

THERMAL ENGINEERING

(Maximum mark:100)

PART A

I. Answer all questions in one or two sentences . Each question carries two marks. Marks

1.What is state of system.

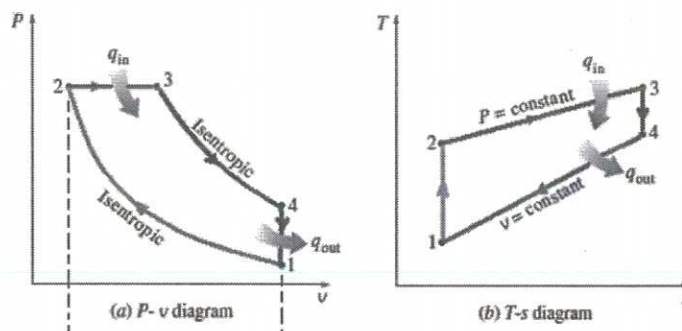
Ans. Thermodynamic state of a system is its condition at a specific time, that is fully identified by values of a suitable set of parameters known as state variables or properties 2

2.Write the expression for air standard efficiency of Otto cycle

Ans. Air standard efficiency of otto cycle is $\eta = 1 - \frac{1}{r^{\gamma-1}}$

Where r compression ratio γ = ratio of specific heat (1+1=2)

3. Draw P-v diagram of four stroke diesel cycle



(1+1=2)

4.Define the term dryness fraction.

The steam **dryness fraction** is used to quantify the amount of water within steam. If steam contains 10% water by mass, it's said to be 90% dry, or have a **dryness fraction** of 0.9. 2

5.What is heat exchanger.

A heat exchanger is a device used to transfer heat between two or more fluids. The fluids can be single or two phase and, depending on the exchanger type, may be separated or in direct contact. 2

PART B

II. Answer any five of the following questions . Each question carries 6 marks

1. Define Boyle's law and Charles law of gases

Boyle's law

Boyle's law or the pressure-volume law states that the volume of a given amount of gas held at constant temperature varies inversely with the applied pressure when the temperature and mass are constant.

$$V \propto \frac{1}{P}$$

Another way to describing it is saying that their products are constant. $PV = C$

Mark distribution = statement 2 marks , equation 1

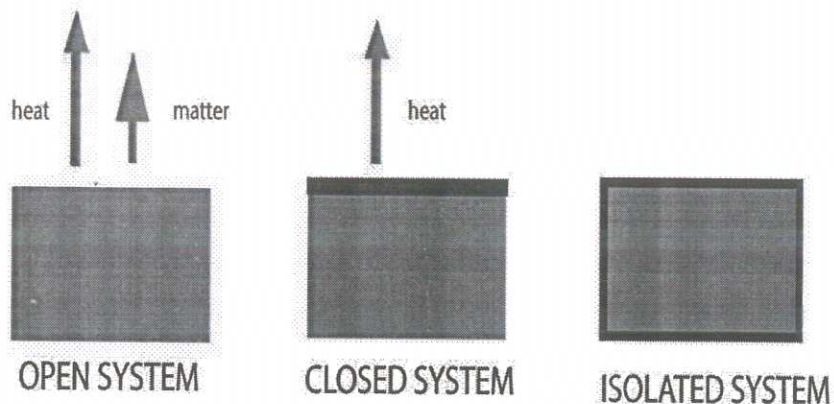
Charles' Law: The Temperature-Volume Law

- This law states that the volume of a given amount of gas held at constant pressure is directly proportional to the temperature.
- V is proportional to T or $V / T = C$

Mark distribution

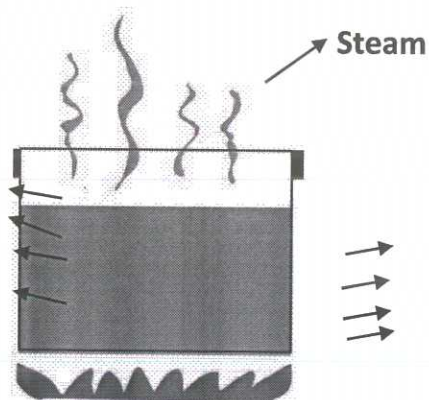
statement :2+2 marks , equation 1 +1

2. With the help of examples explain different systems in thermodynamics



Open systems

- Open systems is one that freely allows energy and matter to be transferred in and out of a system.
- For example boiling water without a lid, Heat escape into the air. At the same time steam (which is matter) also escapes into the air.



Closed System

- A closed system, on the other hand, does not allow the exchange of matter but allows energy to be transferred.
- It allows heat to be transferred from the stove to the water
- Heat is also transferred to the surroundings
- Steam is not allowed to escape
- Example of a closed system – a pressure cooker

Isolated Systems

- This system is completely sealed
- Matter is not allowed to be exchanged with the surroundings
- Heat cannot transfer to the surroundings

Mark distribution = 2+2+2=6

3. Compare SI and CI engine.

S.No.	Spark Ignition Engines (SI)	Compression Ignition Engines (CI)
1	Merits: Otto cycle is employed in petrol engine. Otto cycle is more efficient for a given compression ratio.	Demerits: Diesel engines works on diesel cycle. Diesel cycle is less efficient than Otto cycle for a given compression ratio.
2	Operating speed is more. Speed range is 3000 to 6000 rpm	Operating speed is less. Speed range is 400 to 3500 rpm.
3	Starting is easy, since cranking effort required is less	Starting is difficult since more cranking effort is required.
4	Merits: Initial cost and maintenance cost are less	Demerits: More initial and maintenance costs since the construction is heavy and sturdy.
5	Produces less noise.	Produces more noise.
6	Weight per unit power is less.	Weight per unit power is more.
7	Specific fuel consumption is more.	Specific fuel consumption is less
8	The fuel used is petrol. It is costlier than diesel. It is volatile and fire hazard is more	The fuel used is diesel. It is cheaper than petrol. It is less volatile and fire hazard is less.

