



MADE EASY

Leading Institute for ESE, GATE & PSUs

ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-7 : Full Syllabus Test (Paper-I)

Name :

Roll No :

Test Centres

Delhi ☒ Bhopal ☐ Jaipur ☐
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Student's Signature

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	25
Q.2	38
Q.3	✓
Q.4	—
Section-B	
Q.5	24
Q.6	38
Q.7	47
Q.8	—
Total Marks Obtained	172

Signature of Evaluator

Cross Checked by

Keep up this consistent effort.

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Section : A

Q.1 (a) A spherical, thin-walled metallic container is used to store liquid nitrogen at 77 K. The container has a diameter of 0.5 m and is covered with an evacuated, reflective insulation composed of silica powder. The insulation is 25 mm thick, and its outer surface is exposed to ambient air at 300 K. The convection coefficient is known to be 20 W/m²·K. The heat of vaporization and the density of liquid nitrogen are 2 × 10⁵ J/kg and 804 kg/m³ respectively.

(i) What is the rate of heat transfer to the liquid nitrogen?

(ii) What is the rate of liquid boil-off (liters/day)?

[Take k = 0.0017 for evacuated silica powder at 300 K]

[12 marks]

Given

$D = 0.5 \text{ m}$

$t = 0.025 \text{ m}$

$r_1 = 0.25 \text{ m}$

$r_2 = r_1 + 0.025$

$r_2 = 0.275 \text{ m}$

$k = 0.0017$

rate of

$L_v = 2 \times 10^5 \text{ J/kg}$

$\rho = 804 \text{ kg/m}^3$

$T_o = 300 \text{ K}$

$h_o = 20 \text{ W/m}^2\text{K}$

$T_i = 77 \text{ K}$

T_o

T_i

$$Q = \frac{\Delta T}{R_{\text{total}}} = \frac{(T_o - T_i)}{R_{\text{total}}}$$
$$Q = \frac{300 - 77}{\frac{r_2 - r_1}{4\pi r_2 k} + \frac{1}{4\pi r_2^2 h_o}}$$
$$Q = \frac{300 - 77}{\frac{0.025}{4\pi \times 0.275 \times 0.0017} + \frac{1}{4\pi \times 0.275^2 \times 20}}$$
$$Q = \frac{300 - 77}{17.0219 + 0.052613}$$

$Q = 13.054 \text{ W}$

①

②

$(Q = m \times L_v)$

$(Q = \rho \cdot V \cdot L_v)$

$(m = \rho \cdot V)$

$$13.054 = 804 \times \theta \times 2 \times 10^5$$

$$\theta = \frac{8.11815 \text{ m/s}}{\times 10^{-8} \text{ s}} \quad \text{m/s}$$

$$\theta = 7.014 \text{ degree/day}$$

Ans

12

- Q.1 (b) A two-dimensional incompressible flow field is described by equation (a) $V = \left(\frac{C}{r}\right)$; (b) $V = Cr$, in which V is the tangential velocity at a radius r and C is a constant. Determine for each case the circulation (i) around a circle of radius R , (ii) around a closed path formed by the arcs of two circles of radii R_1 and R_2 and the two radius vectors with an angle θ between them. Also calculate the vorticities of the flows described by these equations.

[12 marks]



Q.1 (c) An ammonia refrigerator produces 20 tons of ice per day from water at 0°C to ice at 0°C . The condensation and evaporation takes at 20°C and -20°C respectively. The temperature of vapour at the end of isentropic compression is 50°C and there is no under cooling of the liquid. The actual COP is 70% of the theoretical COP. Determine:

(i) The rate of NH_3 circulation.

(ii) The size of single acting compressor when running at 240 rpm assuming $L = D$ and volumetric efficiency of 80%.

Take h_{fg} (fusion of ice) = 335 kJ/kg

Use the properties of NH_3 as listed below:

Temperature ($^\circ\text{C}$)	Enthalpy (kJ/kg)		Entropy (kJ/kgK)	
	h_f	h_g	s_f	s_g
20	274.98	1461.58	1.04341	5.0919
-20	89.72	1419.05	0.3682	5.6204

Specific volume of dry vapour at $-20^\circ\text{C} = 0.624 \text{ m}^3/\text{kg}$.

Specific heat of superheated vapour = 2.8 kJ/kgK .

Given 20 tons/day water \rightarrow ice [12 marks]
 $L_{fg} = 335 \text{ kJ/kg}$

$$s_2 = s_2' + c_{p0} \left(\frac{2.8(T_2 - T_2')}{T_2'} \right) \quad s_2 = 5.0919 + 2.8 \times \frac{2.8(50 - 29.3)}{29.3}$$

$$s_2 = 5.3648 \text{ kJ/kg}$$

$$(s_2 = s) \quad 5.3648 = s_f + x_1 s_{fg}$$

$$5.3648 = 0.3682 + x_1 (5.6204 - 0.3682)$$

$$x_1 = 0.9513$$

$$q_1 = (h_f + x_1 h_{fg}) = 89.72 + 0.9513 \times (1419.05 - 89.72)$$

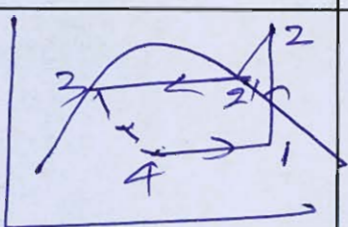
$$q_1 = 1354.36 \text{ kJ/kg}$$

$$h_2 = h_2' + c_{p0} (T_2 - T_2') = 1461.58 + 2.8(50 - 20)$$

$$h_2 = 1545.58 \text{ kJ/kg}$$

$$P_3 = 274.98 = 14 \text{ kJ/kg}$$

$$GE = \frac{20 \times 10^3 \times 335}{24 \times 3600} = 77.546 \text{ kW}$$



$$COP_{\text{refrigerator}} = \frac{q_1 - q_4}{(q_2 - q_1)} = \frac{1354.36 - 274.98}{1545.58 - 1354.36} = 5.644$$

$$COP_{\text{actual}} = 0.7 \times 5.644 = 3.95$$

~~Ans~~

$$m_{N_2} \times (q_1 - q_4) \times 0.7 = 77.546$$

$$m_{N_2} = 20.1026 \text{ kg/s}$$

$$\eta_0 = \frac{W_{\text{net}}}{W_{\text{input}}}$$

$$W = (4Vg) = 0.9513 \times 0.629 = 20.5936 \text{ m}^3/\text{kg}$$

$$0.8 = 0.5936 \times 0.1026$$

$$12 = \frac{7 \times D^3 \times (240)}{60}$$

$$D = L = 0.2893 \text{ m}$$

Ans

Q.1 (d) With the help of Maxwell's relation of thermodynamics, prove that Joule-Thomson coefficient, μ_J of a gas is given by the following expression:

$$\mu_J = \left(\frac{\partial T}{\partial p} \right)_h = \frac{T^2}{c_p} \left[\frac{\partial}{\partial T} \left(\frac{v}{T} \right)_p \right]$$

[12 marks]

Maxwell relation

$$\left(\frac{\partial p}{\partial T} \right)_v = - \left(\frac{\partial s}{\partial v} \right)_T$$

\Rightarrow

$$\left(\frac{\partial p}{\partial T} \right)_v = - \left(\frac{\partial s}{\partial v} \right)_T$$

1



Q.1 (e) What are the functional requirements of an injection system? What is the purpose of a fuel injector? Mention the various parts of an injector assembly.

