SCHEME OF VALUATION

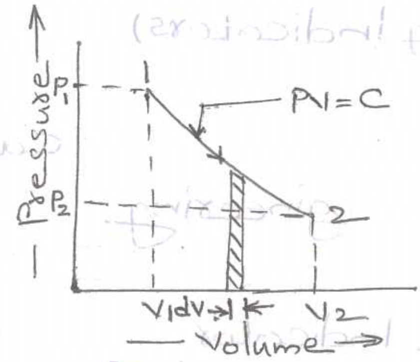
(Scoring Indicators)

Revision – 2015

Course Code – 4024

Course Title – Thermal Engineering

Qst No:	Scoring Indicator	Split up Score	Sub Total	Total
	PART-A			
I	1) It is a region ~~in~~ where our attention is focussed for studying thermodynamic processes.	2		
	2) When two systems are in thermal equilibrium with a third system, the two systems are also in thermal equilibrium with each other.	2		
	3) When air is assumed to be the working substance inside the engine cylinder, the cycle is called air standard cycle.	2		10
	4) Function of steam nozzle is to convert heat energy of steam into kinetic energy.	2		
	5) It states that rate of heat transfer in a given direction by conduction is proportional to temperature gradient in that direction and area normal to the direction of flow	2		
	PART-B			
II	1) We have, $\delta W = P.dv$			
	On integrating from state 1 to state 2			



2

$$\int_1^2 \delta W = \int_1^2 P\,dv$$

For Isothermal Process, $PV=C$ 6

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

Substituting for 'P' in above eqn.

$$W_{1-2} = \int_1^2 \frac{C}{V}\,dv$$ 4

$$= C\int_1^2 \frac{1}{V}\,dv$$

$$= C\left[\ln(V)\right]_{V_1}^{V_2}$$

$$= C\left[\ln(V_2) - \ln(V_1)\right]$$

$$= C \cdot \ln\left[\frac{V_2}{V_1}\right]$$

For Isothermal Process $P_1V_1 = C$

$$\therefore W_{1-2} = P_1V_1\ln(r) = mRT_1\ln(r)$$

where $r = \frac{V_2}{V_1}$ = expansion ratio.

2) i) The gas in the engine cylinder is a perfect gas

ii) The physical constants ~~in the engi~~ of gas in the engine cylinder is same as that of air

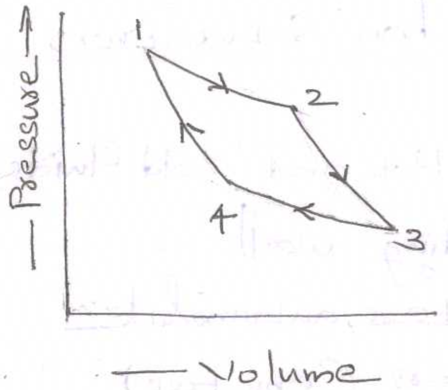
iii) Adiabatic Compressions and expansions takes place without friction.

iv) Heat is supplied and rejected by bringing hot body and cold body incontact with cylinder 1X6 6

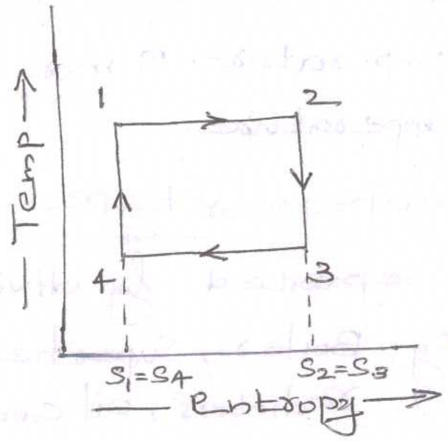
v) The cycle is a closed one and same air is used again and again to repeat the cycle

vi) No chemical reaction takes Place inside the cylinder

3)



P-V diagram



T-S diagram 2 + 2 6

1-2 → Isothermal expansion

2-3 → Isentropic expansion 2

3-4 → Isothermal compression

4-1 → Isentropic compression

4) Indicated Power - Power developed inside the engine cylinder 2

Brake Power - Power obtained as output at the crank shaft 6 2

Mechanical efficiency - Ratio of Brake Power to Indicated Power 2

$$\eta_{mech} = \frac{\text{Brake Power}}{\text{Indicated Power}} \times 100\ \%$$

