SCHEME OF VALUATION

(Scoring Indicators)

Revision : 2015 **Course Code :** 4024

Course Title : THERMAL ENGINEERING

Qst. No	Scoring Indicator	Split up score	Sub Total	Total
	PART – A			
I (1)	**Define a system.** **ANS:** A system is defined as an enclosed space which has been selected for the purpose of analysis, observation and inference.	2	2	2
I (2)	**Explain Boyle's law.** **ANS:** It states that the absolute pressure of a perfect gas varies inversely as its volume when the temperature remains constant. Ie PV = const	2	2	2
I (3)	**Define air standard efficiency of a cycle.** **ANS:** Thermal efficiency of a cycle is defined as the ratio of the workdone to the heat supplied during the cycle. The thermal efficiency obtained with air as the working fluid is known as air standard efficiency.	2	2	2
I (4)	**Define indicated power.** **ANS:** It is the actual power developed inside an engine cylinder during its operation.	2	2	2
I (5)	**Define thermal conductivity** **ANS:** It is the amount of energy conducted through a body of unit area, and unit thickness when the temperature difference is unity.	2	2	2

PART – B

II (1) **State the Clausius and Kelvin-Planck statements of second law of thermodynamics?**

ANS:

Kelvin-Planck statement

It is impossible to construct an engine which operating in a cycle will produce no effect other than the exchange of heat from a single reservoir and produce an equal amount of work. 1

In other words, no actual heat engine working on a cyclic process can convert the whole of the heat supplied to it into mechanical work.

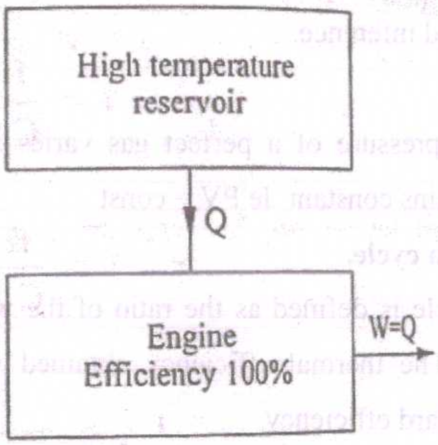


Fig- 1

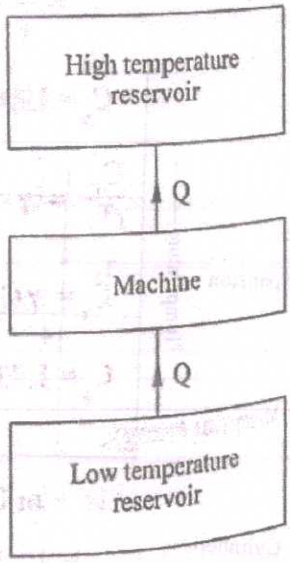
Impossible engine
Kelvin-Planck statement

It means that a part of the heat supplied to the heat engine must be rejected to the surroundings and only the remaining part is converted into work. Hence, the work done by a heat engine will be equal to the difference between heat supplied and heat rejected. 1

Clausius statement

'It is impossible for a self-acting machine working in a cyclic process, to transfer heat from a body at a lower temperature to a body at a higher temperature, without the aid of an external agency'.

In other words, heat cannot flow by itself from a cold body to a hot body without receiving external work. 2



Impossible machine-Clausius statement

Fig-1 | 6 | 6

II (2) **Classify thermodynamic system with example.**

ANS: Thermodynamic system is classified into three

1) Open system
2) Closed system
3) Isolated system

1) Open system

A system in which there is mass transfers as well as energy transfer across the boundary. 2

Eg:-water flowing in a pipe line, steam turbines etc.

2) Closed system

A system in which there is no mass transfers but only energy transfers across the boundary. 2

Eg:- Sun, human body etc.

3) Isolated system

A system in which there is no mass transfer as well as energy transfer across the boundary. 2 | 6 | 6

Eg:- Coffee in a thermo flask, universe etc.

II (3) **Illustrate Carnot cycle with P-V and T-S diagrams**

ANS:

It is a thermodynamic air cycle consisting of four processes. Heat is supplied and rejected isothermally, expansion and compression of air takes place adiabatically.

