Indian Forest Service
(Main) Exam, 2021

ZCVB-B-MCHE

MECHANICAL ENGINEERING

Paper – II

Time Allowed : ***Three*** *Hours*

Maximum Marks : ***200***

Question Paper Specific Instructions

Please read each of the following instructions carefully before attempting questions :

There are ***EIGHT*** *questions in all, out of which* ***FIVE*** *are to be attempted.*

Questions no. ***1*** *and* ***5*** *are* ***compulsory****. Out of the remaining* ***SIX*** *questions,* ***THREE*** *are to be attempted selecting at least* ***ONE*** *question from each of the two Sections A and B.*

Attempts of questions shall be counted in sequential order. Unless struck off, attempt of a question shall be counted even if attempted partly. Any page or portion of the page left blank in the Question-cum-Answer Booklet must be clearly struck off.

All questions carry equal marks. The number of marks carried by a question/part is indicated against it.

Unless otherwise mentioned, symbols and notations have their usual standard meanings.

Assume suitable data, if necessary and indicate the same clearly.

Neat sketches may be drawn, wherever required.

Newton may be converted to kgf using the equality 1 kilonewton (1 kN) ---- 100 kgf, if found necessary.

All answers should be in SI units.

Answers must be written in ***ENGLISH*** *only.*

Take : 1 kcal = 4·187 kJ and 1 kg/cm^2 *– 0·98 bar*

1 bar = 10^5 *pascals*

Universal gas constant = 8314·6 J/kmol-K

Psychrometric chart is enclosed.

SECTION A

Q1. (a) Derive the following Clausius-Clapeyron equations :

$$\frac{dP}{dT} = \frac{h_{fg}}{T(V_g - V_f)}$$

and

$$\frac{dP}{P} = \frac{h_{fg}}{RT^2} dT$$

Also explain the physical significance of these equations. *8*

(b) An iron cube at a temperature of 400°C is dropped into an insulated bath containing 10 kg water at 25°C. The water finally reaches a temperature of 50°C at steady state. Given that the specific heat of water is 4186 J/kg K. Find the entropy changes for the iron cube and the water. Is the process reversible or irreversible ? (Take 0°C as datum) *8*

(c) A 12-cylinder, two-stroke cycle CI engine produces 2440 kW of brake power at 550 rpm using stoichiometric light diesel. The engine has bore of 24 cm, stroke of 32 cm, volumetric efficiency of 97%, mechanical efficiency of 88%, combustion efficiency of 98% and air-fuel ratio of 14·5. Calculate the mass flow rate of fuel entering into the engine, brake specific fuel consumption, indicated specific fuel consumption and specific emissions of hydrocarbons due to unburned fuel. [Take density of air $\rho_a = 1{\cdot}181$ kg/m^3 and R = gas constant for air = 0·287 kJ/kg K] *8*

(d) What are the various methods for the determination of convection heat transfer coefficient ? Explain briefly. *8*

(e) A gray, diffuse opaque surface ($\alpha = 0{\cdot}8$) is at 100°C and receives an irradiation of 1000 W/m^2. If the surface area is 0·1 m^2, calculate,

(i) Radiosity of the surface.

(ii) Net radiative heat transfer rate from the surface.

(iii) Also calculate the above quantities, if the surface is black. Take $\sigma = 5{\cdot}67 \times 10^{-8}$ W/m^2 K^4 *8*

Q2. (a) Oil is being cooled by water in a tube-in-tube parallel flow type heat exchanger. The water enters the inner tube at 15°C and is heated to 50°C. The oil flows in the annulus and is cooled from 130°C to 60°C. Calculate :

(i) Exit temperature of each of the fluids, if the existing heat exchanger is operated as a counter flow heat exchanger,

(ii) The minimum temperature to which oil may be cooled by increasing the tube length with parallel flow operation, and

(iii) The maximum possible effectiveness in parallel flow operation. *15*

(b) A thin hollow stainless steel tube with inner diameter = 7·6 mm and outer diameter = 8 mm is heated with a current of 250 A intensity. The outer surface of the tube is insulated and all the heat generated in the tube wall is transferred through its inner surface. The specific resistance and thermal conductivity of steel are 0·85 $\mu\Omega$m and 18·6 W/mK respectively. Calculate :

(i) Volumetric rate of heat generation in the tube, and

(ii) Temperature drop across the wall. *15*

(c) Why does a nonquasi-equilibrium expansion process deliver less work than the corresponding quasi-equilibrium one ?