5) Wet steam - Steam contains water particles in suspension — 2

Dry steam - Steam do not contains any water particles in suspension — 2 — 6

Superheated steam - Steam whose temperature is more than saturation temperature — 2

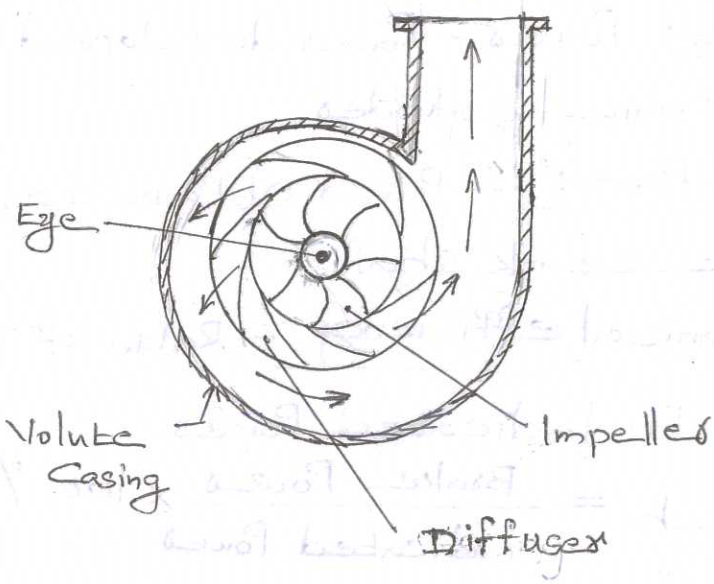
6) Recuperator type - Hot and cold fluids are separated by dividing wall — 2

Eg: Boilers, Superheaters, automobile radiators, oil coolers (any two) — 1

Regenerative type - It is a periodic flow type heat exchanger in which same space is alternately occupied by hot and cold fluids. — 2 — 6

Eg: I.C engines, Melting furnaces, Air heaters for blast furnaces. (any two) — 1

7)



3

Impeller is fitted inside volute casing. Around the impeller diffuser is fitted, which is a stationary part.

Air is sucked through eye of impeller and when it flows through the curved vanes of impeller which rotates at high speed, it gains kinetic energy. Air at high velocity then flows through diffuser, a part of KE is converted to pressure energy. When the air flows through casing, the remaining ~~press~~ KE also is converted to pressure energy. 3 6

PART-C

III a) Thermodynamic equilibrium - A system is said to be in T/D equilibrium, if it satisfies the following 3 requirements of equilibrium. 1

Mechanical equilibrium - There should not be any unbalanced forces acting on any part of system. 2 7

Thermal equilibrium - There should not be any difference in temperature between different parts of system or between system and surroundings 2

Chemical equilibrium - There should not be any chemical reaction within the system or there should not be any movement of chemical constituent 2

b) i) $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

Temperature at the end of Process,

$$T_2 = \frac{P_2 \cdot T_1}{P_1}$$ 2

$$= \frac{7 \times 350}{2}$$

$$= 1225\,k = 1225 - 273 = \underline{952^\circ c}$$ 15

ii) $P_1V_1 = mRT_1$

mass of gas (m) = $\frac{P_1V_1}{R \cdot T_1}$

$R = C_p - C_v$ 8

$= 1.005 - 0.712$ 2

$= 0.293\ kJ/kg\,k$

$$m = \frac{2 \times 10^2 \times 0.3}{0.293 \times 350}$$

$$= \underline{0.585\ kg}$$

iii) $dU = m \cdot C_v (T_2 - T_1)$

change in I.E = $0.585 \times 0.712\,(1225 - 350)$ 2

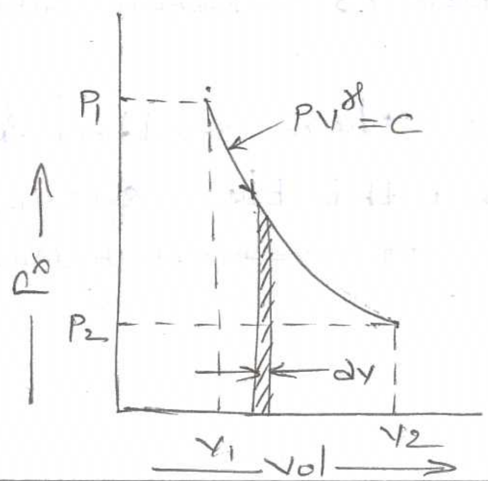
$= \underline{364.5\ kJ}$

iv) change in enthalpy (dH) = $m \cdot C_p (T_2 - T_1)$

$= 0.585 \times 1.005\,(1225 - 350)$ 2

$= \underline{514.43\ kJ}$

IV a)