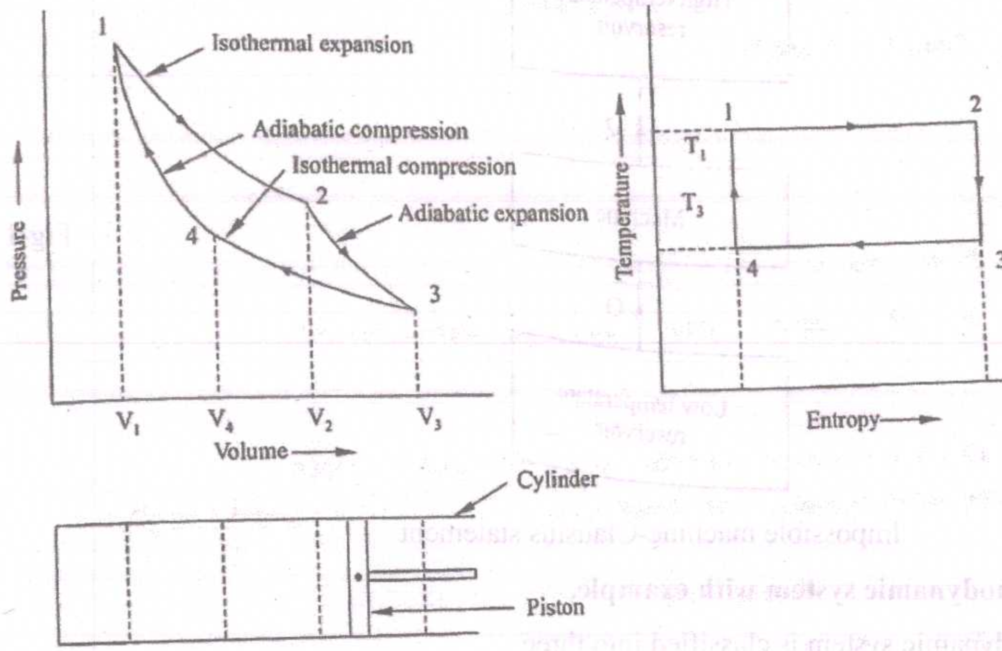


Fig-3

Consider a given mass of air in the cylinder, inside which a friction less piston slides. Let the pressure, volume and temperature of air at state 1 be p_1, V_1 and T_1 respectively. Heat ¡s supplied to this air isothermally from an external hot body. The air expands at temperature T_1 till the state 2 is reached. This process is represented by curve 1-2 in the p-V diagram and a horizontal line 1-2 in the T-S diagram. During this process heat is absorbed from hot body and an equal amount of work is done by the air. At state 2, the source of heat is removed and the air is allowed to expand adiabatically till state 3. This is represented by curve 2-3 in the p-V diagram and a vertical line 2-3 in the T-S diagram.

Let the pressure, volume and temperature of the air at state 3 be p_3, V_3 and T_3 respectively. During the process 2-3 work is done by the air utilising its internal energy. At state 3, an external cold body is brought in contact with the cylinder and heat is rejected isothermally to the cold body at constant temperature T_3. This isothermal compression is represented by the curve 3-4 in the p-V diagram and a horizontal line 3-4 in the T-S diagram. During this process work is done on the air and an equal amount of heat is rejected to the cold body. At state 4, the cold body is removed and the air is compressed adiabatically to the initial state 1. In the p-V diagram this adiabatic compression process is represented by curve 4-1 and in the T-S diagram by a vertical line 4-l. During this process work is done on the air to bring it to the original state.

3 6 6

II (4)	**Define the terms i) Mechanical efficiency ii) Indicated thermal efficiency ii) Relative efficiency.** **ANS** **i)Mechanical efficiency** It is defined as the ratio of brake power to indicated power. Mechanical efficiency, $\eta_m = \frac{Brake\ Power}{Indicated\ Power} = \frac{BP}{IP}$	2		
	ii) Indicated thermal efficiency It is the ratio of heat equivalent of IP per second to heat supplied by fuel per second. Indicated thermal efficiency, $\eta_i = \frac{Heat\ equivalent\ of\ IP\ per\ sec}{Heat\ supplied\ by\ fuel\ per\ sec} = \frac{IP}{FC\ x\ Cf}$ Where, FC = Fuel consumption or mass or volume of fuel burnt/sec C_f = Calorific value of fuel in kJ/kg or kJ/m^3	2		
	iii) Relative efficiency It is defined as the ratio of indicated thermal efficiency to the theoretical or ideal or air standard efficiency. $\eta_R = \frac{Indicated\ thermal\ efficiency}{Air\ standard\ efficiency} = \frac{\eta i}{\eta air}$	2	6	6
II (5)	**List any six uses of steam.** 1. For power generation as in case of steam engines or turbines. 2. For heating as in case of heating installations for buildings. 3. For industrial process work in chemical engineering, sugar and textile industry. 4. For producing hot water required to be supplied in very cold areas. 5. For the operation of power hammers, pile driving machines, hoisting rigs. 6. For the operation of locomotives and ships.	6x1	6	6
II (6)	**Explain with example various modes of transmission of heat.** Modes of heat transfer 1) Conduction 2) Convection 3) Radiation **Conduction** It is the only mode of heat transfer in a solid medium. It is an atomic or molecular process. In this, heat is transferred from particle to particle without the	2		

	movement of particles. Eg:- heat loss from furnaces, hot pipes etc. **Convection** In this transfer of heat energy by the flow of fluid elements or liquid or gas from one point to another which is at a different temperatures. In this heat is transferred from particle to particle with the movement of particle. Eg:- water tube boiler, radiator of car etc.	2		
	Radiation In this heat is transferred in the form of electromagnetic waves. Heat transfer due to radiation takes place from one body to another directly without affecting the medium through which heat travels, like the throw of an object.	2	6	6
II (7)	**State any six uses of compressed air** 1. To run compressed air engines 2. To operate pneumatic brakes for automobiles 3. For providing air blast for blast furnace. 4. For pumping water from deep well (air lift pump). 5. For spray painting works. 6. For boosting (or) supercharging of IC engines. 7. To drive pneumatic tools such as concrete breaking, rock drilling, chipping etc. 8. For spraying fuel into the combustion chamber of diesel engine (air blast injection).	Any 6 points 6x1	6	6
III (a)	**PART – C** **Derive the characteristic equation of a perfect gas.** A relationship between the three properties pressure, volume and temperature of a perfect gas is obtained by combining Boyle's law and Charles law. Let a given mass m of a perfect gas be expanded from state 1 to state 2. Let first part of expansion, ¡e., from 1 to 11 be at constant temperature and the second part of expansion ie. From 11 to 2 be at constant pressure as shown in fig. For the first part of expansion:			