A gas of mass 1·5 kg undergoes a quasi-static expansion which follows a relationship :

$$P = a + b\,V, \text{ where a and b are constants.}$$

The initial and final pressures are 1000 kPa and 200 kPa respectively and the corresponding volumes are 0·20 m^3 and 1·20 m^3. The specific internal energy of the gas is given by the relation

$$U = 1{\cdot}5\ PV - 85\ \text{kJ/kg}$$

where P is in kPa and V is in m^3/kg. Calculate the net heat transfer and the maximum internal energy of the gas attained during expansion. *10*

Q3. (a) Mention four points each of advantages and disadvantages of using hydrogen in SI engines. Explain two methods by which hydrogen can be used in CI engines. *15*

(b) What are the reasons for the HC emissions in the exhaust of an automobile ? How are catalytic converters helpful in reducing HC, CO and NO_x emissions ? Why is it good to place a catalytic converter as close to the engine as possible ? *15*

(c) A long thin glass-walled, 0·3 cm diameter, mercury thermometer is placed in an air stream with convection coefficient of 60 W/m^2K for measuring transient temperature of air. Consider cylindrical thermometer bulb consists of mercury only, for which k = 8·9 W/mK and α = 0·016 m^2/h. Calculate the time constant and time required for temperature change to reach half of its initial value. *10*

Q4. (a) An adiabatic turbine receives a gas (C_P = 1·09 kJ/kg K and C_V = 0·838 kJ/kg K) at 7 bar and 1000°C and discharges at 1·5 bar and 665°C. Determine the Second Law Efficiency and Isentropic Efficiency of the turbine. [Take T_0 = 298 K] *15*

(b) Using Maxwell's relations and the thermodynamic definition for C_P and C_V in terms of gradients, show the following :

(i) $$Tds = C_V dT + T\left(\frac{\partial P}{\partial T}\right)_V dV$$
$$= C_P dT - T\left(\frac{\partial V}{\partial T}\right)_P dP$$

(ii) Joule-Thomson coefficient
$$\mu_J = \frac{1}{C_P}\left[T\left(\frac{\partial V}{\partial T}\right)_P - V\right]$$

(iii) Also prove that there is no change in temperature when an ideal gas is made to undergo Joule-Thomson expansion. *15*

(c) State the three main advantages of induction swirl. The spark plug is fired at 18° bTDC in an engine running at 1800 rpm. It takes 8° of engine rotation to start combustion and get into flame propagation mode. Flame termination occurs at 12° aTDC. Bore diameter is 8·4 cm, and the spark plug is offset by 8 mm from the centreline of the cylinder. The flame front can be approximated as a sphere moving out from the spark plug. Calculate the effective flame front speed during flame propagation. *10*

SECTION B

Q5. (a) Mention the different factors to be considered for selecting the site of hydroelectric power plants. *8*

(b) Discuss the various pollutants emitting from a steam power plant. *8*

(c) Distinguish between Turbomachines and Positive Displacement Machines in respect of the following :

(i) Basic mechanism of energy transfer,

(ii) Features of applications, and

(iii) Features of mechanical construction. *8*

(d) What is an Economiser ? Mention the advantages gained by using Economisers in a modern power plant. *8*

(e) Explain the psychrometric process of steam injection. Give its applications. *8*

Q6. (a) Distinguish among Fans, Blowers and Compressors.

A compressor draws air from the atmosphere at 1·5 bar and 300 K at a velocity of 80 m/s. The isentropic efficiency of the compressor is 70%. The stagnation pressure ratio is 3·2. Find the stagnation pressure at the exit and the power of the driving motor if the mechanical efficiency is 90% for a flow rate of 30 kg/minute. *15*

Take for air

$\gamma = 1{\cdot}4$

$C_P = 1{\cdot}004$ kJ/kg K

(b) It is required to design an air-conditioning system for an industrial process for the following conditions :

Outdoor conditions : 32°C DBT and 65% RH

Inside design conditions : 25°C DBT and 60% RH

Volume flow rate of outside air : 195 m^3/min

Coil ADP : 13°C

The required condition is achieved by first cooling and dehumidifying the outside air and then by heating.