2

We have, $\delta W = P dv$

On integrating from state 1 to state 2.

$$\int_1^2 \delta W = \int_1^2 P . dv$$

For adiabatic process, $PV^{\gamma} = C$

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

Substituting for P in above eqn.

$$W_{1-2} = \int_1^2 \frac{C}{V^{\gamma}} . dv$$

$$= C \int_1^2 \frac{1}{V^{\gamma}} dv$$

$$= C \int_1^2 V^{-\gamma} dv$$

$$= C \left[\frac{V^{-\gamma+1}}{-\gamma+1} \right]_1^2$$

$$= \frac{C}{1-\gamma} \left[V_2^{1-\gamma} - V_1^{1-\gamma} \right]$$ 5 7

For adiabatic Process $P_1 V_1^{\gamma} = P_2 V_2^{\gamma} = C$

X ing the first term by $P_2 V_2^{\gamma}$ & second term by $P_1 V_1^{\gamma}$

$$W_{1-2} = \frac{P_2 V_2 - P_1 V_1}{1-\gamma}$$

$$= \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} = \frac{mR(T_1 - T_2)}{\gamma - 1}$$ 15

b) Pressure at the end of compression (P_2)

$P_1 V_1^n = P_2 V_2^n$

$$\therefore P_2 = P_1 . \left[\frac{V_1}{V_2} \right]^n = 1 \left[\frac{0.192}{0.0142} \right]^{1.37} = 35.44 \text{ bar}$$ 2

mass of gas (m)

$P_1V_1 = mRT_1$

$\therefore m = \dfrac{P_1V_1}{R \cdot T_1} = \dfrac{1\times10^2 \times 0.192}{0.289\times316}$ 2

$= 0.21\ kg$

Work Done $= \dfrac{P_2V_2 - P_1V_1}{n-1}$ 8

~~$= (1\times10^2 \times 35.44)$~~

$= \dfrac{(35.44\times10^2\times0.0142)-(1\times10^2\times0.192)}{0.37}$ 2

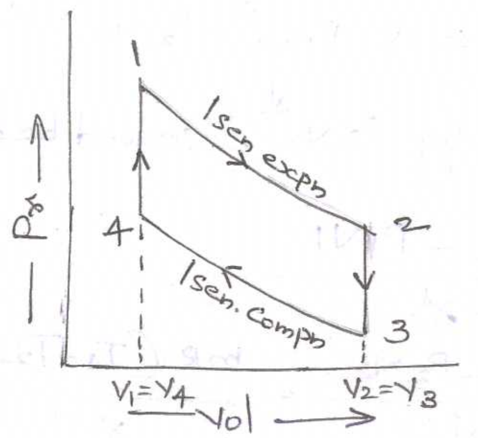
$= 84.12\ KJ$

Heat rejected $= \dfrac{\gamma - n}{\gamma - 1} \times$ Work Done 2

$= \dfrac{0.03}{0.4} \times 84.12$

$= 6.31\ KJ$

V a)



P-V diagram. 2

Isen. expn (1-2) - There is no heat transfer

Const. Vol cooling (2-3) -

Heat rejected $= m \cdot C_v (T_2 - T_3)$

Isen. compn (3-4) - There is no heat transfer

& Const. Vol heating (4-1)

Heat absorbed $= m \cdot C_v (T_1 - T_4)$

Work Done = Heat absorbed − Heat rejected

$$= m \cdot C_v (T_1 - T_4) - m \cdot C_v (T_2 - T_3)$$

Air std efficiency $= \dfrac{\text{Work Done}}{\text{Heat Absorbed}}$

$$= \frac{m \cdot C_v (T_1 - T_4) - m \cdot C_v (T_2 - T_3)}{m \cdot C_v (T_1 - T_4)}$$ 5 7

$$= 1 - \frac{T_2 - T_3}{T_1 - T_4} = 1 - \frac{T_3 \left[\frac{T_2}{T_3} - 1\right]}{T_4 \left[\frac{T_1}{T_4} - 1\right]} \quad \text{--- (1)}$$