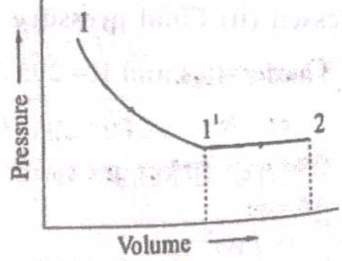


Fig. 1.12

Fig-2

applying Boyle's law,

$$p_1V_1 = p'_1\,V'_1$$

$$p_1V_1 = p_2\,V'_1 \qquad [\Theta\ p'_1 = p_2]$$ 1

For the second part of expansion at constant pressure, applying Charles law,

$$\frac{V'_1}{T'_1} = \frac{V_2}{T_2}$$

$$\frac{V'_1}{T_1} = \frac{V_2}{T_2} \qquad [\Theta\ T'_1 = T_1]$$ 1

$$V'_1 = \frac{V_2}{T_2} \times T_1$$

Substituting this value of V'_1 in the expression,

$$p_1V_1 = p_2\,V'_1$$

$$p_1V_1 = p_2 \times \frac{V_2}{T_2} \times T_1$$

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} = \frac{pV}{T} = \text{Constant}$$ 2

$$\frac{pV}{T} = \text{Constant}$$

i.e., $V = \text{Constant} \times \frac{T}{p}$. This constant depends upon the mass of gas, properties of gas and temperature scale.

$V = mR \times \frac{T}{p}$ where R is a constant, the value of which depends upon the properties of gas and the temperature scale. This constant R is called characteristic gas constant. The equation $pV = mRT$ is called characteristic gas equation or equation of state of a perfect gas. 1 7 7

III (b)	**0.2 m^3 of gas at 1 bar and 100^{0}C is compressed adiabatically to 0.05 m^3. Determine (i) The mass of gas compressed (ii) Final pressure and temperature of gas (iii) Increase in internal energy. Take γ =1.4 and R= 295 J/kgK.** Given:- $V_1 = 0.2 m^3$ | $\gamma = 1.4$ $V_2 = 0.05 m^3$ | $R = 295\ J/kgK$ $P_1 = 1 bar = 1\times10^5\ N/m^2$ $T_1 = 100°C = 100+273 = 373K$ $m=?,\ P_2=?,\ T_2=?,\ \Delta U=?$	1		
	(i) $P_1V_1 = mRT_1$ $m = \frac{P_1V_1}{RT_1} = \frac{1\times10^5\times0.2}{295\times373}$ $m = \underline{\underline{0.1817}}\ kg$	2		
	(ii) $P_1V_1^\gamma = P_2V_2^\gamma$ $P_2 = \frac{P_1V_1^\gamma}{V_2^\gamma} = \frac{1\times10^5\times(0.2)^{1.4}}{(0.05)^{1.4}}$ $= \underline{\underline{696440.4}}\ N/m^2$ $= \underline{\underline{6.9\ bar}}$ Also, $\frac{V_2}{V_1} = \left(\frac{T_1}{T_2}\right)^{1/\gamma-1}$ $\frac{0.05}{0.2} = \left(\frac{373}{T_2}\right)^{\frac{1}{1.4-1}}$ $0.25 = \left(\frac{373}{T_2}\right)^{2.5}$ $(0.25)^{1/2.5} = \left(\frac{373}{T_2}\right)$ $0.57 = \frac{373}{T_2}$ $T_2 = \frac{373}{0.57} = 654.38\ K$ $= 654.38 - 273$ $T_2 = \underline{\underline{381.38\ °C}}$	3 (1½x2)		
	(iii) $\Delta U = \frac{mR(T_2-T_1)}{\gamma-1}$ $= \frac{0.1817\times295(654.38-373)}{1.4-1}$ $= 37705.97\ J$ $= \underline{\underline{37.7\ kJ}}$	2	8	8

IV (a) **Derive the expression for workdone during isothermal expansion process.**

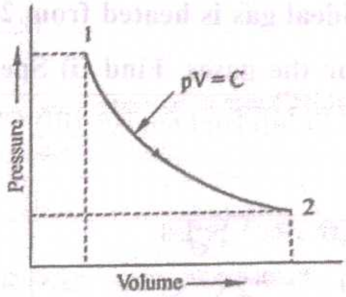


Fig-1

Work done

$${}_1W_2 = \int_{V_1}^{V_2} p\,dV \ldots\ldots\ldots\ldots(i)$$ 1

For an isothermal process, $pV = p_1V_1 = p_2V_2 = \text{Constant}$

or $$p = \frac{p_1V_1}{V}$$ 1

Substituting this value of 'p' in eq. (i)

