Indian Forest Service (Main) Examination, 2024

JBNV-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.

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

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.

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) A researcher measures that a refrigerator consumes 2 kW power, has removed 30,000 kJ of heat from a refrigerated space, is maintained at – 28°C. The ambient temperature is 22°C and the running time of the refrigerator for the process is 18 minutes. Determine if these measurements are reasonable. *8*

(b) Explain the term chemical equilibrium. How are equilibrium products of combustion different from non-dissociated species ? Also explain the effect of temperature on the equilibrium composition. *8*

(c) What is adiabatic flame temperature ? How is it calculated for a given hydrocarbon fuel ? Explain the factors which influence the adiabatic flame temperature for a given fuel-air mixture at a particular equivalence ratio. *8*

(d) What is the typical range of convective heat transfer coefficient for the following cases ? *8*

(i) Gases in free convection

(ii) Liquids in free convection

(iii) Gases in forced convection

(iv) Liquids in forced convection

(e) A three-cylinder, four-stroke cycle SI engine having bore 68·5 mm and stroke 72·0 mm runs at 3000 rpm with air – fuel ratio 15 : 1 and develops indicated mean effective pressure 10 bar. Calorific value of the fuel used is 44,000 kJ/kg. Mechanical efficiency is 0·85, combustion efficiency is 0·97 and volumetric efficiency is 0·9. Density of air is 1·18 kg/m^3. Determine : *8*

(i) Indicated power in kW

(ii) Rate of air flow into the engine in kg/s

(iii) Brake thermal efficiency

(iv) Brake specific fuel consumption in kg/kWh.

Q2. (a) Helium gas is throttled steadily from 450 kPa and 65°C. During the process, 2·5 kJ/kg of heat is released from it to the surroundings at 25°C and 100 kPa. If the entropy of the helium increases by 0·20 kJ/kg K in the valve, determine the temperature and pressure at the exit and the entropy generation during the process. The following properties of helium may be used for calculations : *15*

$R = 2{\cdot}0769$ kPa m^3/kg K

$C_p = 5{\cdot}1926$ kJ/kg K

(b) The compression ratio of an engine working on Diesel cycle is 20. The temperature at the end of compression is 1050 K. The calorific value of the fuel is 42000 kJ/kg and the specific heat at constant pressure of the products of combustion is given by $C_p = (0{\cdot}997 + 28 \times 10^{-6}\ T)$ kJ/kg K. Combustion is completed at 6·5% of the stroke. Determine the air – fuel ratio. *15*

(c) The temperature of air stream in a tube is measured with the help of a thermometer placed into a protective well filled with oil. The thermometer well is made of a steel tube (k = 53 W/mK), 120 mm long and 1·5 mm thick. The surface heat transfer coefficient from the air to the protective well is 22 W/m^2K and the temperature recorded by the thermometer is 85°C. Estimate the measurement error if the temperature at the base of the well is 40°C. *10*

Q3. (a) A four-stroke six-cylinder CI engine develops 240 kW when running at 1000 rpm. The specific fuel consumption is 0·24 kg/kWh. The values of pressure of air in the cylinder at the beginning of injection and at the end of injection are 40 bar and 60 bar, respectively. The fuel injection pressures at the beginning and end of injection are 200 and 600 bar, respectively. Assume the effective pressure difference to be the average pressure difference during the injection period. Take the coefficient of discharge for the injector to be 0·6 and the density of fuel to be 850 kg/m^3. Determine the nozzle area required per injector if the injection is carried out during the 12° rotation of the crank. If the number of orifices used in a nozzle are two, find the diameter of an orifice. *15*

(b) (i) What are the important components present in modern automotive diesel vehicle Common Rail Direct Injection (CRDI) systems ? Briefly explain how this system differs from inline injector system present in conventional multi-cylinder diesel engines. *10*

(ii) Briefly explain the NO formation mechanism in the cylinder during combustion in IC engines. *5*