For Isen. expn (1-2)

$$\frac{T_2}{T_1} = \left[\frac{V_1}{V_2}\right]^{\gamma - 1} = \left[\frac{1}{\gamma}\right]^{\gamma - 1} \quad \text{--- (2)}$$

where, γ = expn. ration $= \dfrac{V_2}{V_1}$

For Isen. Compn (3-4)

$$\frac{T_3}{T_4} = \left[\frac{V_4}{V_3}\right]^{\gamma - 1} = \left[\frac{1}{\gamma}\right]^{\gamma - 1}$$

where, γ = compn. ration $= \dfrac{V_3}{V_4} = \dfrac{V_2}{V_1}$ --- (3)

From (2) & (3) $\dfrac{T_2}{T_1} = \dfrac{T_3}{T_4} = \left[\dfrac{1}{\gamma}\right]^{\gamma - 1} = \dfrac{1}{(\gamma)^{\gamma - 1}}$

or

$$\frac{T_2}{T_3} = \frac{T_1}{T_4}$$

Substituting in eqn (1)

$$\eta_{air\,std} = 1 - \frac{T_3}{T_4}$$

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

b) Stroke Volume $(V_s) = \frac{\pi}{4} d^2 L$

$$= \frac{\pi}{4} (0.15)^2 \times 0.25$$

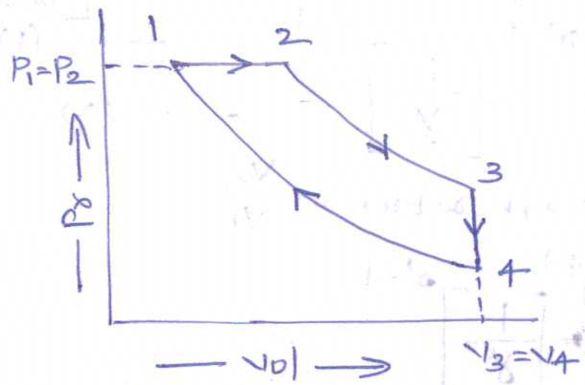
$$= 4.4179 \times 10^{-3}\ m^3$$

Comp. ratio $(r) = \frac{V_c + V_s}{V_c}$

~~4×10^{-4}~~

$$= \frac{0.4 \times 10^{-3} + 4.4179 \times 10^{-3}}{0.4 \times 10^{-3}}$$

$$= \underline{12.}$$ 2



2

Volume at cut-off, $V_2 = V_c + 0.05 V_s$

$$= 0.4 \times 10^{-3} + (0.05 \times 4.4179 \times 10^{-3})$$

~~$= 6.2 \times 10^{-4}\ m^3$~~

$$= 0.62 \times 10^{-3}\ m^3$$

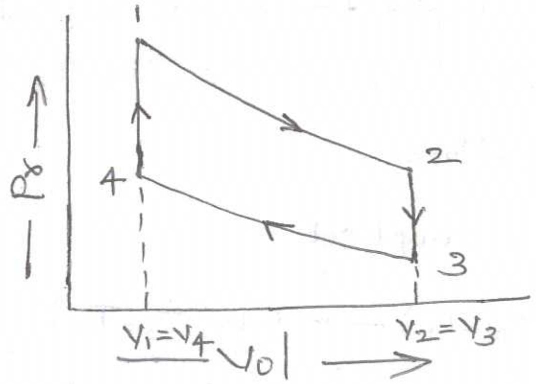
Cut-off ratio $(\rho) = \frac{V_2}{V_1} = \frac{0.62 \times 10^{-3}}{0.4 \times 10^{-3}} = 1.55$ 2

$$\eta_{airstd} = 1 - \frac{1}{(r)^{\gamma-1}}\left[\frac{\rho^{\gamma}-1}{\gamma(\rho-1)}\right]$$ 2 8

$$= 1 - \frac{1}{(12)^{0.4}}\left[\frac{(1.55)^{1.4}-1}{1.4\times0.55}\right]$$

$$= 0.59 = \underline{59\,\%}$$

VI a)