$${}_1W_2 = \int_{V_1}^{V_2} \frac{p_1V_1}{V}\,dV$$

$$= p_1V_1 \int_{V_1}^{V_2} \frac{dV}{V}$$

$$= p_1V_1 \left[\ln V\right]_{V_1}^{V_2}$$

$$= p_1V_1 (\ln V_2 - \ln V_1)$$

$${}_1W_2 = p_1V_1 \ln\left\{\frac{V_2}{V_1}\right\}$$ 2

Also for an isothermal process

$$p_1V_1 = p_2V_2$$

$$\therefore \frac{V_2}{V_1} = \frac{p_1}{p_2}$$

Substituting this,

$${}_1W_2 = p_1V_1 \ln\left\{\frac{p_1}{p_2}\right\}$$ 2 | 7 | 7

IV (b)	**1kg of an ideal gas is heated from 20^0 C to 100^0 C assuming, R=264 J/kgK and γ = 1.18 for the gases. Find (i) Specific heat at constant pressure and volume (ii) Change in internal energy (iii) Change in enthalpy.**			
	Given: $m = 1kg$, $T_1 = 20°c = 293K$, $T_2 = 100°c = 373K$, $R = 264 J/kgK$, $\gamma = 1.18$	1		
	i) $C_p = \frac{\gamma R}{\gamma - 1} = \frac{1.18 \times 264}{(1.18-1)}$, $C_p = 1730.6 J/kgK$; $C_v = \frac{R}{\gamma-1} = \frac{264}{(1.18-1)}$, $C_v = 1466.6 J/kgK$	3 (½×2)		
	ii) $\Delta U = m C_v (T_2 - T_1) = 1 \times 1466.6 (373-293) = 117,328 J = 117.33 kJ$	2		
	iii) $\Delta H = m C_p (T_2 - T_1) = 1 \times 1730.6 (373-293) = 138,448 J = 138.44 kJ$	2	8	8
V (a)	**Derive the expression for air standard efficiency of Otto cycle.** Otto cycle is the theoretical cycle of spark ignition engine. Air standard Otto cycle consists of four reversible processes. Heat is supplied and rejected at constant volume. Expansion and compression of air takes place adiabatically. Fig. shows these processes on p-V and T-S diagrams.			

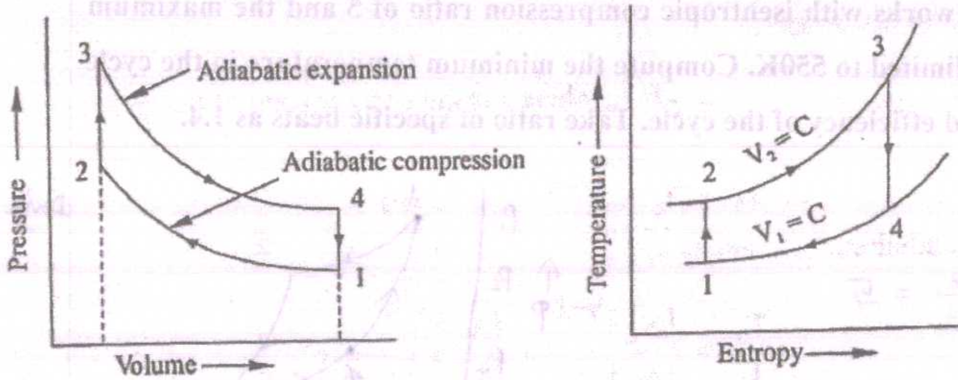


Fig-2

Heat supplied during constant volume process, 2 - 3 = $m\,C_v(T_3 - T_2)$

Heat rejected during constant volume process, 4 - 1 = $m\,C_v(T_4 - T_1)$

Air standard efficiency,

$$\eta = 1 - \frac{\text{Heat rejected}}{\text{Heat supplied}}$$

$$\eta = 1 - \frac{\text{Heat rejected}}{\text{Heat supplied}}$$ 1

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

$$= 1 - \left\{\frac{T_4 - T_1}{T_3 - T_2}\right\} \text{..............(i)}$$ 1

For the adiabatic process 1-2,

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

$$= r^{\gamma-1}, \text{ where r is the compression ratio, } \frac{V_1}{V_2}$$

$$\therefore T_2 = T_1 \times r^{\gamma-1} \text{..............(ii)}$$ 1

For the adiabatic process 3- 4,

$$\frac{T_3}{T_4} = \left\{\frac{V_4}{V_3}\right\}^{\gamma-1} = \left\{\frac{V_1}{V_2}\right\}^{\gamma-1} = r^{\gamma-1}$$

$$\therefore T_3 = T_4 \times r^{\gamma-1} \text{............(iii)}$$ 1

Substituting equations (ii) and (iii) in the expression for efficiency, equation (i),

$$\eta = 1 - \frac{(T_4 - T_1)}{T_4 r^{\gamma-1} - T_1 r^{\gamma-1}}$$

$$= 1 - \frac{(T_4 - T_1)}{(T_4 - T_1) r^{\gamma-1}}$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$ 1 7 7

V (b) **A Carnot cycle works with isentropic compression ratio of 5 and the maximum temperature is limited to 550K. Compute the minimum temperature in the cycle and air standard efficiency of the cycle. Take ratio of specific heats as 1.4.**