Mark : 6 X 1=6

4. Draw valve timing diagram of four stroke petrol engine

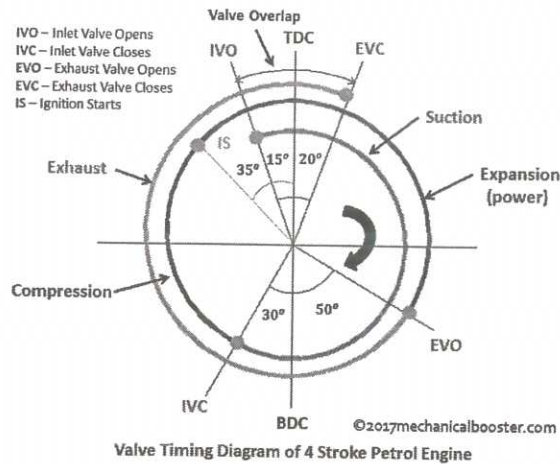


Diagram :2, Indication:2, Angles:2

5. Differentiate between wet steam, Dry steam and super heated steam (mod3)

Unsaturated steam or wet steam

- When we start boiling the water, its temperature goes on increasing till it reaches the boiling point at that pressure. If further heat is added to the water, it converts to steam after absorbing the latent heat of evaporation.
- If the generated steam contains wetness from non-vaporized water molecules that are carried over into the distributed steam. Such steam is called wet steam

Saturated steam or dry steam

- steam does not contain even slightest amount of water droplets, it is called as dry saturated steam

Superheated Steam If saturated steam is further heated, its temperature goes on increasing beyond the boiling point. Such steam, with temperature higher than the boiling point at that pressure is called as superheated steam

Mark: 2+2+2=6

6. Explain with example various mode of heat transfer

Heat flows from higher temperature to lower temperature. Though it looks simple, heat transfer is a quite complex phenomenon. There are three basic modes of heat transfer.

Conduction-

- It is the mode of heat transfer particularly in solids and also for liquid at rest. In this mode of heat transfer, the heat transfers from one atom to its neighboring atom through molecular vibrations.
- At the molecular level, First heat energy of a higher energy level molecule converts to vibrating kinetic energy and this kinetic energy is transferred to neighboring atoms and so on.
- Again process repeats until the temperature difference between two neighboring atoms is zero

Convection:

- This mode of heat transfer particularly occurs in fluids in motion. That is in both liquids and gases that are in motion.
- This mode of heat transfer occurs due to the transfer of energy through the bulk mass.

Radiation:

- In this mode, heat can transfer even through a vacuum. Heat transfer occurs as quantum packets of light energy.
- This is the mode by which we receive solar energy from the sun.

Mark: 2+2+2=6

7. State function of an air compressor, what are the uses of compressed air.

- An air compressor is a machine that uses an electric motor or gas engine to power a device that sucks in successive volumes of air from the atmosphere, compresses (squeezes) each volume of air in a confined place to increase its pressure by making the volume smaller, and then transfers the high-pressure air to a receiver tank

Use of compressed air

1. Operation tools like drill hammers etc.
2. Filling the air in automobile tyres
3. Spray painting
4. Increasing inlet pressure of I.C. engine
5. To operate air motor I mines where fire risk are more
6. Pumping water
7. Gas turbine power plant
8. Conveying the materials like sand and concrete along pipe line
9. For sand blasting
10. Operating blast furnace
11. Operating air brakes used in buses truck trains etc

Mark :6x1=6

UNIT -1

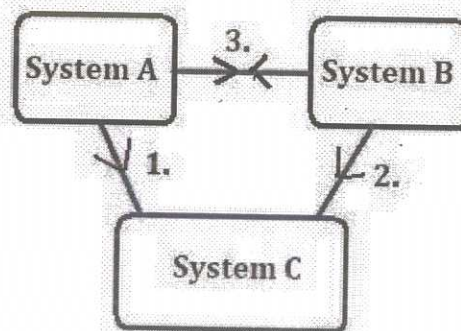
III (a) Explain laws of thermodynamics with the help of neat diagrams

7

zeroth law thermodynamics

6 marks

- The **zeroth law of thermodynamics** states that if two **thermodynamic** systems are each in thermal equilibrium with a third, then they are in thermal equilibrium with each other



- If two systems, A and B, are in thermal equilibrium with a third system, C, then A and B are in thermal equilibrium with each other. It is analogous to the transitive property in math (if $A=C$ and $B=C$, then $A=B$).

First law thermodynamics

- First law of thermodynamics is merely a statement of energy conservation principles
- First law of thermodynamics stated as “ when a system undergoes thermodynamic cycle ,then net heat supplied to the system from surroundings is equal to the net work done by the system on the surroundings ie $\Delta Q=\Delta W$
- If a system undergoes a change of state during which both heat and work transfer are involved ,then net energy transferred stored in the system as internal energy ie $Q=W+\Delta U$

Second law of thermodynamics

2 marks

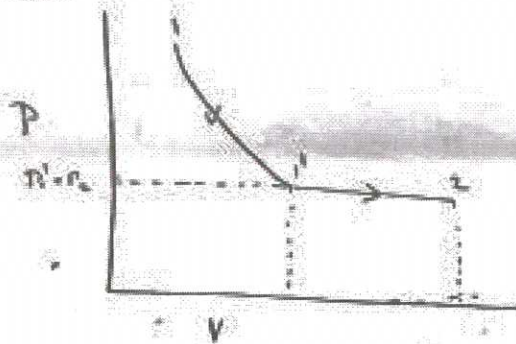
- The second law of thermodynamics states that the total entropy can never decrease over time for an isolated system, that is, a system in which neither energy nor matter can enter nor leave.
- The second law also states that the changes in the entropy in the universe can never be negative

Mark: 3+3+3=9

(b) Derive an expression for characteristic gas equation

6

A relationship between the three properties of pressure, volume and temperature is obtained by combining Boyle's law and Charles law.



- ⇒ Let a given mass 'm' of perfect gas be expanded from 1 to state 2
- ⇒ Let first part of expansion from 1 to 1' be at constant temperature and the second part of expansion is from 1' to 2 at constant pressure.
- ⇒ Consider the first part of ^{expansion 1-1'} Apply Boyle's law

$$P_1 V_1 = P_1' V_1'$$

$$P_1 V_1 = P_2 V_1' \quad [\because P_1' = P_2] \quad \text{--- (1)}$$

⇒ For the second part of expansion 1'-2 to Apply Charles law

$$\frac{V_1'}{T_1'} = \frac{V_2}{T_2}$$

$$\frac{V_1'}{T_1} = \frac{V_2}{T_2} \quad [\because T_1' = T_1]$$

$$V_1' = \frac{T_1}{T_2} \times V_2 \quad \text{--- (2)}$$

Apply value of V_1' in eqn (1).

$$P_1 V_1 = P_2 \times \frac{T_1}{T_2} \times V_2.$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} = \frac{P V}{T} = \text{Constant.}$$

$$\frac{P V}{T} = C$$

$$P V = C \times T$$

This constant depend upon mass of gas and properties of gas,

$$P V = m R T$$

where R is called characteristic gas constant.