2

7

$T_3 = 316\,K$

$T_4 = 596\,K$

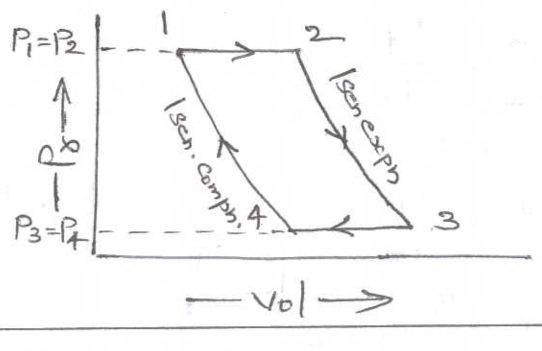
$$\frac{T_3}{T_4} = \left[\frac{V_4}{V_3}\right]^{\gamma-1} = \left[\frac{1}{r}\right]^{\gamma-1} = \frac{1}{(r)^{0.4}}$$ 2

$$\therefore r = \left[\frac{T_4}{T_3}\right]^{1/0.4} = 4.885$$

$$\eta_{airstd} = 1 - \frac{1}{(r)^{\gamma-1}} = 1 - \frac{1}{(4.885)^{0.4}}$$ 3

$$= 0.47 = \underline{47\,\%}$$

b)



2

Const Pr. heating (1-2)

Heat supplied to air $= m \cdot C_p (T_2 - T_1)$

Isen. expn (2-3) - There is no heat transfer

Const. Pr. cooling (3-4)

Heat rejected $= m \cdot C_p (T_3 - T_4)$

Isen. compn (4-1) - There is no heat transfer.

Work Done = Heat supplied − Heat rejected

$$= m \cdot C_p (T_2 - T_1) - m \cdot C_p (T_3 - T_4)$$

$$\eta_{airstd} = \frac{\text{Work Done}}{\text{Heat supplied}}$$

$$= \frac{m \cdot C_p (T_2 - T_1) - m \cdot C_p (T_3 - T_4)}{m \cdot C_p (T_2 - T_1)}$$ 15

$$= 1 - \frac{T_3 - T_4}{T_2 - T_1} = 1 - \frac{T_3 \left[1 - \frac{T_4}{T_3}\right]}{T_2 \left[1 - \frac{T_1}{T_2}\right]} \quad \text{—— (1)}$$

For Isen. expn (2-3)

$$\frac{T_3}{T_2} = \left[\frac{P_3}{P_2}\right]^{\frac{\gamma - 1}{\gamma}} = \left[\frac{V_2}{V_3}\right]^{\gamma - 1} \quad \text{—— (2)}$$

For Isen. compn (4-1)

$$\frac{T_4}{T_1} = \left[\frac{P_4}{P_1}\right]^{\frac{\gamma - 1}{\gamma}} = \left[\frac{V_1}{V_1}\right]^{\gamma - 1} \quad \text{—— (3)}$$

From (2) and (3) $\frac{T_3}{T_2} = \frac{T_4}{T_1}$

or

$$\frac{T_4}{T_3} = \frac{T_1}{T_2} \qquad (\because P_1 = P_2 \text{ and } P_3 = P_4)$$

Substituting in eqn (1) $\eta_{airstd} = 1 - \frac{T_3}{T_2}$

Also from (2) and (3)

$$\left[\frac{V_2}{V_3}\right]^{\gamma-1} = \left[\frac{V_1}{V_4}\right]^{\gamma-1}$$

or

$$\frac{V_2}{V_3} = \frac{V_1}{V_4} = \frac{1}{r}$$ 5

7

$$\therefore \frac{T_3}{T_2} = \frac{1}{(r)^{\gamma-1}}$$

$$\therefore \eta_{airstd} = 1 - \frac{1}{(r)^{\gamma-1}}$$

VII a) The complete record of heat supplied and heat rejected during certain time by an engine is entered in tabular form known as heat balance sheet. 1½

Heat input (HIP)	KJ	%	Heat rejected	KJ	%
Heat Supplied through Fuel	—	—	Heat equivalent of BP (HBP)	—	—
			Heat lost through cooling water (H_w)	—	—
			Heat lost through exhaust gas (H_g)	—	—
			Heat lost unaccounted (H_{Losses})	—	—
Total		100	Total		100

7

(Minute Basis)

Heat supplied through fuel $= m_f \times CV$ KJ/min 1

$H_{BP} = BP \times 60$ KJ/min 1

$H_w = m_w \times Cp_w (t_{wo} - t_{wi})$ KJ/min 1

$H_g = m_g \times Cp_g (t_{go} - t_a)$ KJ/min 1½

where, m_g = mass of exhaust gas/min.
= mass of air + mass of fuel

Cp_w and Cp_g are Sp. heats of water and exhaust gases respectively.