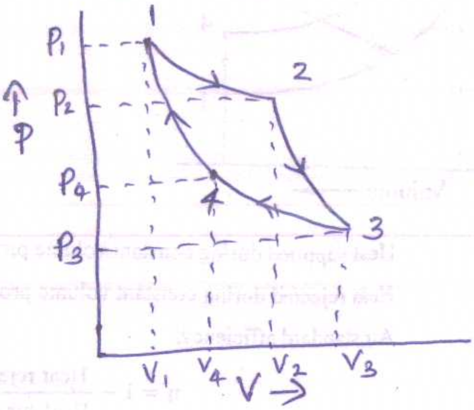
Given :-

$$\frac{V_4}{V_1} = \frac{V_3}{V_2} = 5$$

$T_1 = T_2 = 550\,K$

T_3 or $T_4 = ?$

$\gamma = 1.4$



Data — 1

Fig-2

For the process 4-1

$$\frac{V_1}{V_4} = \left(\frac{T_4}{T_1}\right)^{\frac{1}{\gamma-1}}$$

$$\frac{T_4}{T_1} = \left(\frac{V_1}{V_4}\right)^{\gamma-1}$$

$$\frac{T_4}{T_1} = \left(\frac{1}{5}\right)^{1.4-1}$$

2

$$\frac{T_4}{550} = 0.525$$

$$T_4 = 0.525 \times 550$$

$$= \underline{\underline{288.75\,K}}$$

3 | 8 | 8

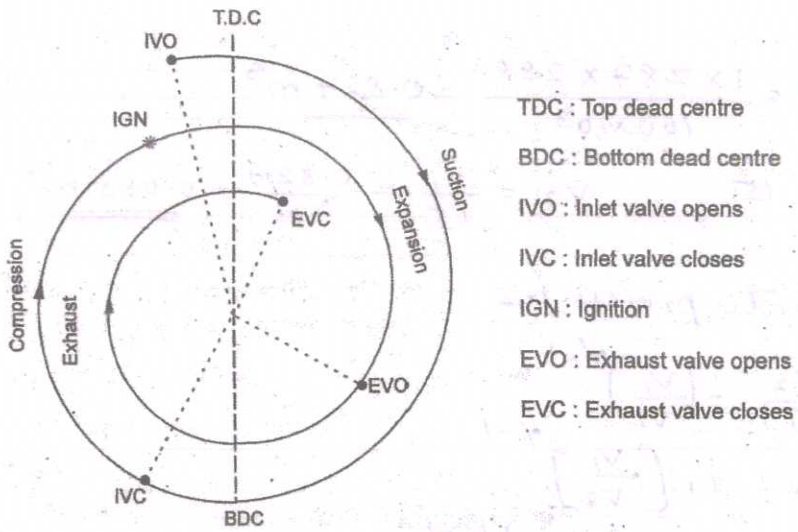
ie, the minimum temperature in the cycle,

$$T_3 = T_4 = \underline{\underline{288.75\,K}}$$

VI (a) **With the help of a neat sketch explain the valve timing diagram of a four stroke cycle petrol engine.**

ANS:

One revolution of the crank s haft ¡s equal to 360^0. This angle is called crank angle. In actual practice, the inlet valve opens a few degrees before the start of the suction stroke because the valve opens and closes slowly, and therefore some time should be provided for the valve to open fully at the beginning of the suction stroke. It may be noted that during the suction stroke, there is a possibility that the full amount of air-fuel mixture is not admitted, if the inlet valve ¡s closed at the end of the suction stroke. This insufficient air-fuel mixture will not produce the intended power. So it is necessary that the inlet valve should remain open even after the completion of theoretical suction stroke. This helps to admit full amount of air-fuel mixture into the engine cylinder. The inlet valve closes at a crank angle after the BDC as shown in Fig.



Valve timing diagram of four stroke petrol engine

Fig-3

Now the charge is compressed (with both valves closed) and then ignited with the help of a spark plug before the end of the compression stroke (At a crank angle 6° to 20^0 before the TDC). This is done as the charge requires some time to ignite. By the time, the piston reaches TDC, the burnt gases push the piston downwards and the expansion or working stroke takes place. Now the exhaust valve opens before the piston again reaches BDC and starts moving up thus performing exhaust stroke. The exhaust valve closes after the crank has moved a little beyond the TDC. This is done as the burnt gases continue to leave the engine cylinder although the piston is moving

4 | 7 | 7

downwards. It may be noted that for a small fraction of a crank revolution, both the inlet and outlet valves are in open condition. This is known as valve overlap.

VI (b)

1 kg of air at temperature of 15^{0}C and pressure of 100 kPa is taken through a Diesel cycle. The compression ratio is 15 and the heat added is 1850 kJ. Calculate the ideal cycle efficiency.

Given:

$m = 1\,kg$

$T_1 = 15^0C = 288K$

$P_1 = 100\,kPa = 100\times10^3\ N/m^3$ 1

$r = 15 = \frac{V_1}{V_2}$

$Q_{added} = 1850\,kJ$

$\eta = ?$

$P_1V_1 = mRT_1$

$V_1 = \frac{mRT_1}{P_1} = \frac{1\times287\times288}{100\times10^3} = \underline{\underline{0.827\,m^3}}$ 1

Given, $\frac{V_1}{V_2} = 15$, $\therefore V_2 = \frac{V_1}{15} = \frac{0.827}{15} = \underline{\underline{0.055\,m^3}}$