[12 marks]



Q.2 (a) Lubricating oil of specific gravity 0.82 and dynamic viscosity $12.066 \times 10^{-2} \text{ N.s/m}^2$ is pumped at a rate of $0.02 \text{ m}^3/\text{s}$ through a 0.15 m diameter 300 m long pipe.

Calculate the pressure drop, average shear stress at the wall of the pipe and the power required to maintain the flow:

- (i) if the pipe is horizontal;
- (ii) if the pipe is inclined at 15° with the horizontal and the flow is
 1. in the upward direction,
 2. in the downward direction.

Also determine the slope of the pipe and the direction of flow so that the pressure gradient along the pipe is zero.

Soln $\rho = 0.82 \times 1000 = 820 \text{ kg/m}^3$ [20 marks]

$$\mu = 12.066 \times 10^{-2} \text{ N.s/m}^2$$

$$Q = 0.02 \text{ m}^3/\text{s} \quad D = 0.15 \text{ m}$$

$$L = 300 \text{ m}$$

Horizontal ($\theta = 0^\circ$)

$$Q = \frac{\pi}{4} \times 0.15^2 \times v \quad R = D/2 = 0.075$$

$$Q = 1.13 \text{ m/s}$$

$$Re = \frac{\rho \cdot V \cdot D}{\mu} = \frac{820 \times 1.13 \times 0.15}{12.066 \times 10^{-2}}$$

$$Re = 153.717 \quad \text{Laminar flow}$$

$$Q = \frac{32 \mu V L}{W D^2}$$

$$T = -\frac{\sigma}{2} \left(\frac{\partial P}{\partial x} \right)$$

$$(Q \times W) = \frac{32 \mu V L}{D^2} \quad (W = 58)$$

$$\Delta P = \frac{32 \times 12.066 \times 10^{-2} \times 1.13 \times 300}{0.15^2}$$

$$\Delta P = 58174.208 \text{ N/m}^2$$

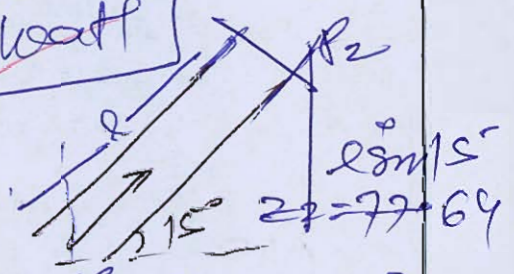
$$T = -\frac{\sigma}{2} \left(\frac{\partial P}{\partial x} \right) = T_{eo} = -\frac{R}{2} \left(\frac{\Delta P}{L} \right)$$

$$T_{eo} = \left(\frac{0.15/2}{2} \right) \left(\frac{58174.208}{300} \right) = 7.271 \text{ N/m}^2$$

$$Power = \Delta P \times Q = 58174.208 \times 0.02$$

$$P = 1163.484 \text{ watt}$$

of pipe in section



$$\frac{P_1}{58} + \frac{V^2}{78} + Z = \frac{P_2}{58} + \frac{V^2}{78} + Z + h_L \quad (V_1 = V_2)$$

$$\left(\frac{P_1 - P_2}{58} \right) = (h_L + L \frac{8 \mu V}{D^2})$$

$$h_L = \frac{32 \mu V L}{W D^2}$$

$$h_L = \frac{32 \times 12.066 \times 1.13 \times 300}{820 \times 9.81 \times 0.15^2}$$

$$h_L = 7.2318 + 300 \frac{8 \mu V}{D^2}$$

$$\Delta P = 682771.856 \text{ N/m}^2$$

$$T = -\frac{\sigma}{2} \left(\frac{\partial P}{\partial x} \right) \quad T = -\frac{R}{2} \left(\frac{P_1 + Z}{58} + \frac{P_2 - Z}{58} \right)$$

$$T = \frac{0.075}{2} \left[\frac{(P_1 - P_2) - \rho g h}{2} \right]$$

$$T = \frac{0.075}{2} \left[\frac{682771.856 - 820 \times 9.81 \times 77.645}{2} \right]$$

$$T = 7.271 \text{ N/m}^2$$

15

- Q.2 (b) The steam consumption in a Parson's reaction turbine running at 400 rpm is 5 kg/s. The pressure of the steam at a certain stage is 2 bar, its dryness is 0.96 and the power developed by the stage is 4.4 kW. The discharging blade tip angle is 20° for both fixed and moving blades and the axial velocity of flow is 0.72 of the blade velocity. Calculate the drum diameter and the blade height, assuming the tip leakage as 5 percent and neglect the blade thickness.

Take $v_{g@2 \text{ bar}} = 0.8851 \text{ m}^3/\text{kg}$

[20 marks]

Given
 400 rpm $\dot{m} = 5 \text{ kg/s}$
 $P = 2 \text{ bar}$ $x = 0.96$
 1 stage $P = 4.4 \text{ kW}$
 $v_{ax} = 0.72 (v)$
 tip leakage = 5%
 Parson turbine = 50% reaction
 $V_{a1} = V_{a2}$
 $V_{w2} = V_1$
 $\alpha = \beta$
 $\beta = 0$

(Given) $\phi = 20^\circ$

$$Q_g = 0.885 \text{ m}^3/\text{kg}$$

$$Q_1 = 0.96 \times 0.885$$

$$= 0.8496$$

$$\text{m}^3/\text{kg}$$

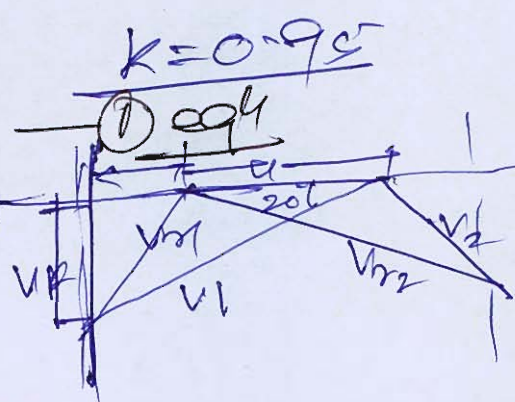
$$Q = Q_1 \times m$$

$$= 4.24848 \text{ m}^3/\text{s}$$

$$Q = k \times \pi D B \times V_F$$

$$P_d = \dot{m} (V_{u01} + V_{u02}) C_{u1}$$

$$4.4 \times 10^3 = 5(u) ($$

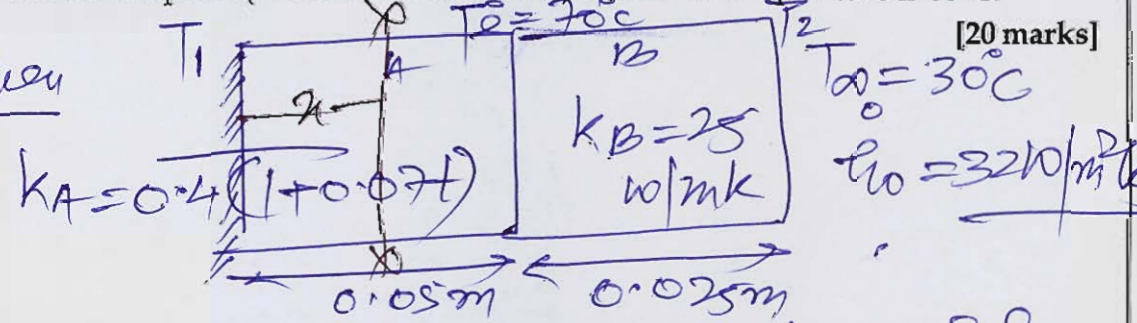


3

- Q.2 (c) An infinite composite slab is made of two layers A and B of different materials. The layer A is 5 cm thick, has thermal conductivity $0.4 (1 + 0.07 t)$ W/mK, where t is the temperature in $^{\circ}\text{C}$, and its exposed surface is insulated (There is a very thin source of heat). The layer B is 2.5 cm thick, has thermal conductivity 25 W/mK and its outside surface is exposed to a fluid at 30°C where the convective heat transfer coefficient is $32 \text{ W/m}^2\text{K}$. The temperature at the interface between the two layers is estimated to be 70°C . Determine:

1. rate of heat flux from the slab to the fluid.
2. maximum temperature in the system, and
3. location of the point (from insulated surface) where the temperature is 80°C .