(c) Consider a 300 litre storage water heater initially filled with warm water at 40°C. The warm water is taken out from the storage tank through a 2 cm diameter hose at an average velocity of 0·5 m/s while cold water enters the tank at 22°C at a rate of 5 lpm. Determine the amount of water in the storage water heater after 15 minutes. Assume the pressure in the storage tank remains constant at 1 atm. *10*

Q4. (a) Water is heated while flowing through a 1·5 cm × 3·5 cm rectangular cross-section tube at a velocity of 1·2 m/s. The entering temperature of water is 40°C, and the tube wall is maintained at 85°C. Determine the length of tube required to raise the temperature of water to 70°C. Properties of water at mean bulk temperature of 55°C are as under : ρ = 985·5 kg/m^3, C_p = 4·18 kJ/kg K, ν = 0·517 × 10^{-6} m^2/s, k = 0·654 W/mK and Pr = 3·26. Assume fully developed flow. Use the empirical correlation $Nu_d = 0{\cdot}023\ Re_d^{0{\cdot}8}\ Pr^n$, where n = 0·3 for cooling and 0·4 for heating. *15*

(b) An insulated piston-cylinder device contains 2·5 litres of saturated liquid water at a constant pressure of 140 kPa. An electric resistance heater inside the device is turned on and 2100 kJ of electrical work is done on the water.

Assuming the surroundings to be at 25°C and 100 kPa, determine the minimum work with which this process could be accomplished and the energy destroyed during this process. The properties table is attached. *15*

Table of Properties

p	t_s	Specific volume m^3/kg		Specific internal energy, kJ/kg		Specific enthalpy kJ/kg			Specific entropy kJ/kg K		
bar	°C	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0·32	70·6	0·001023	4·92	295·5	2470·3	295·5	2332·4	2627·9	0·962	6·784	7·746
0·34	72·0	0·001024	4·65	301·4	2472·1	301·4	2328·8	2630·2	0·979	6·746	7·725
0·35	72·7	0·001024	4·53	304·2	2473·0	304·2	2327·2	2631·4	0·987	6·728	7·715
0·36	73·4	0·001025	4·41	307·0	2473·8	307·0	2325·5	2632·5	0·996	6·710	7·706
0·38	74·6	0·001026	4·19	312·4	2475·5	312·4	2322·3	2634·7	1·011	6·676	7·687
0·40	75·9	0·001027	3·99	317·6	2477·0	317·6	2319·2	2636·8	1·026	6·644	7·670
0·45	78·7	0·001028	3·58	329·6	2480·7	329·6	2312·0	2641·6	1·060	6·571	7·631
0·50	81·3	0·001030	3·24	340·5	2483·9	340·6	2305·4	2646·0	1·091	6·503	7·594
0·55	83·7	0·001032	2·96	350·5	2486·8	350·5	2299·3	2649·8	1·119	6·442	7·561
0·60	85·9	0·001033	2·73	359·8	2489·6	359·9	2293·6	2653·5	1·145	6·387	7·532
0·65	88·0	0·001035	2·53	368·5	2492·1	368·5	2288·3	2656·8	1·169	6·335	7·504
0·70	90·0	0·001036	2·37	376·7	2494·5	376·7	2283·3	2660·0	1·192	6·288	7·480
0·75	91·5	0·001037	2·22	384·3	2496·7	384·4	2278·6	2663·0	1·213	6·243	7·456
0·80	93·5	0·001039	2·087	391·6	2498·8	391·7	2274·1	2665·8	1·233	6·202	7·435
0·85	95·1	0·001040	1·972	398·5	2500·7	398·6	2269·8	2668·4	1·252	6·163	7·415
0·90	96·7	0·001041	1·869	405·1	2502·6	405·2	2265·7	2670·9	1·270	6·125	7·395
0·95	98·2	0·001042	1·777	411·3	2504·4	411·4	2261·8	2673·2	1·287	6·090	7·377
1·00	99·6	0·001043	1·694	417·4	2506·1	417·5	2258·0	2675·5	1·303	6·057	7·360
1·01325	**100**	**0·001044**	**1·673**	**418·9**	**2506·5**	**419·0**	**2257·0**	**2676·0**	**1·307**	**6·048**	**7·355**
1·1	102·3	0·001045	1·549	428·7	2509·2	428·8	2250·9	2679·7	1·333	5·994	7·327
1·2	104·8	0·001047	1·428	439·2	2512·1	439·3	2244·2	2683·5	1·361	5·937	7·298
1·3	107·1	0·001049	1·325	449·0	2514·8	449·1	2238·0	2687·1	1·387	5·884	7·271
1·4	109·3	0·001051	1·237	458·2	2517·3	458·4	2232·0	2690·4	1·411	5·835	7·246
1·5	111·4	0·001053	1·159	466·9	2519·7	467·1	2226·5	2693·6	1·434	5·789	7·223
1·6	113·3	0·001054	1·091	475·2	2521·9	475·1	2221·1	2696·5	1·455	5·747	7·202
1·7	115·2	0·001056	1·031	483·0	2523·9	483·2	2216·0	2699·2	1·475	5·706	7·181
1·8	116·9	0·001058	0·977	490·5	2525·9	490·7	2211·2	2701·8	1·494	5·668	7·162
1·9	118·6	0·001059	0·929	497·6	2527·7	497·8	2206·5	2704·3	1·513	5·631	7·144
2·0	120·2	0·001061	0·886	504·4	2529·5	504·7	2201·9	2706·7	1·530	5·597	7·127
2·1	121·8	0·001062	0·846	511·1	2531·2	511·3	2197·6	2708·9	1·547	5·564	7·111
2·2	123·3	0·001063	0·810	517·4	2532·8	517·6	2193·4	2711·0	1·563	5·532	7·095
2·3	124·7	0·001065	0·777	523·5	2534·3	523·7	2189·3	2713·1	1·578	5·502	7·080
2·4	126·1	0·001066	0·747	529·4	2535·8	529·6	2185·4	2715·0	1·593	5·473	7·066
2·5	127·4	0·001067	0·719	535·1	2537·2	535·4	2181·5	2716·9	1·607	5·446	7·053