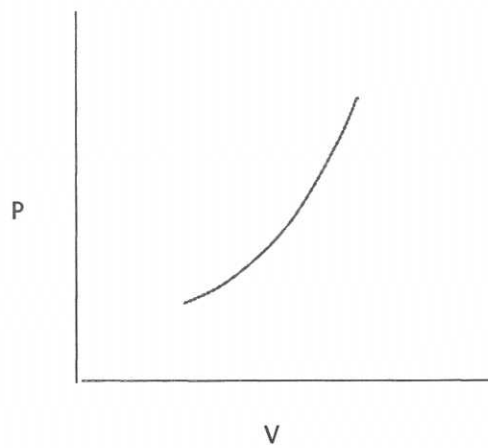
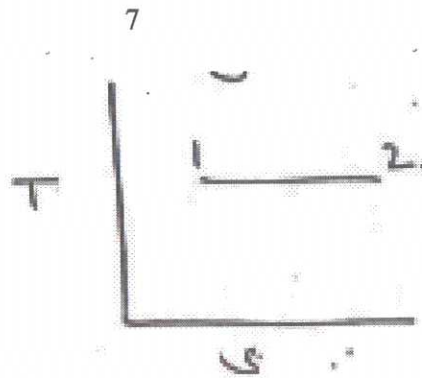
⇒ The equation $P V = m R T$ is known as characteristic gas equation.

Mark distribution Figure :3Derivation :4

OR

IV (a) What is isothermal process?. With help of PV and TS diagram derive an expression for work done during the same

In a thermodynamic process temperature remains constant is known as isothermal process



A thermodynamic process in which temperature remains constant is known as isothermal process.

P.V.T relationship

We know for a perfect gas $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$

For isothermal process $T_1 = T_2$

$$\therefore \boxed{P_1 V_1 = P_2 V_2}$$

Change in internal energy

Change in internal energy during a process is given by

$$\Delta u = m c_v (T_2 - T_1), \text{ but } T_2 = T_1 = T$$

\therefore Since there is no temperature difference $\Delta u = 0$

Work done

\therefore Work done during a thermodynamic process is given by

$$W_{1-2} = \int_1^2 P \, dV \quad \text{--- (1)}$$

but for a isothermal process $P_1 V_1 = P_2 V_2 = P V$

$$\text{or } P = \frac{P_1 V_1}{V}$$

$$\therefore \text{ eqn (1)} \Rightarrow W_{1-2} = \int_1^2 \frac{P_1 V_1}{V} \, dV$$

$$W = P_1 V_1 \int_1^2 \frac{1}{V} dV$$

$$W = P_1 V_1 \ln[V]_1^2$$

$$W = P_1 V_1 [\ln V_2 - \ln V_1]$$

$$\{\ln a - \ln b = \ln\left(\frac{a}{b}\right)\}$$

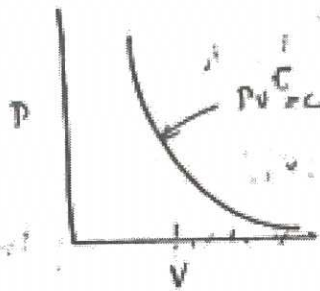
$$W = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$$

$$W = P_1 V_1 \ln\left(\frac{P_2}{P_1}\right)$$

Mark distribution: Figure : 2 mark, Definition : 1 mark, Derivation : 4 marks

(b) Explain with help of PV diagram Explain Adiabatic process. Also write expressions for work done, heat transfer and internal energy during the process

A thermodynamic process in which heat transfer remains constant known as adiabatic process



P.V. T relationship

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

Work done

→ Work done during the process $W_2 = \int P dv$.

But we know that $P_1 V_1^\gamma = P_2 V_2^\gamma = P V^\gamma =$

$$\text{or } P V^\gamma = C$$

$$\therefore P = \frac{C}{V^\gamma}$$

$$\therefore W_2 = \int \frac{C}{V^\gamma} dv$$

$$W_2 = C \int_{V_1}^{V_2} V^{-\gamma} dv$$

$$= C \left[\frac{V^{-\gamma+1}}{-\gamma+1} \right]_{V_1}^{V_2}$$

$$= \frac{C}{1-\gamma} \left[V_2^{1-\gamma} - V_1^{1-\gamma} \right]$$

$$\text{but } C = P_2 V_2^\gamma = P_1 V_1^\gamma$$

$$\therefore W_{12} = \frac{1}{1-\gamma} \left[P_2 V_2^{\gamma} V_2^{1-\gamma} - P_1 V_1^{\gamma} V_1^{1-\gamma} \right]$$

$$\text{or } W_{12} = \frac{1}{1-\gamma} \left[P_2 V_2 - P_1 V_1 \right]$$

$$\text{or } W_{12} = \frac{P_2 V_2 - P_1 V_1}{1-\gamma}$$

$$\text{or } W_{12} = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

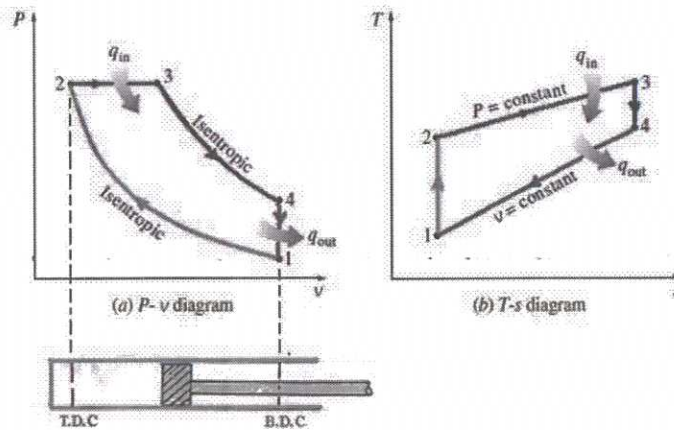
$$\text{or } W_{12} = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

Mark distribution: Figure : 2 mark, Definition : 2 mark, Derivation : 4 marks

UNIT 2

V (a) With the help of PV and TS diagram explain diesel cycle.

7



- The Diesel Cycle is the ideal cycle that closely approximates a compression-ignition IC engine.
- The Diesel Cycle like Otto cycle consists of four reversible processes.
- Initially, the piston is at its lowest position (BDC) and the cylinder is full of air (represented as point 1 on p-v and T-s diagram).

Process 1-2 Isentropic Compression:

- The piston moves from BDC position to TDC position,
- compression of the air occurs isentropically ending at point 2 and thus raising the pressure and temperature of the air (represented as process 1-2 on p-v and T-s diagram).
- This process is taken as adiabatic because the time taken during compression is quite small due to high speed of engines

Process 2-3 Constant-pressure heat addition:

- Heat is added in the compressed air at constant pressure from external reservoir for a short period till condition 3 is reached (represented as process 2-3 on p-v and T-s diagram).