Soln



[20 marks]

T_1 $T_2 = 70^{\circ}\text{C}$ $T_{\infty} = 30^{\circ}\text{C}$

$k_A = 0.4(1 + 0.07t)$ $k_B = 25 \text{ W/mK}$ $h_0 = 32 \text{ W/m}^2\text{K}$

0.05 m 0.025 m

$q_{\text{conduction}} = q_{\text{convection at outside}}$

$\frac{T_2 - T_2}{(L_B / k_B A)} = h_0 \times A (T_2 - T_{\infty})$

$\frac{(70 - T_2) \times 25}{0.025} = 32 \times (T_2 - 30)$

$$70 - T_2 = 0.032 T_2 - 0.96$$

$$T_2 = 68.759^\circ\text{C}$$

$$\begin{aligned} \text{Rate of heat loss} &= h_0(T_2 - T_\infty) \\ &= 32 \times (68.759 - 30) \\ q'' &= 1240.288 \text{ W/m}^2 \end{aligned}$$

Since at $\frac{\partial T}{\partial x} = 0$ and q'' is at $\frac{\partial T}{\partial x} = 0$ surface

$$T_1 = T_{\text{max}}$$

$$q_A = q_B = \frac{T_1 - T_\infty}{\frac{L_A}{(k_m)(A)}} = q''(A)$$

$$\Rightarrow \frac{(T_1 - 70)}{0.05} (0.4 (1 + 0.07 (T_1 + 70))) = 1240.288$$

$$(T_1 - 70) (1 + 0.07 (T_1 + 70)) = 155.036$$

$$(T_1 - 70) (2 + 0.07 T_1 + 4.9) = 310.072$$

$$(T_1 - 70) (0.07 T_1 + 6.9) = 310.072$$

$$(0.07 T_1^2 + 6.9 T_1 - 4.9 T_1 - 483) = 310.072$$

$$0.07 T_1^2 + 2 T_1 - 793.072 = 0$$

$$T_1 = 93.109^\circ\text{C}$$

$$T_{\text{max}} = 93.109^\circ\text{C}$$

(let) at x m from Insulating surface
 $T_\infty = 80^\circ\text{C}$, $q'' = q_c = \frac{(T_1 - T_\infty) k_m}{L_A}$

$$1240.288 = 0.4 (1 + 0.07 (\frac{93.109 + 80}{2})) (\frac{93.109 - 80}{x})$$

$$1240.288 = 2.8235 (\frac{93.109 - 80}{x})$$

$$1240.288 = \frac{3701036}{n}$$

$$\lambda = 0.0298 \text{ m} \\ = 2.98 \text{ cm}$$

from insulating surface of pipe

20

Q.3 (a) A water heater tank contains 150 kg of water at 6 bar and 15°C. The water is to be heated to 6 bar and 75°C. Assume that the pressure is maintained constant by an internal diaphragm. The environment is at 1 bar and 10°C. Calculate

- (i) The change in the availability of the water.
- (ii) The total change in availability when heated electrically.
- (iii) The total availability change when heated by condensing steam at $p = 1$ bar.
- (iv) The irreversibility when heated electrically.
- (v) The irreversibility when heated by condensing steam at $p = 1$ bar.

[Use Steam Tables attached at the end]

[20 marks]

Q.3 (b) The impeller of a centrifugal pump has an outer diameter of 27 cm and rotates at a speed of 1440 rpm. The impeller has 10 blades, each of 6 mm thickness. The blades are backward facing at 35° to the tangent. The breadth of the flow passages at the outlet is 12 mm. Pressure gauges are fitted close to the pump at the suction and discharge pipes and both are 2.4 m above the water level of the supply sump. When the discharge is 25 L/S, the pressure readings are 4 m water (vacuum) in the suction end and 16 m of water (gauge) at the delivery end of the pump. If 50% of the velocity is recovered as static head in the volute. If mechanical efficiency of the pump is 0.85. Determine:

- (i) Theoretical head
- (ii) Manometric efficiency
- (iii) Losses in the impeller
- (iv) Capacity of the motor to drive the pump

[Assume that there is no whirl at inlet and no whirl slip]

[20 marks]





Q.3 (c) A very long, 10 mm diameter copper rod ($k = 370 \text{ W/mK}$) is exposed to an environment at 20°C . The base temperature of the rod is maintained at 120°C . The heat transfer coefficient between the rod and the surrounding air is $10 \text{ W/m}^2\text{K}$.

- (i) Determine the heat transfer rate for finite lengths, 0.02, 0.04, 0.08, 0.2, 0.4, 0.8, 1 and 10 meters assuming heat loss at the end, and
- (ii) Compare the results with that of an infinitely long fin whose tip temperature equals the environment temperature of 20°C .

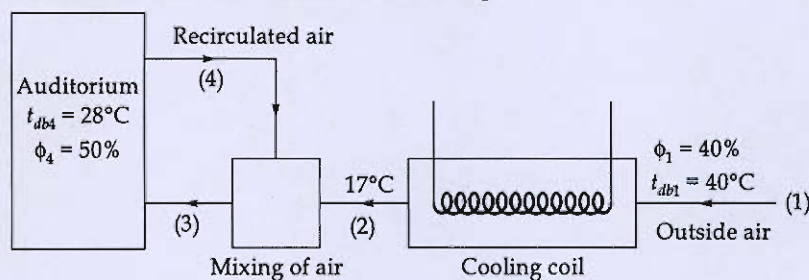
[20 marks]



Q.4 (a) An air-conditioned auditorium is to be maintained at 28°C DBT and 50% R.H. as shown in figure. The ambient condition is 40°C DBT and 40% R.H. The total sensible heat load is 34 kW and the total latent heat load is 45000 kJ/h. 65% of the return air is recirculated and mixed with 35% of make up air after the cooling coil. The condition of air leaving the coil is 17°C . Determine:

- (i) Room sensible heat factor.
- (ii) Condition of air entering the auditorium
- (iii) Amount of make up air
- (iv) Apparatus dew point
- (v) By pass factor of the cooling coil

[Use Psychrometric chart attached at the end]



[20 Marks]



Q.4 (b) Explain the working principles of a Cyclone separator and a bag filter used in particulate matter removal from industrial flue gases with the help of neat sketches.