b) Torque (T) = Net load × Mean radius
$= 0.17 \times \frac{0.625}{2} = 0.053$ KN-m

BP = $2\pi NT$ KW
where, N = rotational speed in rps
T = Torque in KN-m 15

$BP = 2\pi \times \frac{450}{60} \times 0.053$ 2
= 2.5 KW

IP = $P_m L A n$ KW
where, P_m = Mean effective Pr. in KN/m²
n = No: of working strokes/sec 8

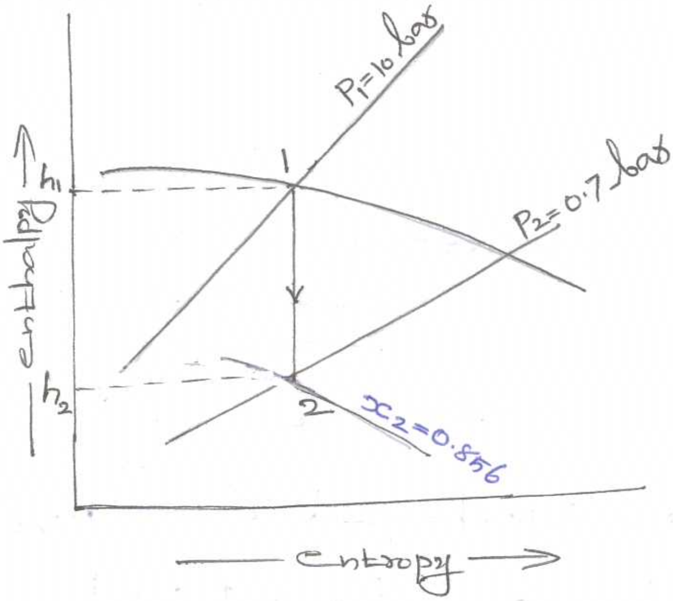
For, four stroke engine, $n = \frac{N}{2}$ 2
$= \frac{7.5}{2} = 3.75$

$IP = 770 \times 0.15 \times \frac{\pi}{4}(0.1)^2 \times 3.7$
= 3.4 KW

$\eta_{mech} = \frac{BP}{IP} \times 100$
$= \frac{2.5}{3.4} \times 100$ 2
= 73.5 %

$ITE = \frac{IP}{mf \times CV} = \frac{3.4}{\frac{0.83}{3600} \times 42000} = 0.351$ 2
= 35.1 %

VIII a)



2

From mollier chart, $h_1 = 2778$ kJ/kg.

$h_2 = 2335$ kJ/kg

Heat drop $(h_d) = h_1 - h_2$

$= 443$ kJ/kg.

7

Velocity of steam issuing from Nozzle $= 44.72\sqrt{h_d}$ 3

$= 44.72\sqrt{443}$

$= \underline{941.25 \text{ m/s}}$

From moller diagram, dryness fraction of steam issuing from nozzle $(x_2) = \underline{0.856}$ 2

b) From steam tables, Corresponding to pr. of 6 bar

$h_f = 670.4$ kJ/kg, $h_{fg} = 2085$ kJ/kg, $t_{sat} = 158.8°C$ 2

i) When steam is wet

Enthalpy of wet steam $(h) = h_f + (x \times h_{fg})$

where, x = dryness fraction of steam

$h = 670.4 + (0.9 \times 2085)$

$= 2546.9$ kJ/kg.

Since water is at 25 °c, heat already present in water $= Cp_w \times 25$

$= 4.2 \times 25 = 105$ kJ | 3

$\therefore$ Heat actually required $= 2546.9 - 105$

$= 2441.9$ kJ | 8

ii) When steam is superheated

Enthalpy of 1 kg of superheated steam (h_{sup})

$$h_{sup} = h_g + Cp_{steam}(t_{sup} - t_{sat})$$

$$h_g = h_f + h_{fg}$$ | 3

$$\therefore h_{sup} = (670.4 + 2085) + 2.3(250 - 158.8)$$
$$= 2755.4 + (2.3 \times 91.2)$$
$$= 2965.16 \text{ kJ/kg}$$