Process 3-4 Isentropic Expansion (power stroke):

- The air at high pressure and temperature expands isentropically causing the piston to move from TDC position to BDC position (represented as process 3-4 on p-v and T-s diagram).
- It is also called power stroke because work is done by the system

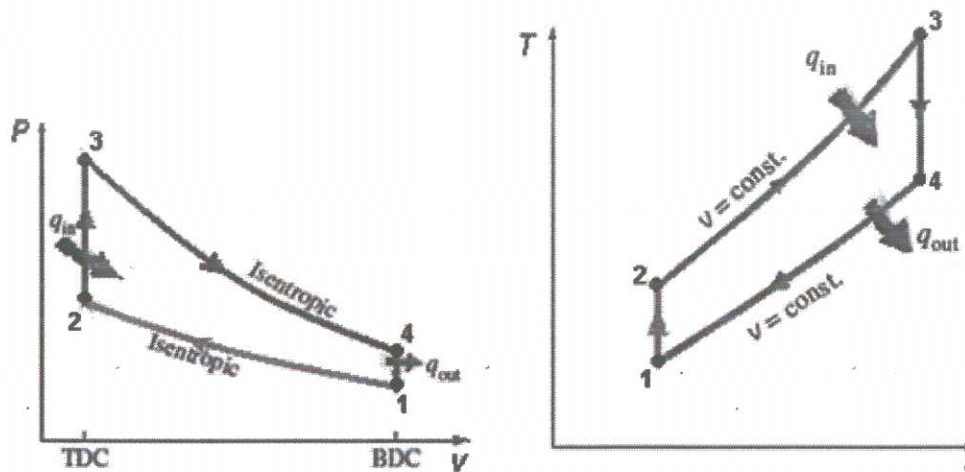
Process 4-1 Constant-volume heat rejection:

- The piston is momentarily at rest at BDC position and heat is rejected instantaneously from the air of cylinder to external reservoir for a short period so that both pressure and temperature decrease at a constant volume to its initial lowest point 1

Mark = Figure : 2 mark , Explanation: 5 marks

(b) Derive an expression for air standard efficiency of otto cycle

8



The air-standard-Otto cycle is the idealized cycle for the spark-ignition internal combustion engines. This cycle is shown above on p-v and T-s diagrams. The Otto cycle 1-2-3-4 consists of following four process:

Process 1-2: Reversible adiabatic compression of air.

Process 2-3: Heat addition at constant volume.

Process 3-4: Reversible adiabatic expansion of air.

Process 4-1: Heat rejection at constant volume.

Air Standard Efficiency:

$$\eta_{th} = \frac{\text{Net workdone}}{\text{Net heat added}}$$

Since processes 1-2 and 3-4 are adiabatic processes, the heat transfer during the cycle takes place only during processes 2-3 and 4-1 respectively. Therefore, thermal efficiency can be written as,

$$\eta_{th} = \frac{\text{Heat added} - \text{Heat rejected}}{\text{Heat added}}$$

Consider 'm' kg of working fluid,

$$\text{Heat added} = mC_V (T_3 - T_2)$$

$$\text{Heat Rejected} = mC_V (T_4 - T_1)$$

$$\eta_{th} = \frac{mC_V (T_3 - T_2) - mC_V (T_4 - T_1)}{mC_V (T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

For the reversible adiabatic processes 3-4 and 1-2, we can write,

$$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{\gamma-1} \quad \text{and} \quad \frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

$$v_2 = v_3 \quad \text{and} \quad v_4 = v_1$$

$$\frac{T_4}{T_3} = \frac{T_1}{T_2} = \frac{T_4 - T_1}{T_3 - T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

$$\eta_{th} = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

The ratio $\frac{V_1}{V_2}$ is called as compression ratio, r .

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

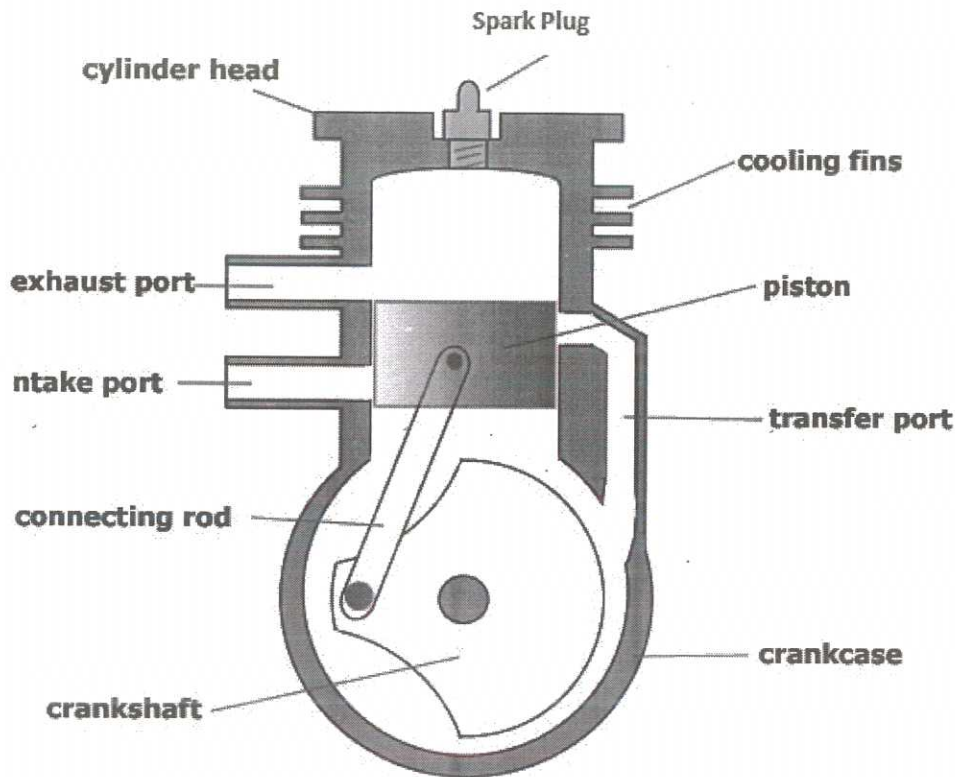
OR

VI (a) Explain working of two stroke petrol engine

9

1st Stroke:

- To start with let us assume the piston to be at its B.D.C. position. The arrangement of the ports is such that the piston performs two jobs simultaneously.
- As the piston starts rising from its B.D.C. position it closes the transfer port and the exhaust port.
- The charge (mixture, of the air and petrol) which is already there in the cylinder, as the result of the previous running of the engine is compressed at the same time with the upward movement of the piston vacuum is created in the crank case (which is gas tight).
- As soon as the inlet port is uncovered; the fresh charge is sucked in the crank case.
- The charging is continued until the crank case and the space in the cylinder beneath the piston is filled with the charge.
- At the end of this stroke, the piston reached the T.D.C. position.