[20 Marks]



- Q.4 (c) A vertical gate of width B and height H retains water on one side upto its top edge. Find the depths of two horizontal lines which divide the gate into three portions such that the total pressure on each portion is equal. Also locate the position of the centre of pressure for each of the three portions. Hence show that if a gate is divided into N such portions each of which is subjected to equal total pressure then the height of the each portion is given by

$$h_n = H \sqrt{\frac{n}{N}}$$

and the depth of centre of pressure for each portion below the top of the gate is given by

$$\bar{h}_n = \frac{2}{3} H \frac{[n^{3/2} - (n-1)^{3/2}]}{\sqrt{N}}$$

where $n = 1, 2, 3, \dots, N$

[20 marks]





Section : B

- Q.5 (a) A single basin type tidal power plant has a basin area of 4 km^2 . The tidal range of 12 m on average. Power generation is carried out only during the flood cycle and the turbine stops operating when the head on it falls below 3.6 m. Assuming the density of seawater to be 1027 kg/m^3 and the turbine-generator efficiency as 72%. Determine:
- The average power output (in MW) generated during a single filling of the basin.
 - The average annual energy output (in kWh) of the plant, assuming two tidal cycles per day and 365 days in a year.

[12 marks]

Given $A = 4 \text{ km}^2$ $R = 12 \text{ m}$ $R_2 = 3.6 \text{ m}$
 $\rho = 1027 \text{ kg/m}^3$ $\eta_{TG} = 72\%$

$$P_{av} = \left(\frac{1}{2} \frac{\rho A g (R^2 - R_2^2)}{t} \right) \quad \text{Given only one flood cycle}$$

$$t = 22350 \text{ sec}$$

$$P_{av} = \frac{1}{2} \times 0.72 \times 1027 \times 4 \times 10^6 \times 9.81 \times (12^2 - 3.6^2) \div 22350$$

$$P_{av} = 85.06 \text{ MW}$$

average annual energy output (kWh)
 two tidal cycle/day and 365 days

12 Hence total no. of cycle per year $= 365 \times 2 \times 360$
 $= 705.8$
 $= 706$

$$\begin{aligned} \text{Average energy} &= \frac{1}{2} \times \eta_{TG} \times \rho A g (R^2 - R_2^2) \times 706 \\ &= \frac{1}{2} \times 0.72 \times 1027 \times 4 \times 10^6 \times 9.81 \times (12^2 - 3.6^2) \times 706 \\ &= 3.7282 \times 10^8 \text{ kWh} \end{aligned}$$

- Q.5 (b) A merchant ship coming into port has a draught of 1.25 m. After unloading its cargo it has a draught of 1 m. Find the ratio of the periodic times before and after leaving the cargo if the breadth of the ship is 7 m and it is assumed that the centre of gravity remains at the water line.

[12 marks]

1

- Q.5 (c) What is the function of a thermostatic expansion valve used in vapour compression refrigeration systems? Discuss with the help of a neat sketch the working of an internally equalized thermostatic expansion valve. How does it differ from an externally equalized thermostatic expansion valve?

[12 marks]

- Q.5 (d) An axial flow compressor of 50% reaction blading has isentropic efficiency of 82%. It draws air at 17°C and compresses in the pressure ratio of 4 : 1. The mean blade speed and flow velocity are constant throughout the compressor. The inlet and outlet angles of blades are 45° and 15° respectively (angles measured from axial direction). Blade speed = 180 m/s and work input factor = 0.84 . Calculate (i) flow velocity and (ii) number of stages.

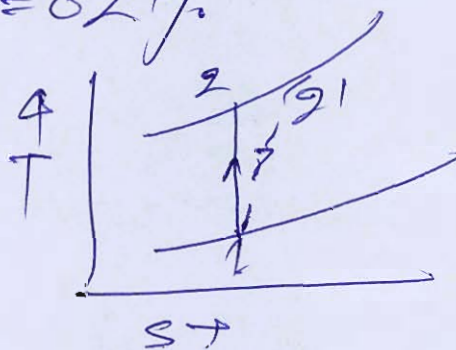
[12 marks]

Given $R = 0.5$ $\eta_{is} = 82\%$

$$T_1 = 17^\circ\text{C} = 290\text{ K}$$

$$\alpha_p = 4$$

$$\left[\begin{array}{l} \beta_1 = 45 = \alpha_2 \\ \beta_2 = 15 = \alpha_1 \\ V_{r1} = V_2 \\ V_{r2} = V_1 \end{array} \right]$$



$$u = 180\text{ m/s} \quad \phi_{sa} = 0.84$$

50% reaction
blade
+ cubic

$$T_2 = T_1 (\alpha_p)^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = 290 (4)^{\frac{0.4}{1.4}}$$

$$T_2 = 430.929\text{ K}$$

$$(\text{Work input to compressor}) = c_p (T_2' - T_1)$$

$$\eta_s = \frac{T_2 - T_1}{T_2' - T_1}$$

$$W_{su} = \frac{c_p (T_2 - T_1)}{\eta_s}$$

$$W_{su} = \frac{1.005 \times (430.929 - 290)}{0.82} = 172.724 \text{ kJ/kg}$$

$$u = V_f (t_{m1} + t_{m2})$$

$$u = V_f (t_{m2} + t_{m1}) \quad (L_1 = \beta_2)$$

$$V_f = \frac{180}{t_{m15} + t_{m45}}$$

$$V_f = 141.96 \text{ m/s} \quad \text{# AS}$$

$$W_{su} = \eta \times \phi_{su} \times V_f \times u (t_{m\beta_1} - t_{m\beta_2})$$

$$\eta = \text{no. of stage}$$

$$172.724 \times 10^3 = \eta \times 0.84 \times 141.96 \times 180 \times (t_{m45} - t_{m15})$$

(12)

$$\eta = 10.99 \approx 11$$

$$\eta = 10.99 \approx 11$$

AS
stage

Q.5 (e) What are the components of a photovoltaic (PV) system? How long do PV systems last? What's the difference between PV and other solar energy technologies? Briefly explain.
[12 marks]

Q.6 (a) What is a fuel cell and what are its main advantages? Classify fuel cells based on

- (i) Type of electrolyte
- (ii) Types of the fuel and oxidant
- (iii) Operating temperature
- (iv) Application
- (v) Chemical nature of electrolyte

- It converts chemical energy of fuel into electrical energy. [20 marks]
- It is static power conversion device in which two electrodes namely anode and cathode are used.
fuel such as H_2 / N_2H_4 / CH_3OH etc are supplied at anode and air or oxygen is supplied at cathode.
the space between the electrodes and cathode is filled with electrolyte which allows the exchange of ions and completes the electrical circuit.

Hence due to exchange of ions the electrical current flows through external circuit.

Advantages - of static power conversion device Hence free from any vibration.

- chemical energy converted into directly electrical energy hence no mechanical constraint efficiency can be 100%.
- It does not require any water cooling.
- Maintenance and inspection is easy and less costly.

classification

types of electrolyte

- ① Phosphoric acid fuel cell
- ② Alkaline fuel cell
- ③ Proton Exchange Membrane fuel cell
- ④ ~~Direct~~ Molten fuel cell
- ⑤ Metal carbonate fuel cell
- ⑥ Solid oxide fuel cell

types of fuel and oxidant

<u>Primary</u>	<u>Secondary</u>
H_2 / N_2H_4 / CH_3OH	CH_3OH

Operating temperatures

- low temperature fuel cell (50-150°C)

- Medium Temp. fuel cell (50-250°C)
- High temperature fuel cell (250-600°C)
- Very high temperature fuel cell (600-1100°C)

Chemical Nature of Electrolyte

- Acidic Electrolyte fuel cell
- Basic Electrolyte fuel cell
- Neutral Electrolyte fuel cell

Applications

- Transportation
- Aviation
- Portable applications

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Q.6 (b) A six cylinder four stroke CI engine develops 150 kW output at 1600 rpm. The calorific value of the fuel is 42000 kJ/kg and its percentage composition by mass is 85% carbon, 14% hydrogen and 1% non-combustibles. The absolute volumetric efficiency is 83%, the indicated thermal efficiency is 37% and the mechanical efficiency is 78%. The air consumption is 115% in excess of that required for stoichiometric combustion. Estimate the volumetric composition of dry exhaust gas and determine the bore and stroke of the engine taking a stroke/bore ratio as 1.25. Assume the density of the air at the given conditions as 1.26 kg/m³ and air having only 23% of oxygen by mass and 21% by volume.