Calculate the following :

(i) The cooling capacity of the cooling coil and its bypass factor.

(ii) Heating capacity of the heating coil in kW and surface temperature of the heating coil if its bypass factor is 0·35.

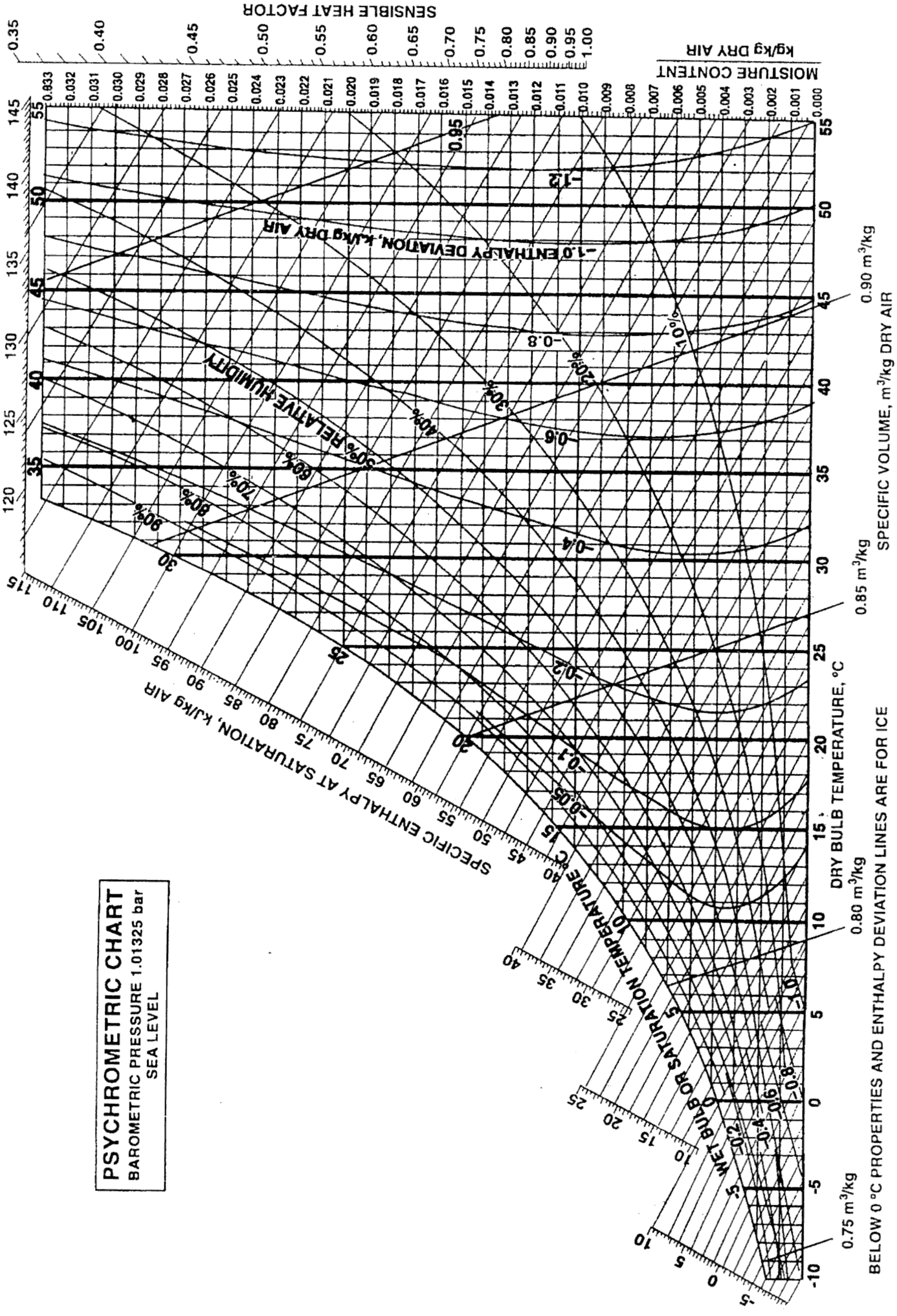
(iii) The mass of water vapour removed per hour.