2nd Stroke:

- Slightly before the completion of the compression stroke, the compressed charge is ignited by means of a spark produced at the spark plug.
- Pressure is exerted on the piston due to the combustion of the charge is pushed in the downward direction producing some useful power. The downward movement of the will first close the inlet port and then it will compress the charge already sucked in the crank case.
- Just the end of power stroke, the piston uncovered the exhaust port and the transfer port simultaneously the expanded gases start escaping through the exhaust port and the same time the fresh charge which is already compressed in the crank case, rushed into the cylinder through the transfer port and thus the cycle is repeated again.
- The fresh charge coming into the cylinder also helps in exhausting the burnt gases out of the cylinder through the exhaust port. This is known as scavenging.
- **MARK= Figure 4 marks , explanation 5 marks**

- (b) Calculate the air standard efficiency of an engine working on otto cycle if the pressure at the beginning and end of compression are 1 bar and 7 bar respectively. Take γ as 1.4 (Pa201)

Solution: Given

Pressure at the beginning of compression,

$$p_1 = 1 \text{ bar} = 1 \times 10^2 \text{ kN/m}^2$$

Pressure at the end of compression,

$$p_2 = 7 \text{ bar} = 7 \times 10^2 \text{ kN/m}^2$$

Adiabatic index, $\gamma = 1.41$

Considering the adiabatic compression process 1-2

$$p_1 V_1^\gamma = p_2 V_2^\gamma \quad \text{or} \quad \frac{p_2}{p_1} = \left(\frac{V_1}{V_2} \right)^\gamma = r^\gamma$$

$$\therefore \text{Compression ratio, } r = \left(\frac{p_2}{p_1} \right)^{\frac{1}{\gamma}} = \left(\frac{7 \times 10^2}{1 \times 10^2} \right)^{\frac{1}{1.41}} = 3.975$$

$$\text{Air standard efficiency, } \eta_{\text{otto}} = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{(3.975)^{1.41-1}}$$

$$= 0.4321 = 43.21 \% \quad (\text{Ans})$$

6

UNIT 3

VII (a). Explain Morse test of multi cylinder petrol engine

- During the test the engine is run at a constant speed and at same throttle opening.
- First the b.p. of the engine with all cylinders operative is measured by means of dynamometer.
- Next, the b.p. of the engine is measured with each cylinder rendered inoperative one by one by shorting the spark plug in case of petrol engine or by cutting off the fuel supply in case of diesel engine.
- When any cylinder is rendered inoperative, the speed abruptly goes down. Before taking any reading, the initial speed must be restored by adjusting the load.
- It is assumed that the f.p. of the inoperative cylinder remains the same as it were when the cylinder was operative.

- Considering the case of a 4-cylinder engine

Let, B = b.p. of the engine with all cylinders operative

B_1 = b.p. of the engine with cylinder no. 1 inoperative

B_2 = b.p. of the engine with cylinder no. 2 inoperative

B_3 = b.p. of the engine with cylinder no. 3 inoperative

B_4 = b.p. of the engine with cylinder no. 4 inoperative

I_1, I_2, I_3 and I_4 = i.p. of cylinders 1, 2, 3 and 4 respectively.

F_1, F_2, F_3 and F_4 = f.p. of cylinders 1, 2, 3 and 4 respectively.

Therefore,
$$B = (I_1 - F_1) + (I_2 - F_2) + (I_3 - F_3) + (I_4 - F_4)$$

$$= (I_1 + I_2 + I_3 + I_4) - (F_1 + F_2 + F_3 + F_4)$$

- When cylinder No.1 is rendered inoperative, it does not develop any power; on the contrary

$$B_1 = (I_2 + I_3 + I_4) - (F_1 + F_2 + F_3 + F_4)$$

- Some power is lost due to movement of piston inside the cylinder. Then,

From the above equations, $B - B_1 = I_1$

Similarly, $B - B_2 = I_2$

$$B - B_3 = I_3$$

and $B - B_4 = I_4$

Therefore, total i.p. of the engine = $I_1 + I_2 + I_3 + I_4 = I$ (say)
and mechanical efficiency = B/I .

- (b). Define (1) Mechanical efficiency (2) brake thermal Thermal efficeinecy (3) Relative efficiency
(4) Specific fuel consumption (5) Indicated power (6) Brake power (7) Frictional power (8) volumetric efficiency

8

Mechanical efficiency

It is the ratio of brake power to indicated power

$$\eta_m = \frac{BP}{IP}$$

Indicated thermal efficiency

- It is defined as amount thermal energy required to develop 1 KW of Indicated power in one hour
- Mathematically it is the ratio of IP to Heat in fuel per BP in one hour

$$\eta_{bte} = \frac{IP \times 3600}{mf \times C}$$

- Where mf = mass of fuel consumed in kg per hour
 C = Calorific value of the fuel in J/Kg

Brake thermal efficiency

- It is defined as amount thermal energy required to develop 1 KW of brake power in one hour
- Mathematically it is the ratio of BP to Heat in fuel per BP in one hour
- $\eta_{bte} = \frac{BP \times 3600}{mf \times C}$
- Where mf = mass of fuel consumed in kg per hour
 C = Calorific value of the fuel in J/Kg

Overall efficiency

- It is the ratio of work obtained at the crank shaft in given time to the energy supplied by the fuel during same time
- Mathematically it is $\eta_o = \frac{BP \times 3600}{mf \times C}$

Relative efficiency

- It is the ratio of indicated thermal efficiency to air standard efficiency
- Mathematically $\eta_r = \frac{\text{Indicated thermal efficiency}}{\text{Air standard efficiency}}$

Volumetric efficiency It is the ratio of actual volume of charge admitted during suction stroke at NTP to swept volume of piston