[20 marks]

Given $k=6$ $n=10/2$ $BP=150 \text{ kW}$
 $N=1600 \text{ rpm}$ $CV=42000 \text{ kJ/kg}$

$(\eta_{co})_{\text{absolute}} = 83\%$ $\eta_{\text{ind}} = 37\%$
 $\eta_m = 78\%$ $\text{air consumption} = 115\% \text{ excess}$

$\frac{L}{D} = 1.25$ $\rho = 1.26 \text{ kg/m}^3$

?



Q.6 (c) In a jet propulsion unit air is drawn into the rotary compressor at 20°C and 1.01 bar and delivered at 4.04 bar . The isentropic efficiency of compression is 80% and the compression is uncooled. After delivery the air is heated at constant pressure until the temperature reaches 720°C . The air then passes through a turbine unit which drives the compressor only and has an isentropic efficiency of 75% before passing through the nozzle and expanding to atmospheric pressure of 1.01 bar with an efficiency of 85% . Neglecting any mass increase due to the weight of the fuel and assuming that R and γ are unchanged by combustion, determine:

- The power required to drive the compressor.
- The air-fuel ratio if the fuel has a calorific value of 42000 kJ/kg .
- The pressure of the gases leaving the turbine.
- The thrust per kg of air per second.

Neglect any effect of the velocity of approach.

Assume for air: $R = 0.287\text{ kJ/kgK}$; $\gamma = 1.4$

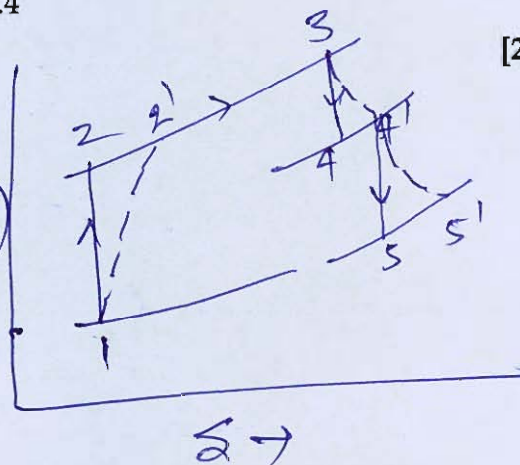
[20 marks]

Given

$$T_1 = 20^\circ\text{C} = 293\text{ K}$$

$$P_1 = 1.01\text{ bar}$$

$$P_2 = 4.04\text{ bar}$$



$$\frac{P_2}{P_1} = \frac{4.04}{1.01} = 4 \quad \eta_c = 80\%$$

$$T_2 = T_1 (P_2/P_1)^{\gamma/\gamma-1} \quad T_2 = 293 (4)^{\frac{0.4}{1.4}}$$

$$\eta_c = \frac{T_2 - T_1}{T_2' - T_1} = \frac{435.38 - 293}{T_2' - 293} \quad T_2' = 435.38 \text{ K}$$

$$T_2' = 470.98 \text{ K}$$

$$T_3 = 720^\circ\text{C} = 993 \text{ K}$$

for turbine of direct compressor

$$(m \dot{m}_a) \times c_p (T_3 - T_4') = m \dot{m}_a c_p (T_2' - T_1)$$

$$(T_3 - T_4') = (T_2' - T_1)$$

$$993 - T_4' = 470.98 - 293$$

$$T_4' = 815.02 \text{ K}$$

$$\eta_T = \frac{T_3 - T_4'}{T_3 - T_4} \Rightarrow 0.75 = \frac{993 - 815.02}{993 - T_4}$$

$$T_4 = 755.69 \text{ K}$$

3-4 process

$$\frac{T_3}{T_4} = (P_3/P_4)^{\gamma/\gamma-1} = \left(\frac{4.04}{P_4} \right)^{\frac{0.4}{1.4}}$$

$$\frac{993}{755.69} = \left(\frac{4.04}{P_4} \right)^{\frac{0.4}{1.4}}$$

$$P_4 = 1.553 \text{ bar}$$

for nozzle

4' → 5

$$P_4 = P_4' = 1.553 \text{ bar}$$

$$P_5 = 1.01 \text{ bar}$$

$$\eta_n = 0.85$$

$$T_5 = \frac{T_4'}{(P_4'/P_5)^{\gamma/\gamma-1}}$$

$$\eta_n = \frac{P_4'}{P_5} = \frac{1.5533}{1.01} = 1.5379$$

$$T_5 = \frac{815.02}{(1.5379)^{0.4}} \times \frac{1.04}{1.04}$$

$$T_5 = 720.704 \text{ K}$$

$$m_7 = \frac{T_4' - T_5'}{T_4' - T_5} \quad 0.85 = \frac{T_4' - T_5'}{815.02 - 720.704}$$

$$T_5' = 734.85 \text{ K}$$

Power required for air to be compressed

$$= c_p (T_2' - T_1)$$

$$= 1.005 (470.98 - 293) = 178.87 \text{ kJ/kg}$$

air fuel ratio

$$m_f \times c_{p,f} = m_a c_p T_3 - m_a c_p T_2'$$

$$m_f \times 42000 = m_a \times c_p (993 - 470.98)$$

$$\left(\frac{m_a}{m_f} \right) = \frac{42000}{1.005 \times 522.02} = 80.05$$

Pressure of gas leaving turbine

$$P_4 = 1.553 \text{ bar}$$

Energy for nozzle

$$\frac{c_4'^2 + c_4'^2}{2000} = \frac{c_5'^2 + c_5'^2}{2000}$$

(neglecting) $\frac{c_5'^2}{2000} = c_p (T_4' - T_5')$

$$c_5' = \sqrt{2000 \times 1.005 \times (815.02 - 734.85)}$$

$$c_5' = 401.42 \text{ m/s}$$

$$F_{\text{nozzle}} = m_a (c_5' - c_a)$$

$$F_{\text{nozzle}} = 401.42 \text{ N (kg)} \quad \#$$

Ans

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Q.7 (a) A tank of volume 0.9 m^3 initially contains liquid vapour mixture at 240°C and dryness fraction is 0.6 . From the top of the tank, saturated water vapour is withdrawn at 240°C through the valve and simultaneously heat is transferred to maintain the constant pressure. This continues till the dryness fraction becomes 0.9 at the same temperature. Neglect the changes in kinetic and potential energy.

(i) Calculate the initial mass in the tank.

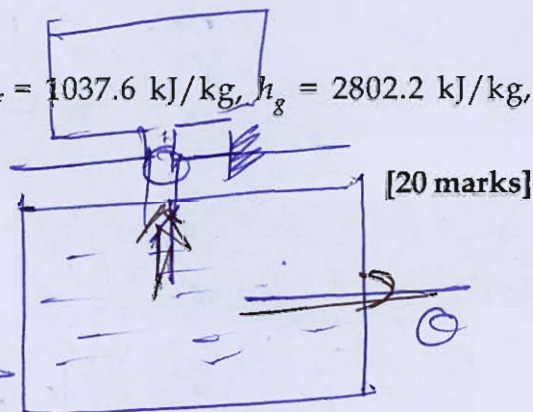
(ii) Calculate the final mass in the tank.