For the adiabatic process 1-2

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

$$T_2 = T_1\left[\frac{V_1}{V_2}\right]^{\gamma-1}$$ 1

$$= 288\times(15)^{1.4-1}$$

$$T_2 = \underline{850.8\,K}$$

For the costant pressure process 2-3

$${}_2Q_3 = m\,C_p(T_3 - T_2)$$

$$1850 = 1\times1.005\times(T_3 - 850.8)$$ 1

$$T_3 = \underline{\underline{2691.6\,K}}$$

	$\frac{V_2}{T_2} = \frac{V_3}{T_3}$ $V_3 = V_2 \times \frac{T_3}{T_2}$ $= 0.055 \times \frac{2691.6}{850.8}$ $V_3 = 0.174\ m^3$ Cut off ratio, $\rho = \frac{V_3}{V_2} = \frac{0.174}{0.055} = \underline{3.16}$ Air standard efficiency, $\eta = 1 - \frac{1}{\gamma r^{\gamma-1}}\left[\frac{(\rho^{\gamma}-1)}{(\rho-1)}\right]$ $= 1 - \frac{1}{1.4(15)^{1.4-1}}\left[\frac{(3.16)^{1.4}-1}{3.16-1}\right]$ $= 1 - 0.24 \times 1.855$ $= 1 - 0.4452$ $= 0.5548$ $\eta = \underline{55.48\%}$	1 1 2	8	8
VII (a)	**Derive the expression of velocity of steam leaving a nozzle.** Consider 1 kg of steam flow through a nozzle Let V_1 = Velocity of steam at the entrance of the nozzle in m/s V_2 = Velocity of steam at the exit of the nozzle in m/s h_1 = Enthalpy of steam at the entrance of the nozzle in kJ/kg h_2 = Enthalpy of steam at the exit of the nozzle in kJ/kg We know that the kinetic energy of steam at the entrance = $KE = \frac{1}{2}mV_1^2 = \frac{1}{2}\times 1 \times V_1^2 = \frac{V_1^2}{2} J = \frac{V_1^2}{2000} kJ$ In a steady flow process in a nozzle	1 2		

	$h_1 + \frac{V_1^2}{2000} = h_2 + \frac{V_2^2}{2000} + \text{Losses}$	2		
	$V_2 = \sqrt{V_1^2 + 2000(h_1 - h_2)} = \sqrt{V_1^2 + 2000\,h_d}$ Where hd = Enthalpy drop or heat drop during expansion of steam in a nozzle Since the entrance velocity(V_1) of staem is negligible as compared to V_2 $V_2 = \sqrt{2000\,h_d} = 44.72\sqrt{h_d}$ As we have seen that due to friction there is a reduction in heat drop and hence the exit velocity of steam is also reduced correspondingly. Thus the above relation may be written as $V_2 = 44.72\sqrt{K\,h_d}$ where K is the nozzle coefficient or nozzle efficiency.	2	7	7
VII (b)	**A two cylinder 4-stroke cycle I.C engine is to be designed to develop 15kW IP at 1200 rpm. The m.e.p of the cycle is limited to 600kPa. Determine the bore diameter, and stroke of the engine if stroke = 1.2 x bore diameter.**			
	Given: $K = 2$ $IP = 15\,kW = 15\times10^3\,W$ $N = 1200\,rpm$, $n = \frac{N}{2} = \frac{1200}{2} = 600\,rpm$ $P_m = 600\,kPa = 600\times10^3\,N/m^2$ $L = 1.2d$, $d = ?$, $L = ?$	2		
	$IP = \frac{P_m L A n K}{60}$ $15\times10^3 = \frac{600\times10^3 \times 1.2d \times \frac{\pi}{4}d^2 \times 600 \times 2}{60}$	2		
	$d^3 = \frac{15\times10^3 \times 60}{600\times10^3 \times 1.2 \times \frac{\pi}{4} \times 600 \times 2}$ $d = 0.109\,m$ $d = 109\,mm$	2		
	Stroke length, $L = 1.2d$ $= 1.2\times109$ $= 130.8\,mm$	2	8	8

VIII (a) **Explain with neat diagram, the working of a simple double acting steam engine.**