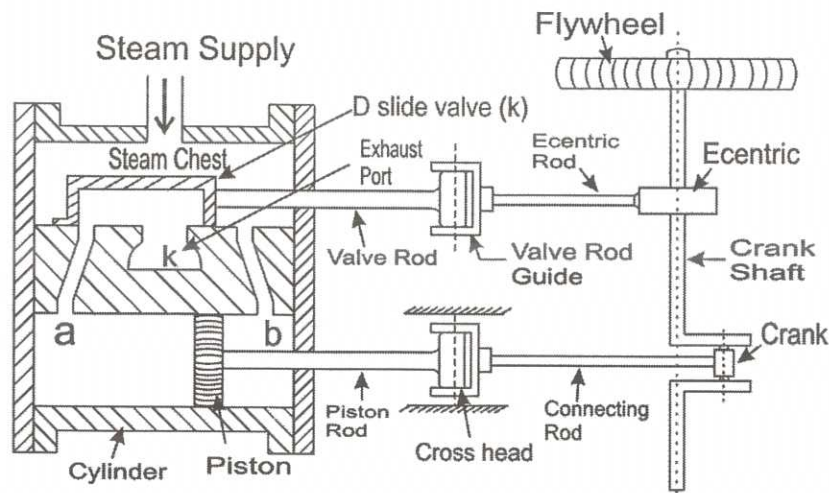
- Mathematically $\eta_v = \frac{\text{volume of charge admitted}}{\text{swept volume of piston}}$

MARK DISTRIBUTION : 8 X 1=8

OR

VIII(a).With the help of neat diagram explain working of double acting steam engine

Steam engine is a device which converts heat energy into mechanical energy and heat is supplied into the engine through the medium of steam.



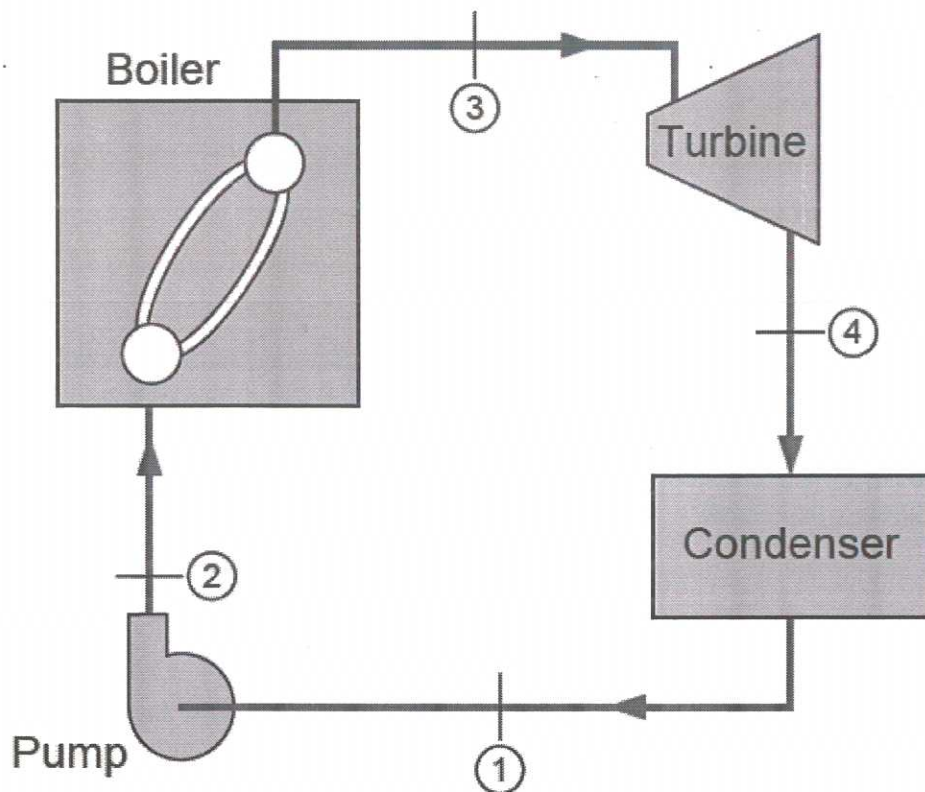
- In a *steam engine*, high-pressure superheated steam from boiler is fed into the steam chest.
- Here a D-shaped valve V, called D-slide valve, moves to and fro in a steam chest and this valve regulates the supply of steam into the engine cylinder is operated by a mechanism E, called eccentric which is situated on the crankshaft.
- There are two different ports A and B in which steam is led into the cylinder on the two sides of the piston and K is the exhaust port in which steam is led out of the cylinder.
- When D slide valve moves to the right, steam from steam chest enters from the left side through port A.
- This high-pressure steam pushes the piston to the right side of the crank end. This is called the forward stroke of the piston.
- With the movement of piston, crosshead moves to the right thus pushing the connecting rod which also pushes the crank to the right side.
- Now the crank and crankshaft both rotate in clockwise direction, show in the picture.
- When piston is in extremely right side or nearer to crank end cover, the V valve is moving towards the left direction and open the steam port B in which steam is entering into the cylinder through this port. So, the piston is now moving left side direction or away from the crank. This is called the returned stroke of the piston
- This process is continuously running and as such the steam engine works.

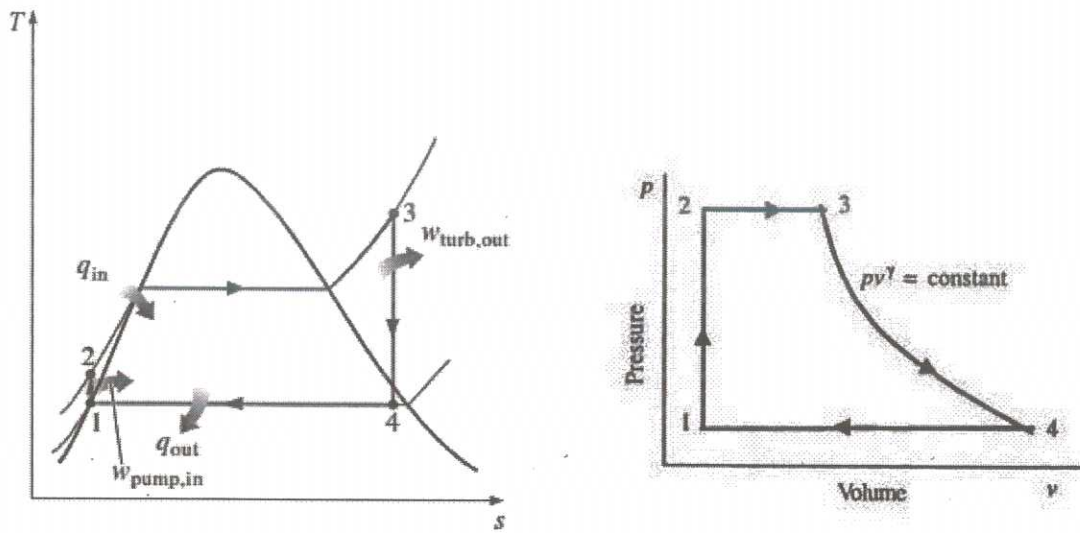
MARK DISTRIBUTION: FIGURE -4 marks , Explanation 3 marks

(b) Draw the line diagram of Rankine cycle. Explain each process in the cycle using PV and TS diagrams.