(iii) What is the amount of heat transfer?

Properties at $T = 240^\circ\text{C}$

$$v_f = 0.001229 \text{ m}^3/\text{kg}, v_g = 0.05965 \text{ m}^3/\text{kg}, h_f = 1037.6 \text{ kJ/kg}, h_g = 2802.2 \text{ kJ/kg},$$

$$u_f = 1033.48 \text{ kJ/kg}, u_g = 2602.4 \text{ kJ/kg}$$



Given
Initial condition
 $V = 0.9 \text{ m}^3$
 $T_1 = 240^\circ\text{C}$
 $x_1 = 0.6$

Final condition
 $x_2 = 0.9$
 $T_2 = 240^\circ\text{C}$

at initial condition

$$v_1 = v_f + x_1 v_{fg}$$

$$v_1 = 0.001229 + 0.6 (0.05965 - 0.001229)$$

$$v_1 = 0.0362816 \text{ m}^3/\text{kg}$$

$$m_{\text{initial}} = \frac{V_1}{v_1} = \frac{0.9}{0.0362816}$$

$$m_{\text{initial}} = 24.8 \text{ kg} \quad \underline{\underline{\text{Ans}}}$$

Final mass in tank

$$v_2 = v_f + x_2 v_{fg}$$

$$v_2 = 0.001229 + 0.9 (0.05965 - 0.001229)$$

$$v_2 = 0.0538079 \text{ m}^3/\text{kg}$$

$$m_f = \frac{V}{v_2} = \frac{0.9}{0.0538079}$$

$$m_{\text{final}} = 16.726 \text{ kg}$$

Ans

amount of heat transfer

$$m_2 c_{p2} - m_1 c_{p1} = m_e h_{e2} - m_e h_{e1}$$

$$= m_e h_{e2} - m_e h_{e1}$$

$$= 0 + 10$$

$$m_2 c_{p2} - m_1 c_{p1} = -m_e h_{e1} - 0$$

$$m_2 - m_1 = m_e - m_e$$

$$16.726 - 24.8 = m_e$$

$$m_e = 8.074 \text{ kg}$$

$$C_1 = C_f + x_1 C_{fg}$$

$$= 1033.48 + 0.6(2602.4 - 1033.48)$$

$$C_1 = 1974.832 \text{ kJ/kg}$$

$$C_2 = C_f + x_2 C_{fg}$$

$$= 1033.48 + 0.9(2602.4 - 1033.48)$$

$$C_2 = 2445.508 \text{ kJ/kg}$$

$$h_{e2} = \text{saturated water vapor} = h_g @ 24^\circ\text{C}$$

$$h_{e2} = 2802.2 \text{ kJ/kg}$$

from equation ①

$$m_2 C_2 - m_1 C_1 = -m_e h_{e1} - 0$$

$$\Rightarrow 16.726 \times 2445.508 - 24.8 \times 1974.832$$

$$= -8.074 \times 2802.2 - 0$$

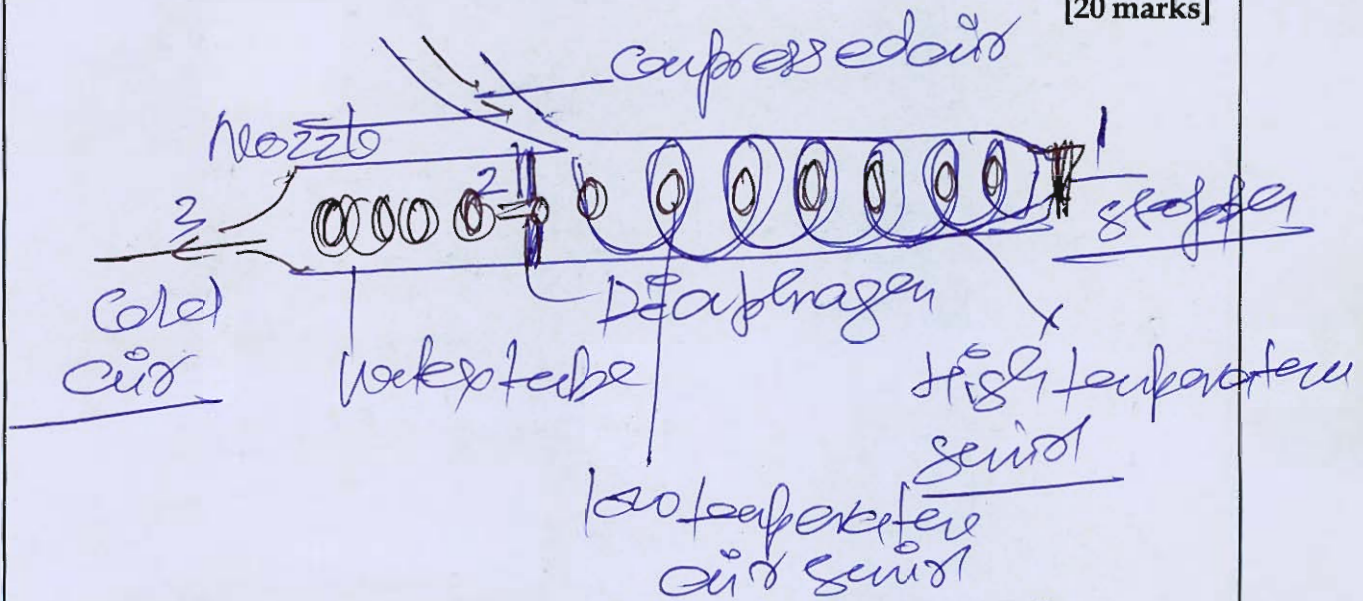
$$-0 = 14552.696 \text{ kJ}$$

$$0 = 14552.696 \text{ kJ} \quad \# \text{ Ans}$$

Negative sign means heat rejected

- Q.7 (b) Explain the construction and working of vortex tube with a suitable schematic diagram. Also draw T-s diagram and mention points clearly.

[20 marks]



It consists of vortex tube, in which compressed air enters through nozzle tangentially at high temperature and pressure as it undergoes forward motion its temperature decreases due to collision with itself and form of spiral (swirl) motion and also with the wall of the vortex tube and by the ~~inter~~ heat transfer from the smaller spiral air motion moving in opposite direction, as it moves forward it becomes hotter and hotter and at the end it stops momentarily by stopper and kinetic energy converted into

pressure energy as pressure at point
1 is more than atmospheric pressure
it causes the backward motion

in the form of low speed which
as backward motion in the tube,
decreases the temperature by heat
transfer to the larger section
moving forward.

at the end it passes through diaphragm
and low temperature air is made
available.

- It has low COP
- low quantity of cold air is easily
available
- It is not suitable for motor load
demand.