Heat actually required $= 2965.16 - 105$

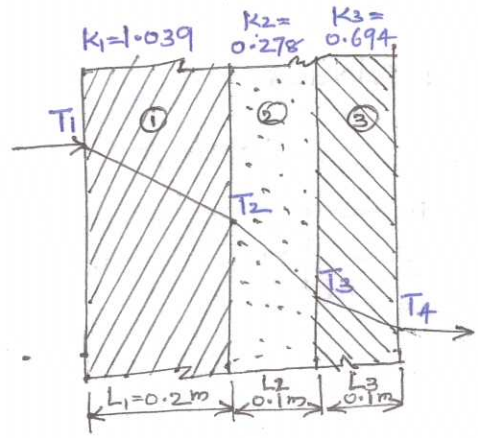
$= 2860.16$ kJ

IX (a) i) Thermal conductivity – Quantity of heat transfer per unit area per unit temperature gradient | 2

ii) Convection – mode of heat transfer through fluid due to fluid motion | 2

iii) Free convection – If fluid motion is due to density difference caused by temperature difference, mechanism of heat flow is called free convection | 1½ | 7

iv) Forced convection – If fluid motion is caused by external mechanism such as fan, ~~or~~ blower, pump etc, the mechanism of heat flow is called forced convection. | 1½ b)



① Fire clay Brick

② Insulation

③ Common Brick 2

$T_1 = 870°C$

$T_4 = 38°C$

For composite Section 15

$$Q = \frac{A(T_1 - T_4)}{\sum \frac{L}{K}}$$

$$\sum \frac{L}{K} = \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3}$$ 3 8

$$= \frac{0.2}{1.039} + \frac{0.1}{0.278} + \frac{0.1}{0.694}$$

$$= 0.696 \ m^2\text{-}K/W$$

Rate of heat flow/unit area $= \frac{1 \times (870 - 38)}{0.696}$

$$= \underline{1195 \ W}$$

Interface temp. between common brick and Insulation is T_3.

$$Q = \frac{K_3 A (T_3 - T_4)}{L_3}$$ 3

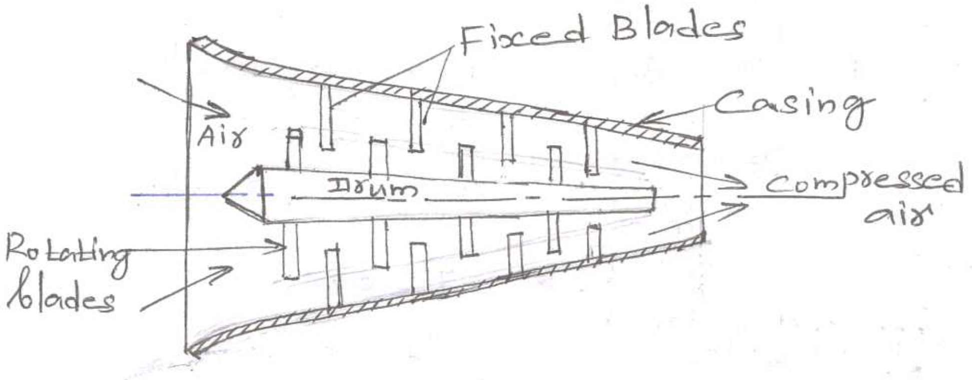
$$1195 = \frac{0.694 \times 1 (T_3 - 38)}{0.1}$$

$$T_3 - 38 = \frac{1195 \times 0.1}{0.694} = 172°C$$

$$\therefore T_3 = 172 + 38$$

$$= \underline{210°C}$$

X a)



Axial Flow Compressor 4

It consists of number of rotating blades fixed to a drum. The drum rotates inside air tight casing to which number of stator blades are fixed. The air enters from left side. As drum rotates, the rotor blades imparts kinetic energy to air and stator converts the kinetic energy to static pressure through diffusion. A pair of rotary and fixed blade is called stage. The c/s area between drum and casing is reduced in flow direction to maintain ~~velocity~~ axial velocity as air is compressed. 7 3 15

b) i) When compression is adiabatic

$$\text{Power req}(P) = \frac{\gamma}{\gamma-1} P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

$$= \frac{1.4}{0.4} \times 100 \times \frac{1.2}{60} \left[\left(\frac{8}{1}\right)^{\frac{0.4}{1.4}} - 1\right]$$

$$= 5.68\ kW$$

4 8

ii) When compression is Isothermal

$$\text{Power req}(P) = P_1V_1 \ln(r) \qquad r = \frac{P_2}{P_1}$$

$$= 100 \times \frac{1.2}{60} \times \ln\left[\frac{8}{1}\right] = 4.16\ kW$$

4