234yf is less favorable.

(ii) **ODP**

The Ozone Depletion Potential (ODP) is the potential for a single molecule of the refrigerant to destroy the Ozone layer. All of the refrigerants use R11 as a calibration and thus R11 has an ODP of 1.0. The less the value of the ODP, the better the refrigerant is, for the Ozone layer and the Environment.

---

Q.4(d) Explain the effect of clearance volume on multi stage Air compressor without intercooling by using P V diagram.

Ans.:

- **Less amount of air sucked per stroke:** Clearance volume should be very small, because the compressed air left in the clearance volume, first re-expands with decrease in pressure in the cylinder causing the inlet valve to open and suction starts. If clearance volume is large, it will delay the opening of inlet valve. Therefore, the amount of air sucked per stroke will be reduced.
• Decrease in volumetric efficiency: Due to clearance volume, the actual volume of air sucked per stroke is less than swept volume. Therefore volumetric efficiency decreases.

• Increase in required compressor power: More power is required to drive the compressor for same pressure ratio, due to increase in volume to be handled.

• Results in low compression ratio: If clearance volume is more, then the final pressure obtained after compression will reduce. Thus, high compression pressure value is limited or restricted due to clearance volume and we obtain low compression ratio.

Q.4(e) Explain the working of 'Turbo Prop' with neat sketch. [4]

Ans.: The turbo prop engine is shown in figure. It is very similar to turbo jet engine, the major difference being that the turbine is designed so that it develops shaft power for driving a propeller to provide most of the propulsive thrust, and only a small amount of thrust is provided by jet.

![Fig.: Turbo propeller](image)

In this case, nearly 80 to 90% of the power propulsion is generated by turbine and is transmitted to the propeller through reduction gear. The remaining 10 to 20% of the thrust is developed by expanding the turbine exhaust in a nozzle of suitable design.

Quite often, the thrust output of the unit is increased by heating the turbine exhaust before expansion in the nozzle.

The turboprop combines in it the merits of turbojet engine i.e. low specific weight, small frontal area, simplicity and lower vibration and merits of the propeller i.e. high power for the take off and climb and high propulsive efficiency at high speeds.

A variation of turbo prop engine is known as 'turbo shaft engine'. This is a gas turbine power plant in which, all delivered power is in the form of shaft power. Turbo shaft engines are currently used both to powder helicopters and for various land and marine applications.

Advantages of Turboprop Engine
• It develops higher thrust and power at the time of take off and climb.
• The specific fuel consumption is low.
• It has low frontal area and low weight.
• It has low vibrations and noise.
• It has high efficiency and wide range of speed.

Disadvantages of Turboprop engine:
• It needs reduction gear unit which increases cost and weight.
• The propulsive efficiency decreases rapidly at high speed above 800 km/hr due to flow separation and shocks.

Applications of Turboprop Engine:
Turboprop engines are suitable for application at subsonic speed, it is used in military and civil aircrafts.
Q.5 Attempt any TWO of the following : [12]

Q.5(a) Following observations were recorded during a trial on single cylinder four stroke oil engine:

Cylinder bore = 15 cm
Length of stroke = 25 cm
Mean effective pressure = 7.35 bar
Engine speed = 400 rpm
Brake torque = 225 N.m.
Fuel consumption = 3 kg/hr
Calorific value of fuel = 44200 kJ/kg

Determine:
(i) Mechanical efficiency
(ii) Brake thermal efficiency
(iii) Brake specific fuel consumption

Ans.:

Indicated mean effective pressure is given by:

\[ P_m = \frac{\text{Area of indicator diagram} \times \text{Spring index}}{\text{Length of indicator diagram}} = \frac{450 \text{mm}^2 \times 8.17 \text{N/cm}^2 \text{mm}}{50 \text{mm}} = 73.53 \text{N/cm}^2 \]

\[ \Rightarrow \text{Indicated power of engine is given by} \]

\[ IP = P_m \times A L N = P_m \times \frac{\pi}{4} \times \frac{d}{2} \times L \times N \quad \text{...(for 4-stroke engine]} \]

\[ = 7.35 \times 10^5 \text{N/m}^2 \times \frac{\pi}{4} \times (0.15)^2 \text{m}^2 \times 0.25 \text{m} \times \frac{400 \text{rev}}{60} \]

\[ = 10818 \text{ watt} = 10.818 \text{ kW} \]

Brake power of engine is given by, \[ BP = (W - S) \times r \times 2\pi N = T \times 2\pi N \]

\[ = 225 \text{ N.m} \times 2\pi \times \frac{400 \text{ rev}}{60} = 9424.77 \text{ N.m/s} \]

\[ = 9.424 \text{ kW} \]

\[ \Rightarrow \text{Mechanical efficiency of engine is given by,} \]

\[ \eta_m = \frac{BP}{IP} \times 100 = \frac{9.424}{10.818} \times 100 = 87.11\% \]

Brake thermal efficiency of engine is given by:

\[ \eta_b = \frac{\text{Brake power}}{\text{Heat supplied}} \times 100 = \frac{BP}{m_f \times CV} \times 100 = \frac{9.424 \text{kJ/s}}{\frac{3}{60 \times 60} \text{kg/s} \times 44200 \text{kJ/kg}} \]

\[ = 25.6\% \]