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Q.7 (c) Air at temperature of 20°C enters a gas turbine plant working at pressure ratio of 5. Turbine inlet temperature is 780°C . Polytropic efficiency of compressor and turbine is 0.88. Assume, $c_p = 1.005 \text{ kJ/kg-K}$ for air and gases, calorific value of fuel = 42 MJ/kg of fuel. Calculate the following:

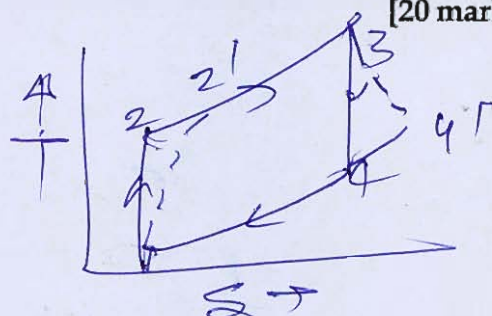
- Specific output of the plant (in kJ/kg of air)
- Overall efficiency of the plant
- Air fuel ratio
- Specific fuel consumption

[20 marks]

Given

$$T_1 = 20^{\circ}\text{C} = 293 \text{ K}$$

$$\text{pr} = 5$$



$$T_3 = 780^{\circ}\text{C} = 1053 \text{ K}$$

$$\eta_c = \eta_t = 0.88$$

$$c_p = 1.005$$

$$\text{C.V.} = 42 \times 10^6 \text{ J/kg of fuel}$$

1-2 process

$$T_2 = T_1 (\text{pr})^{\frac{\gamma}{\gamma-1}}$$

$$T_2 = 293 (5)^{\frac{0.4}{1.4}}$$

$$T_2 = 464.048 \text{ K}$$

$$T_4 = \frac{T_3}{(\text{pr})^{\frac{\gamma}{\gamma-1}}}$$

$$= \frac{1053}{(5)^{\frac{0.4}{1.4}}}$$

$$T_4 = 664.86 \text{ K}$$

$$\eta_c = \frac{T_2 - T_1}{T_2' - T_1} = 0.88 = \frac{464.048 - 293}{T_2' - 293}$$

$$T_2' = 487.37 \text{ K}$$

$$\eta_t = \frac{T_3 - T_4'}{T_3 - T_4} = 0.88 = \frac{1053 - T_4'}{1053 - 664.86}$$

$$T_4' = 711.436 \text{ K}$$

specific work output $\frac{W_{net}}{m} = (h_3 - h_4') - (h_2' - h_1)$

$$= c_p(T_3 - T_4') - c_p(T_2' - T_1)$$

$$= 1.005(1053 - 711.436) - 1.005(487.37 - 293)$$

specific work $= 147.93 \text{ kJ/kg} \quad \# \text{ Ans}$

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$$\eta_{overall} = \frac{W_{net}}{Q_{supp}} = \frac{147.93 \times 100}{c_p(T_3 - T_2')}$$

$$= \frac{147.93 \times 100}{1.005(1053 - 487.37)} = 26.02\%$$

2-3 combustion process $\# \text{ Ans.}$

$$m_{fuel} = (m_a + m_f) c_p T_3 - m_a c_p T_2'$$

$$m_f \times 42000 = \frac{(m_a + m_f) \times 1053 - m_a \times 487.37}{1.005}$$

$$\frac{42000}{1.005} = \frac{(\lambda + 1) \times 1053 - \lambda \times 487.37}{\lambda}$$

$$\lambda = \frac{m_a}{m_f} = 70.89$$

Specific fuel consumption $= \frac{W_{net}}{m_f \times 3600}$

$$= \frac{m_f \times 3600}{m_a (\lambda + 1)}$$

$$= \frac{3600}{70.89 \times 147.93} = 0.343 \text{ kg/kwh}$$

$\# \text{ Ans}$

Q.8 (a) (i) Explain the following terms of solar radiation geometry:

1. Latitude
2. Declination
3. Hour angle

Illustrate these terms with neat sketch.

(ii) Calculate the volume of the fixed dome type biogas digester for the output of the two cows. Also calculate the thermal power available from biogas. Use the following data:

Retention time = 50 days; Dry matter produced = 2 kg/day/cow

Biogas yield = $0.22 \text{ m}^3/\text{kg}$ of dry matter; Percentage of dry matter in cow dung = 18%

Density of slurry = 1090 kg/m^3 ; Burner efficiency = 60%

Heating value of biogas = 22 MJ/m^3 ;

Digester volume occupied by the gas = 10%

[Add equal amount of water to make the slurry]

[10 + 10 marks]





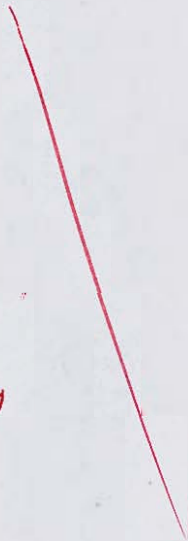
- Q.8 (b) A 4-stroke diesel engine of 3000 c.c. capacity develops 14 kW per m^3 of free air inducted per minute. When running at 3500 rpm it has a volumetric efficiency of 85 percent referred to free air conditions of 1.013 bar and 27°C . It is proposed to boost the power of the engine by supercharging by a blower (driven mechanically from the engine) of the pressure ratio 1.6 and isentropic efficiency of 80 percent. Assuming that at the end of induction the cylinder contains a volume of charge equal to the swept volume at the pressure and temperature of the delivery from the blower? Estimate the increase in brake power to be expected from the engine. Take overall mechanical efficiency as 90 percent.

[20 marks]

|



- Q.8 (c) (i) Explain the different types of condensation based on the condition of the cooling surface, with the help of neat sketches.
- (ii) A reversible cycle using an ideal gas as the working substance consists of an isentropic compression from initial temperature to 555 K, a constant volume process 555 K to 835 K, a reversible adiabatic expansion to 555 K, a constant pressure expansion from 555 K to 835 K followed by a constant volume process to initial temperature. Draw the cycle on p-V and T-s diagrams and determine the initial temperature. Also compute the work done in kJ/kg. Assume $R = 0.287 \text{ kJ/kgK}$, $\gamma = 1.4$.
- [10 + 10 marks]**