Show all processes on a psychrometric chart along with a schematic diagram to carry out the above processes. *15*

(Psychrometric chart is attached)

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

Do not write your Roll No. on this Sheet



(c) Explain the effect of increase in condenser temperature on the performance of vapour compression system. Draw T-S and P-h diagrams also. *10*

Q7. (a) A single cylinder, single acting compressor having bore and stroke of 16 cm and 24 cm respectively runs at a speed of 120 rpm and the indicated mean effective pressure is 2·2 bar. The pressure limits of the refrigeration system operating on ammonia are 9·74 bar and 2·47 bar and the temperatures of refrigerant at entry to and exit from condenser are 40°C and 17°C respectively. The cooling water flow across the condenser is 15·45 kg/min and inlet and outlet temperatures of cooling water are 16°C and 24°C respectively. The mass of ice produced per hour from water at 20°C is 56 kg. Assume the latent heat of ice as 335 kJ/kg. Calculate the following :

(i) Compressor power in kW

(ii) Mass flow rate of ammonia/min

(iii) Coefficient of performance

(iv) Dryness fraction of ammonia entering the compressor

The relevant properties of ammonia are given in the table :

Pressure, P (bar)	Saturation Temperature, T_S (°C)	Enthalpy (h), (kJ/kg)		Specific heat C_P, (kJ/kg K)	
		Liquid	Vapour	Liquid	Vapour
9·74	24	312·87	1482·53	4·61	2·87
2·47	– 14	135·82	1445·2	–	–

Take C_P for water as 4·1868 kJ/kg K.

Draw T-S and P-h diagrams also. The state of ammonia is wet vapour at entry to compressor as mentioned in (iv). If the state of ammonia at entry to compressor is either dry saturated or superheated, then comment what will happen to COP and why. *20*

(b) Explain Load Curves. Distinguish between Base Load and Peak Load power plants. *10*

(c) For a single stage compressor, the pressure, temperature and velocity of air at the inlet are 120 kPa, 300 K and 12 m/s, respectively. The values of the pressure, temperature and velocity at the exit are 220 kPa, 380 K and 90 m/s, respectively. The exit is 2 m above the inlet. Determine,

(i) Actual work,

(ii) Isentropic work, and

(iii) Efficiency of the compressor. *10*

For air, take

$\gamma = 1 \cdot 4$

$C_P = 1 \cdot 004$ kJ/kg K.

Q8. (a) The following data are related to the design of a single-sided centrifugal compressor :

Power input factor $(\psi) = 1 \cdot 02$

Slip factor $(\sigma) = 0 \cdot 8$

Rotational speed (N) = 300 rev/s

Overall diameter of impeller = 0·6 m

Eye-tip diameter = 0·4 m

Eye-root diameter = 0·2 m

Air mass flow $(\dot{m})$ = 10 kg/s

Inlet stagnation temperature (T_{01}) = 300 K

Inlet stagnation pressure (P_{01}) = 1·1 bar

Isentropic efficiency (η_i) = 77%

Density of air (ρ_a) = 1·185 kg/m^3

Effective efficiency of compression (η_{ec}) = 88%

R_{air} = 0·287 kJ/kg K, C_P (air) = 1·005 kJ/kg K

Take $(\gamma/\gamma - 1)_{air} = 3 \cdot 5$ and $C_{r2} = C_{a1}$.

Determine,

(i) Pressure ratio of the compressor and the power required to drive it, assuming that the velocity of the air at inlet is axial,

(ii) Inlet angle of the impeller vanes at root and tip radii of the eye, assuming that the axial inlet velocity is constant across the eye annulus, and

(iii) Axial depth of the impeller channels at the periphery of the impeller. *20*

(b) A water turbine of runner diameter 1·2 m works with a head of 112 m of water, 5 m^3/sec of flow and produces a power of 2700 kW at a speed of 400 rpm. A one-fourth size model of the water turbine is required to be tested in a laboratory. The maximum head available in the laboratory is 8 m of water. Determine,

(i) the flow rate required to be planned,

(ii) the speed at which the model is to be tested, and

(iii) the output of the model. *10*

(c) Give the mass balance of a steam generator. *10*