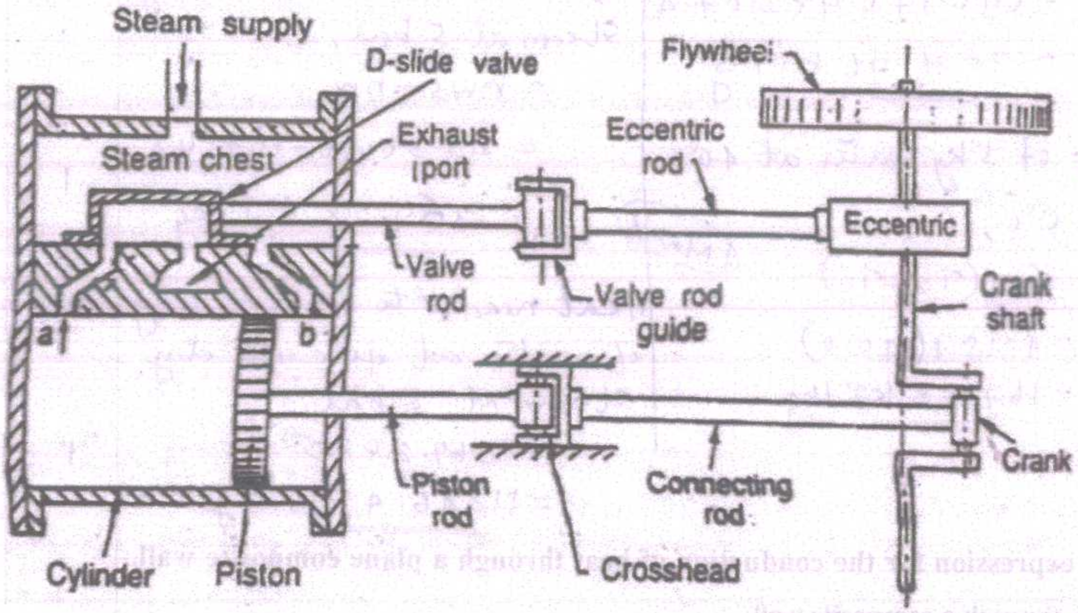


Fig-4

The super-heated steam at high pressure from the steam boiler is fed to the steam chest. This steam is supplied to the engine cylinder through the inlet port on the left side of the piston. Now the piston moves from left to right side. At this time the slide valve covers the exhaust port and the second inlet port (b). When the piston reaches near the end of the cylinder the first inlet port (a) closes and opens the second inlet port (b). Now the steam enters the right side of the piston. This forces the piston from right to left and at the same time the exhaust steam goes out through the exhaust pipe. 3 7 7

VIII (b) **How much heat is needed to convert 5 kg of water at 40^{0}C into 90% dry steam at 5 bar? Take specific heat of water as 4.187 KJ/kgK.**

Given:

$m = 5\ kg$

$T_2 = 40°c$, $T_1 = 0°c$ 1

$x = 0.9$

$P = 5\ bar$

$C_W = 4.187\ kJ/kg$

from steam table corresponding to 10 bar,

$h_f = 640.1\ kJ/kg$ 2

$h_{fg} = 2107.4\ kJ/kg$

(2 Marks)

$h_{ws} = h_f + x(h_{fg})$

$= 640.1 + 0.9 \times 2107.4$

$= 2536.76$ kJ/kg

Enthalpy of 5 kg water at 40°c above 0°c,

$h_w = C_w(T_2 - T_1)$

$= 4.187(40-0)$

$= 167.48$ kJ/kg

(1 Mark)

∴ heat supplied to convert 1 kg of water at 40°c into dry steam at 5 bar, (3 Marks (2+1))

$= h_{ws} - h_w$

$= 2536.76 - 167.48$

$= 2369.28$ kJ/kg 1

Heat needed to convert 5 kg of water at 40°c into dry steam at 5 bar,

$= 2369.28 \times 5$ 1 8 8

$= 11846.4$ kJ/kg

IX (a) Derive an expression for the conduction of heat through a plane composite wall.

Conduction through a composite wall

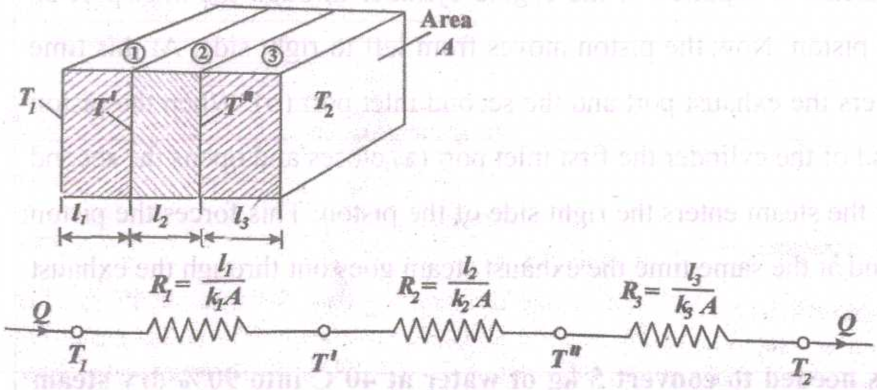


Fig-2

Consider heat conduction through a composite wall consisting of three layers of materials 1, 2 and 3 having thickness l_1, l_2 and l_3 and thermal conductivities k_1, k_2 and k_3 respectively. The area of heat conduction 'A' is constant. Therefore the rates of heat flow at steady state through the individual layers are equal.

The rates of heat flow through the walls are given by Fouriers law.

Layer 1: $Q = \frac{k1A(T1 - T')}{l1}$

$(T1 - T') = Q * \frac{l1}{k1A}$ ……………………(1) 1

Layer 2: $Q = \frac{k2A(T' - T'')}{l2}$

$(T' - T'') = Q * \frac{l2}{k2A}$ ……………………(2) 1

Layer 3: $Q = \frac{k2A(T'' - T2)}{l3}$

$(T'' - T2) = Q * \frac{l3}{k3A}$ ……………………(3) 1

Adding equations (1), (2) and (3), we have

$(T1 - T') + (T' - T'') + (T'' - T2) = QR_1 + QR_2 + QR_3$

$(T1 - T2) = Q\,(R_1 + R_2 + R_3)$

Ie, $Q = \frac{(T1 - T2)}{(R1 + R2 + R3)}$

$Q = \frac{T1 - T2}{R}$

$Q = \frac{T1 - T2}{\frac{l1}{k1A} + \frac{l2}{k2A} + \frac{l3}{k3A}}$ 2 8 8

Ie in general, Rate of heat transfer = Temperature of driving force/ Thermal resistance

IX (b) Heat is conducted through a composite plate composed of two parallel plates of different materials A and B of thermal conductivities 134 W/mK and 60 W/mK and thickness 36 mm and 42 mm respectively. The temperature of outer surface of slab A and B are 96°C and 8°C respectively.