Brake specific fuel consumption is given by

\[ \text{b.s.f.c.} = \frac{m_f \text{kg/hr}}{BP \text{kW}} = \frac{3}{9.424} = 0.318 \text{ kg/kWh} \]

Q.5(b) A single stage reciprocating air compressor has swept volume of 2000 cm³ and runs at 600 rpm. It operates on pressure ratio of 8 and clearance 5% of swept volume. Assume NTP room condition at inlet (\(P = 101.3\text{kPa}, T = 15\text{°C}\)) and polytropic compression and expansion with \(n = 1.25\) calculate:

(i) Indicated power
(ii) Volumetric efficiency
(iii) Mass flow rate
(iv) Isothermal efficiency

Ans.:

Let \(V_s = \text{Swept volume}\)
\(V_c = V_3 = \text{Clearance volume}\)
We have, \(V_s = V_1 - V_3 = V_1 - 0.05 V_s\)
\[ V_1 = 1.05 V_s = 1.05 \times \frac{2000}{10^6}\text{m}^3 \]

Indicated power,
\[ IP = \frac{n}{n-1} PV \left[ \left( \frac{P_s}{P_t} \right)^\frac{n-1}{n} - 1 \right] \times \frac{N}{60} \]
\[ = \frac{1.25}{1.25-1} \times 101.3 \times 1000 \times 1.05 \times \frac{2000}{10^6} \left[ \frac{8}{1} \right]^{\frac{1.25-1}{1.25}} - 1 \times 800 \times \frac{1}{60} \]
\[ = 7313 \text{ watt} = 7.313 \text{ kW} \]

Isothermal power \( P_{is} \) = \( P_s V_1 \log \left( \frac{P_s}{P_t} \right) \times \frac{N}{60} \)
\[ = 101.3 \times 1000 \times 1.05 \times \frac{2000}{10^6} \log \left( \frac{8}{1} \right) \times 800 \times \frac{1}{60} \]
\[ = 5897.8 \text{ watt} = 5.8978 \text{ kW} \]

\[ \text{Isothermal efficiency} = \frac{\text{Isothermal power}}{\text{Indicated power}} \times 100 = \frac{5.8978}{7.313} \times 100 = 80.64\% \]

\[ P_{is} = mRT \]
\[ 101.3 \times 1.05 \times \frac{2000}{10^6} = m \times 0.287 \times (273 + 15) \]
\[ m = 2.5736 \times 10^{-4} \text{ kg} \]

Volumetric efficiency,
\[ \eta_v = 1 - \frac{V}{V_s} \left[ \left( \frac{P_s}{P_t} \right) \right]^\frac{n-1}{n} - 1 \]
\[ = 1 - \frac{0.05 V_s}{V_s} \left[ \left( \frac{8}{1} \right)^{\frac{1}{1.25}} - 1 \right] = 0.7860 = 78.60\% \]

Q.5(c) A simple saturation vapour compression cycle using R-12 is designed for 10 TR capacity. The vapour is dry saturated at the start of compression. For the 268°K evaporator temperature and 308°K condenser temperature, Represent process on P-H and T-S diagram. Find: (i) Mass flow rate of refrigerant (ii) Power required in kW. (iii) C.O.P.

Given enthalpy values:
(i) at the start of compression = 185 kJ/kg
(ii) at the end of compression = 206 kJ/kg
(iii) at the start of expansion = 70 kJ/kg

Ans.:

Refrigeration capacity = 10 \times 3.517 kW = 35.17 kW
(i) \[ m^o = \frac{\text{Refrigeration capacity}}{(h_1 - h_2)} = \frac{35.17}{(185 - 70)} = 0.3058 \text{ kg/sec} \]

(ii) Work done = \( m(h_2 - h_1) = 6.422 \text{ kW} \)

(iii) C.O.P. = \( \frac{h_1 - h_2}{h_2 - h_1} = 5.476 \)

Q.6 Attempt any TWO of the following: [12]

Q.6(a) An IC engine uses 6 kg of fuel per hour having CV of 43,000 kJ/kg.

The brake power developed is 21 kW.

The temperature rise of cooling water is 23°C.

Rate of water flow is 11 kg/min.

The temperature rise of exhaust gas is 250°C

Rate of flow of exhaust gases is 4.6 kg/min

specific heat of water 4.187 kJ/kg K

specific heat of exhaust gas are 1 kJ/kg K

Prepare heat balance sheet on minute basis.