The various processes in simple Rankine cycle are:

- 1–2: Reversible adiabatic pumping process in the pump,
- 2–3: Constant-pressure transfer of heat in the boiler,
- 3–4: Reversible adiabatic expansion in the turbine
- 4–1: Constant-pressure transfer of heat in the condenser.





The four basic components of Rankine cycle are shown in figure 1 each component in the cycle is regarded as control volume, operating at steady state.

Pump: The liquid condensate leaving the condenser at the state 1 is pumped to the operating pressure of the boiler. The pump operation is considered isentropic.

Boiler: The heat is supplied in the working fluid (feed water) in the boiler and thus vapor is generated. The vapor leaving the boiler is either at saturated at the state 3 or superheated at the state 3^{||}, depending upon the amount of heat supplied by the boiler.

Turbine: The vapor leaving the boiler enters the turbine, where it expands isentropically to the condenser pressure at the state 4. The work produced by the turbine is rotary (shaft) work and is used to drive an electric generator or machine.

Condenser: The condenser is attached at the exit of the turbine. The vapor leaving the turbine is wet vapor and it is condensed completely in the condenser to the state 1, by giving its latest heat to some other cooling fluid like water.

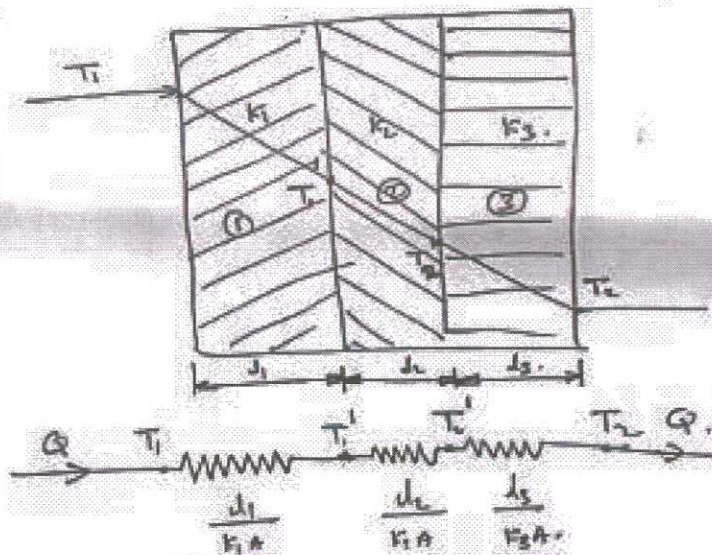
MARK DISTRIBUTION: FIGURE -4 marks , Explanation 4 marks

IX (a). State Fourier law of heat conduction. Also derive an expression to find heat conduction taking place through a composite wall. 10

- Fourier's law states that the time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area."

$$Q = -kA(dT/dx)$$

- Where,
- 'Q' is the heat flow rate by conduction (W)
- 'k' is the thermal conductivity of body material ($W \cdot m^{-1} \cdot K^{-1}$)
- 'A' is the cross-sectional area normal to direction of heat flow (m^2) and
- 'dT/dx' is the temperature gradient ($K \cdot m^{-1}$).



- = Consider heat conduction through a composite wall consisting of three layers of materials 1, 2, and 3 having thickness d_1 , d_2 , and d_3 and thermal conductivity of k_1 , k_2 , and k_3 .
- = The boundary temperatures of each layer as shown in figure.

⇒ The area of heat conduction A is constant, therefore the rates of heat flow at steady state through individual layers are equal ($Q_1 = Q_2 = Q_3 = Q$)

⇒ Under steady conditions, the rate of heat flow through the walls given as Fourier's law.

$$\text{layer 1} \quad Q = k_1 A \left(\frac{T_1 - T_1'}{d_1} \right)$$

$$\text{or } T_1 - T_1' = Q \frac{d_1}{k_1 A}$$

$$T_1 - T_1' = Q R_1 \quad \text{--- (1) } \quad \left[\because R_1 = \frac{d_1}{k_1 A} = \text{Thermal resistance} \right]$$

$$\text{layer 2} \quad Q = k_2 A \left(\frac{T_1' - T_2'}{d_2} \right)$$

$$\text{or } T_1' - T_2' = Q \frac{d_2}{k_2 A}$$

$$\text{or } T_1' - T_2' = Q R_2 \quad \text{--- (2) } \quad \left[\because R_2 = \frac{d_2}{k_2 A} \right]$$

$$\text{layer 3} \quad Q = k_3 A \left(\frac{T_2' - T_2}{d_3} \right)$$

$$\text{or } T_2' - T_2 = Q \frac{d_3}{k_3 A}$$

$$\text{or } T_2' - T_2 = Q R_3 \quad \text{--- (3)}$$

$$\text{(1) + (2) + (3) } \Rightarrow$$

$$T_1 - T_1' + T_1' - T_2' + T_2' - T_2 = Q R_1 + Q R_2 + Q R_3$$

$$\text{or } T_1 - T_2 = Q (R_1 + R_2 + R_3)$$

$$Q = \frac{T_1 - T_2}{R_1 + R_2 + R_3}$$

$$Q = \frac{T_1 - T_2}{\frac{d_1}{k_1 A} + \frac{d_2}{k_2 A} + \frac{d_3}{k_3 A}}$$

(b). Thermal radiation strikes a surface which has reflectivity of 0.55 and a transmissivity of 0.032. The absorbed flux as measured indirectly by heating effect works out to be 95 W/m². Determine rate of incident flux 5

Solution : Given

$$\text{Reflectivity, } \rho = 0.55$$

$$\text{Transmissivity, } \tau = 0.032$$

$$\text{Absorbed flux, } Q_a = 95 \text{ W/m}^2$$

From the law of conservation of energy.