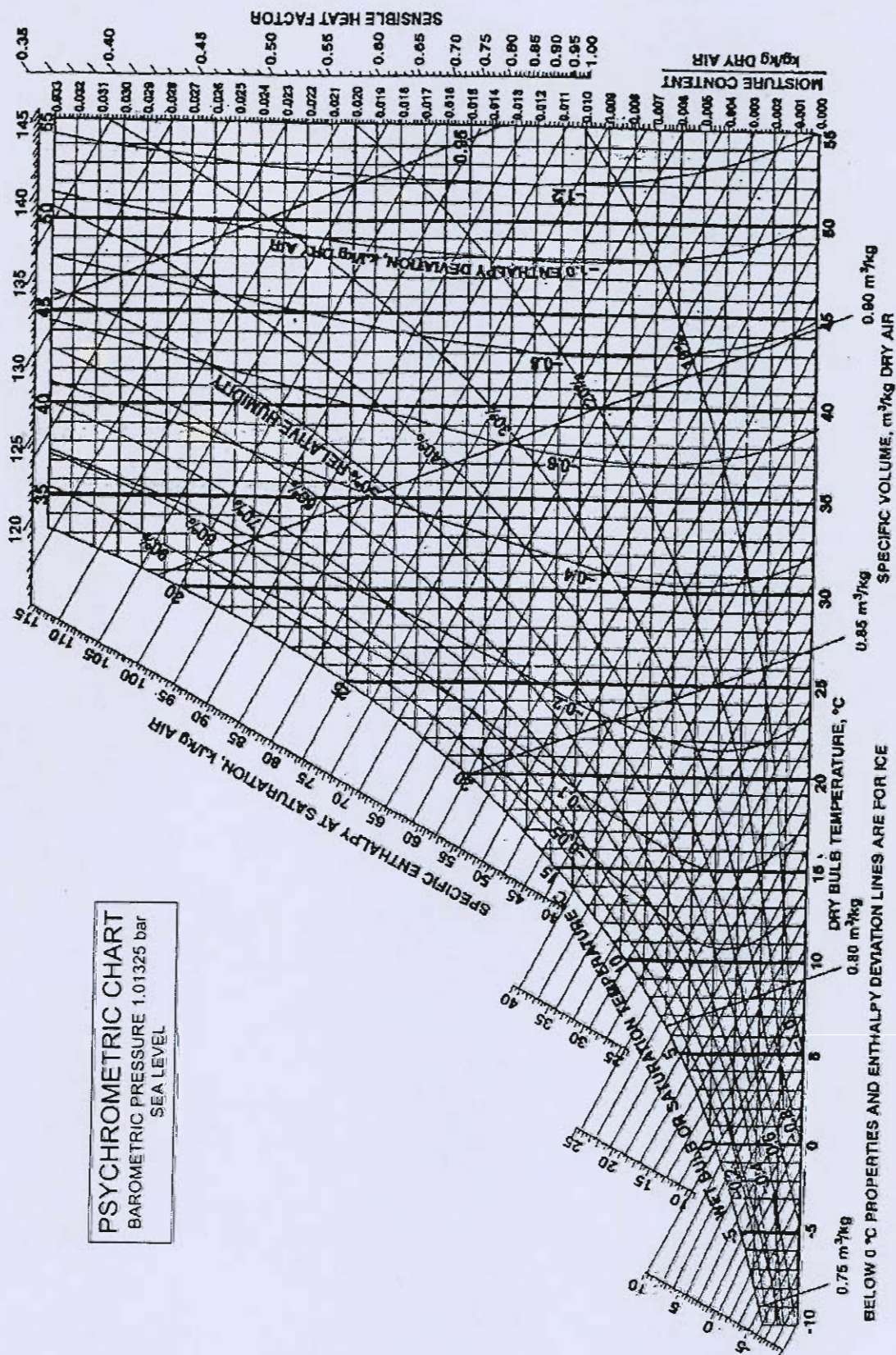


Water/Steam at $p = 0.60 \text{ MPa}$ ($T_{\text{sat}} = 158.826^\circ\text{C}$)

T	v	u	h	s	T	v	u	h	s
$^\circ\text{C}$	m^3/kg	kJ/kg	kJ/kg	kJ/kg K	$^\circ\text{C}$	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
0	0.000999990	-0.03	0.57	-0.00011	270	0.41021	2753.4	2999.5	7.2619
5	0.000999979	21.02	21.62	0.07624	280	0.41831	2769.3	3020.3	7.3000
10	0.00100006	42.01	42.61	0.15103	290	0.42638	2785.4	3041.2	7.3373
15	0.00100067	62.95	63.55	0.22437	300	0.43442	2801.3	3062.0	7.3740
20	0.00100157	83.88	84.48	0.29636	310	0.44243	2817.3	3082.8	7.4100
25	0.00100273	104.78	105.38	0.36707	320	0.45042	2833.3	3103.6	7.4453
30	0.00100415	125.68	126.28	0.43657	330	0.45839	2849.4	3124.4	7.4801
35	0.00100578	146.57	147.17	0.50492	340	0.46634	2865.5	3145.3	7.5144
40	0.00100762	167.46	168.06	0.57217	350	0.47427	2881.5	3166.1	7.5481
45	0.00100966	188.34	188.95	0.63836	360	0.48219	2897.7	3187.0	7.5813
50	0.00101189	209.24	209.85	0.70354	370	0.49010	2913.8	3207.9	7.6141
55	0.00101429	230.14	230.75	0.76773	380	0.49799	2930.0	3228.8	7.6464
60	0.00101687	251.06	251.67	0.83098	390	0.50587	2946.3	3249.8	7.6782
65	0.00101961	271.98	272.59	0.89333	400	0.51374	2962.6	3270.8	7.7097
70	0.00102251	292.92	293.53	0.95479	410	0.52160	2978.8	3291.8	7.7407
75	0.00102557	313.86	314.48	1.0154	420	0.52945	2995.2	3312.9	7.7713
80	0.00102879	334.83	335.45	1.0752	430	0.53729	3011.6	3334.0	7.8016
85	0.00103217	355.82	356.44	1.1342	440	0.54513	3028.1	3355.2	7.8315
90	0.00103569	376.83	377.45	1.1925	450	0.55296	3044.7	3376.5	7.8611
95	0.00103937	397.86	398.48	1.2500	460	0.56078	3061.2	3397.7	7.8903
100	0.00104321	418.91	419.54	1.3068	470	0.56859	3077.9	3419.1	7.9192
105	0.00104719	440.00	440.63	1.3630	480	0.57640	3094.7	3440.5	7.9478
110	0.00105134	461.12	461.75	1.4184	490	0.58420	3111.4	3461.9	7.9761
115	0.00105564	482.27	482.90	1.4733	500	0.59200	3128.2	3483.4	8.0041
120	0.00106010	503.45	504.09	1.5275	520	0.60758	3162.1	3526.6	8.0592
125	0.00106472	524.69	525.33	1.5812	540	0.62315	3196.1	3570.0	8.1132
130	0.00106951	545.97	546.61	1.6343	560	0.63870	3230.4	3613.6	8.1663
135	0.00107447	567.29	567.93	1.6869	580	0.65424	3265.0	3657.5	8.2183
140	0.00107961	588.67	589.32	1.7390	600	0.66976	3299.8	3701.7	8.2695
145	0.00108492	610.11	610.76	1.7905	620	0.68528	3334.9	3746.1	8.3198
150	0.00109042	631.61	632.26	1.8417	640	0.70078	3370.3	3790.8	8.3693
155	0.00109611	653.16	653.82	1.8923	660	0.71628	3405.9	3835.7	8.4180
158.826	0.00110060	669.72	670.38	1.9308	680	0.73176	3441.8	3880.9	8.4659
158.826	0.31558	2566.8	2756.1	6.7592	700	0.74725	3478.0	3926.4	8.5131
160	0.31668	2569.0	2759.0	6.7659	720	0.76272	3514.6	3972.2	8.5597
165	0.32129	2578.3	2771.1	6.7937	740	0.77819	3551.3	4018.2	8.6056
170	0.32583	2587.5	2783.0	6.8206	760	0.79365	3588.3	4064.5	8.6508
175	0.33032	2596.4	2794.6	6.8466	780	0.80911	3625.6	4111.1	8.6954
180	0.33475	2605.1	2806.0	6.8720	800	0.82457	3663.2	4157.9	8.7395
185	0.33915	2613.8	2817.3	6.8968	820	0.84002	3701.0	4205.0	8.7830
190	0.34350	2622.4	2828.5	6.9211	840	0.85547	3739.1	4252.4	8.8260
195	0.34783	2630.9	2839.6	6.9449	860	0.87091	3777.6	4300.1	8.8684
200	0.35212	2639.3	2850.6	6.9683	880	0.88635	3816.2	4348.0	8.9103
210	0.36063	2656.0	2872.4	7.0139	900	0.90178	3855.1	4396.2	8.9518
220	0.36905	2672.5	2893.9	7.0580	920	0.91722	3894.4	4444.7	8.9927
230	0.37740	2688.9	2915.3	7.1008	940	0.93265	3933.8	4493.4	9.0332
240	0.38568	2705.1	2936.5	7.1426	960	0.94808	3973.6	4542.4	9.0733
250	0.39390	2721.3	2957.6	7.1832	980	0.96351	4013.5	4591.6	9.1129
260	0.40208	2737.3	2978.5	7.2230	1000	0.97893	4053.7	4641.1	9.1521
270	0.41021	2753.4	2999.5	7.2619					

Ref. Point for S.H.F. is 25°C, 50% R.H.

Do not write your Roll No. on this Sheet



Space for Rough Work

Space for Rough Work

Space for Rough Work