Ans.: Brake power developed = 21 kW

\[ \therefore \text{Heat equivalent of BP} = 21 \text{ kW} \]

\[ \therefore \text{Heat supplied} = \text{Mass flow rate of fuel} \times \text{C.V. of fuel} \]

\[ = \frac{6}{60} \times 43,000 = 71.66 \text{ kW} \]

\[ \therefore \text{Heat carried by cooling water} = m_w \times C_{Pw} \times (\Delta t)_{\text{water}} = \frac{11}{60} \times 4.187 \times 23 \]

\[ = 17.655 \text{ kW} \]

\[ \therefore \text{Heat carried by exhaust gas} = m_{eg} \times C_{peg} \times (T_{eg} - T_{room}) \]

\[ = \frac{4.6}{60} \times 1 \times (250) = 19.16 \text{ kW} \]

\[ \therefore \text{Unaccounted heat} = \text{Heat supplied} - (\text{Heat equivalent of B.P.} + \text{Heat carried by cooling water} + \text{Heat carried by exhaust gas}) \]

\[ = 71.66 - (21 + 17.655 + 19.16) \]

\[ = 13.845 \text{ kW} \]

\begin{center}
\begin{tabular}{|c|c|c|c|c|}
\hline
\textbf{Heat Supplied} & \textbf{kW} & \% & \textbf{Heat Expenditure} & \textbf{kW} & \% \\
\hline
Heat supplied by fuel & 71.66 & 100 & Heat equivalent of B.P. & 21.00 & 29.30 \\
\hline
Heat carried by cooling water & 17.655 & 24.63 & \\
Heat carried by exhaust gas & 19.16 & 26.73 & \\
Unaccounted heat & 13.845 & 19.14 & \\
\hline
Total & 71.66 & 100 & Total & 71.66 & 100.00 \\
\hline
\end{tabular}
\end{center}

Q.6(b) State the methods to improve efficiency of air compressor. Explain working of Two stage air compressor with perfect intercooling with the help of P-V diagram [6]

Ans.: The methods to improve efficiency of air compressor [2 marks]

- Spraying cold water into cylinder during compression.
- Providing cooling water jackets.
- Use of multistage compressor.
- Providing fins on exterior surface of compressor cylinder.
- Use of intercooler in multistage compression.
Two stage air compressor with perfect intercooling

- Figure shows schematic arrangement of two-stage reciprocating air compressor with water-cooled intercooler.
- It consists of a low-pressure cylinder and a high-pressure cylinder.
- Fresh air is sucked from the atmosphere in the low-pressure cylinder during its suction stroke at intake pressure $P_1$ and temperature $T_1$.

![Fig.: Two stage compression](image)

- The air, after polytropic compression in the low-pressure cylinder from 1 to 2, is delivered to the intercooler at pressure $P_2$ and temperature $T_2$.
- In the intercooler, the air is cooled at constant pressure $P_2$ with decrease in temperature from $T_2$ to $T_3$. Inter-cooling process is represented as 2-3. If temperature $T_3$ is equal to initial temperature $T_1$, then the intercooler is said to be perfect intercooler.
- After inter-cooling, air is sucked in the high pressure cylinder during its suction stroke.
- Now, the air is polytropically compressed in H.P. cylinder from 3 to 4, which completes second stage of compression. The compressed air is delivered from high-pressure cylinder at pressure $P_3$ and temperature $T_4$.

Complete Inter-cooling

![Fig.1: Complete inter-cooling of a two stage reciprocating air compressor](image)

- “When the temperature of air leaving the intercooler ($T_3$) is equal to the temperature of original atmospheric air ($T_1$), then the inter-cooling is said to be complete or perfect inter-cooling”.
- In the process 2-3, the inter-cooling is carried out at constant pressure ($P_2 = P_3$).
- In this case, point 3 lies on the isothermal curve as shown in figure 1. The compression process in two stages is carried out as 1-2-3-4 i.e. from $P_1$ to $P_2$ and then $P_2$ and $P_3$, where $P_2$ is intermediate pressure. The path 1-2-5 shows single stage polytropic compression process.
- Area under the curve 1-2-3-4 indicates work required for two stage compression with perfect or complete inter-cooling.
- Area under the curve 1-2-5 indicates the work required for single stage compression.
It is clear that, work required during two stage compression is less than single stage compression. The shaded area 2-3-4-5 shows the work saved due to perfect inter-cooling.

**Incomplete or Imperfect Inter-cooling**

- "When the temperature of air leaving the inter-cooler (T₃) is more than the original atmospheric air temperature (T₁), then the inter-cooling is said to be incomplete or imperfect inter-cooling".
- In this case, point 3 lies on the right hand side of isothermal curve (PV = C) as shown in figure 2. The shaded area 2-3-4-5 shows the work saved due to incomplete inter-cooling.
- Also, it is very clear from figure 1 and 2 that, amount of work saved due to perfect inter cooling is more than work saved due to imperfect inter-cooling.

\[\text{Fig.2: Incomplete inter-cooling of a 2-stage reciprocating air compressor}\]

Q.6(c) The air is at 24 °C DBT and 40 % Relative humidity.
With the help of psychrometric chart find following properties of air with units and plot the same on psychrometric chart.

(i) Dew point temperature
(ii) Wet bulb temperature
(iii) SP volume of air
(iv) Enthalpy of air
(v) SP humidity of air

**Ans.:**

(i) Dew point temperature = 9.8°C
(ii) Wet bulb temperature = 15.7°C
(iii) SP volume of air = 0.851639 m³/kg
(iv) Enthalpy of air = 44kJ/kg
(v) SP humidity of air = 0.0076 kg