$$\alpha + \rho + \tau = 1$$

$$\alpha + 0.55 + 0.032 = 1$$

$$\alpha = 1 - 0.55 - 0.032 = 0.418$$

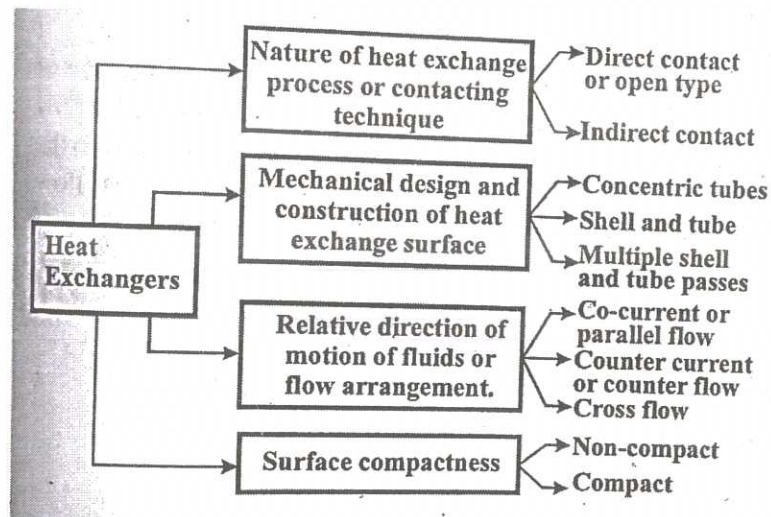
$$\text{Absorptivity, } \alpha = \frac{Q_a}{Q_i}$$

$$\therefore \text{Rate of incident flux, } Q_i = \frac{Q_a}{\alpha} = \frac{95}{0.418} = 227.2727 \text{ W/m}^2$$

OR

X (a) What is heat exchanger . How it is classified , explain With suitable sketches classification based on flow direction.

A heat exchanger is a device used to transfer heat between two or more fluids. The fluids can be single or two phase and, depending on the exchanger type, may be separated or in direct contact



Direct contact

- A heat exchanger in which fluid exchange heat by coming in to direct contact is called a direct contact or open heat exchanger
- Eg. Cooling tower

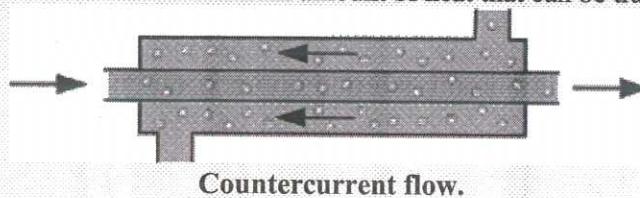
Indirect contact

- Heat exchanger in which hot and cold fluid flow simultaneously on either of separating wall known as indirect heat exchanger or recuperators
- Since fluids are separated by a wall, hence it can not be allowed to mix the fluid by direct contact
- Eg. Radiator

2. Classification of Heat Exchangers by Flow Configuration

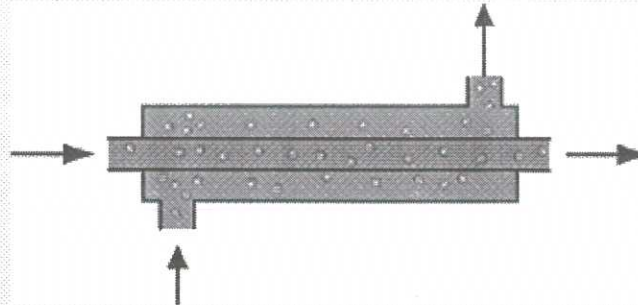
Counter flow heat exchanger

- In counterflow exchanger in which the two fluids flow parallel to each other but in opposite directions. This type of flow arrangement allows the largest change in temperature of both fluids and is therefore most efficient (where efficiency is the amount of actual heat transferred compared with the theoretical maximum amount of heat that can be transferred).



Parallel Flow heat exchanger

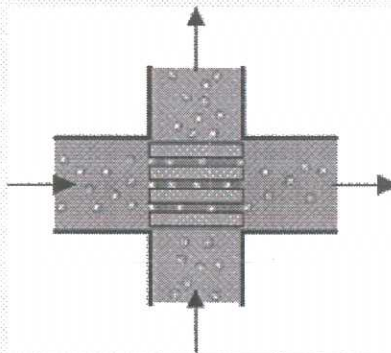
- In Parallel flow heat exchangers, the streams flow parallel to each other and in the same direction as shown in figure. This is less efficient than countercurrent flow but does provide more uniform wall temperatures.



Parallel flow.

Crossflow heat exchangers

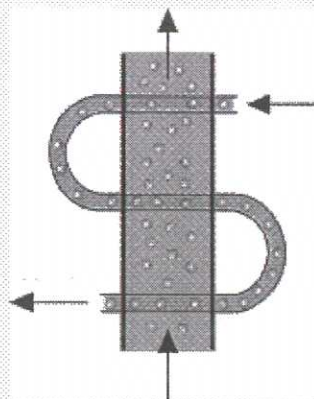
- Crossflow heat exchangers are intermediate in efficiency between countercurrent flow and parallel flow exchangers. In these units, the streams flow at right angles to each other as shown in Fig



Crossflow.

Hybrid heat exchanger

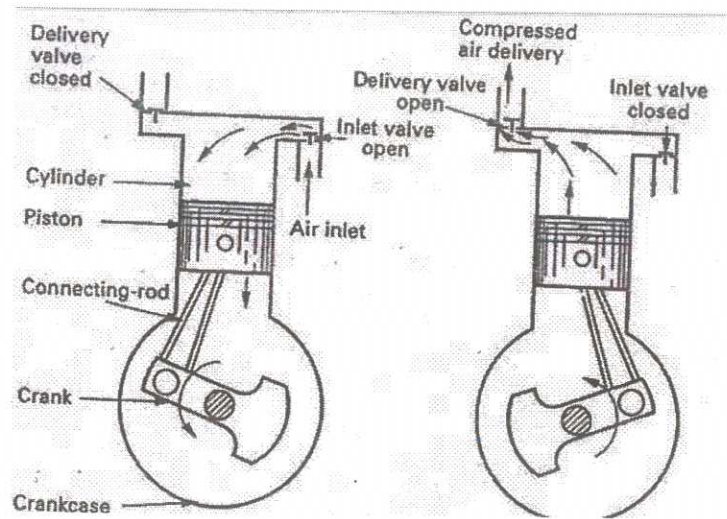
- In industrial heat exchangers, hybrids of the above flow types are often found. Examples of these are combined crossflow/countercurrent heat exchangers and multi pass flow heat exchangers. (See for example Figure 4.)



Hybrid flow.

Mark distribution: 1+3+4

(b) With help diagram explain working of single stage reciprocating air compressor 7



It works on the two-stroke cycle, as the piston descends on the suction stroke, the internal pressure falls until it is lower than that in the suction inlet pipe. And the suction valve opens to admit air from atmosphere. At the bottom of the stroke, this valve closes again and the compression stroke begins. When the cylinder pressure is higher than that in the discharge pipe, the discharge valve opens and the compressed air passes to the air bottle. Clearance air left at the top of the stroke must re-expand before a fresh charge can enter the cylinder.

Mark: Figure 3, Explanation 3

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