Given;

$K_1 = 134\ W/mK$

$K_2 = 60\ W/mK$

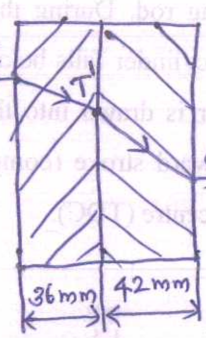
$l_1 = 36\ mm = 36 \times 10^{-3}\ m$

$l_2 = 42\ mm = 42 \times 10^{-3}\ m$

$T_A = 96^\circ C = 96 + 273 = 369\ K$

$T_B = 8^\circ C = 8 + 273 = 281\ K$

$A = 10\ m^2$



2

$Q = \frac{(T_1 - T_2)}{(R_1 + R_2)}$ 1

$R_1 = \frac{l_1}{K_1 A} = \frac{36 \times 10^{-3}}{134 \times 10} = 2.68 \times 10^{-5}$ 1

$R_2 = \frac{l_2}{K_2 A} = \frac{42 \times 10^{-3}}{60 \times 10} = 7 \times 10^{-5}$ 1

$Q = \frac{(369 - 281)}{(2.68 \times 10^{-5} + 7 \times 10^{-5})}$

$$Q = 909090.9 \text{ W}$$
$$= 909.09 \text{ kW}$$

1

Also, $$Q = \frac{T_A - T'}{R_1}$$

$$909090.9 = \frac{369 - T'}{2.68 \times 10^{-5}}$$

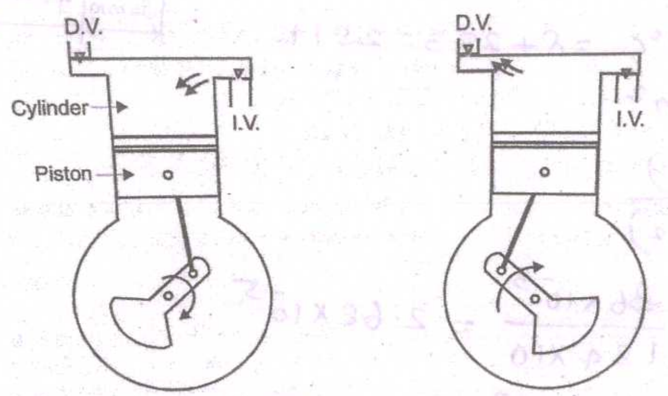
$$T' = 344.6 \text{ K}$$

2 | 8 | 8

X (a) **Explain the working of single stage reciprocating compressor with neat sketch.**

ANS:

The compressor is driven by a prime mover (electric motor or engine). The rotary motion of the engine is converted into the reciprocating motion of the piston by the crank shaft and connecting rod. During the downward stroke of the piston (suction stroke) the pressure inside the cylinder falls below the atmospheric pressure. Now the inlet valve opens and atmospheric air is drawn into the cylinder till the piston reaches bottom dead centre (BDC). During upward stroke (compression stroke) the piston travels bottom dead centre (BDC) to top dead centre (TDC).



a) Suction stroke (b) Delivery stroke

Working of single stage reciprocating aircompressor

Fig-3

When the air pressure inside the cylinder rises above atmospheric, the inlet valve closes. The pressure increases steadily. When the air pressure exceeds the resistance of the spring on delivery valve, the delivery valve opens. Now the

	compressed air is discharged through the outlet valve to the air receiver tank. At the end of compression stroke, a small volume of compressed air will be left in the clearance space. When the piston moves down for the next suction stroke, the air in the clearance space expands the pressure falls down. The inlet valve again opens and the cycle is repeated.	4	7	7

X (b) **A single acting single stage air compressor is required to compress 1 kg of air from 100 kPa to 400 kPa. The initial temperature is 27°C. Calculate the power required to drive the compressor for the isothermal compression process, if the speed is 100 rpm. Assume characteristic gas constant as 0.287 kJ/kgK.**

Given:

$m = 1 kg$

$P_1 = 100 kPa = 100 kN/m^2$

$P_2 = 400 kPa = 400 kN/m^2$

$T_1 = 27°C$

$T_1 = 27 + 273 = 300 K$ 2

$N = 100 rpm$

$R = 0.287 kJ/kgK$

Work required for Isothermal compression,

$\oint W = P_1 V_1 \log_e r$

$= P_1 V_1 \log_e \left(\frac{P_2}{P_1}\right)$ 2

$\oint W = m R T_1 \log_e \left(\frac{P_2}{P_1}\right)$

$\oint W = 1 \times 0.287 \times 300 \times \log_e \left(\frac{400}{100}\right)$ 2

$\oint W = \underline{119.36 kJ}$

		∴ Power required, $P = \frac{\oint W N}{60}$ $= \frac{119.36 \times 100}{60}$ $= \underline{\underline{198.93\ kW}}$ X ——— x	2	8	8