(c) What does cetane number represent ? How is it experimentally determined for a given CI engine fuel using CFR engine ? Describe the test conditions and procedure followed. *10*

SECTION B

Q5. (a) Draw the schematic diagram of a one shell pass and two tube pass heat exchanger and show the axial temperature distribution assuming hot fluid passes through the shell and cold fluid passes through the tubes. *8*

(b) Draw the schematic diagram of a vapour compression refrigeration system (VCR) with a liquid vapour heat exchanger (LVHE). What is the effect of LVHE on COP of the VCR system ? Also draw P-H diagram. *8*

(c) The pressure, temperature and velocity of air at the inlet to a single stage compressor respectively are, 100 kPa, 22°C and 8 m/s. The respective values at the exit are 210 kPa, 95°C and 70 m/s. The exit is 1 m above the inlet. Calculate the actual work, isentropic work and efficiency of the compressor. For air, take $C_p = 1{\cdot}004$ kJ/kg K and $\gamma = 1{\cdot}4$. *8*

(d) A single-stage impulse steam turbine operates close to the maximum blading efficiency. The blades are equiangular, and the friction effects in blades may be neglected. The mean blade velocity is 200 m/s and the steam flow rate is 0·75 kg/s. Find : *8*

(i) the discharge angle at which the steam leaves the blades.

(ii) the diagram power.

(e) Explain the principle of regeneration in a simple steam power plant cycle using a schematic and T-s diagrams. How does it improve the cycle efficiency ? What are the limitations observed ? *8*

Q6. (a) A hemispherical cavity of radius 0·75 m is covered with a plate having a hole of 0·25 m diameter drilled at its centre. The inner surface of the plate is maintained at 550 K by a heater embedded in the surface. Assuming the surfaces to be black and the hemisphere to be well insulated, calculate (i) the temperature of the surface of the hemisphere, and (ii) the power input to the heater. Neglect the radiation heat transfer from surroundings to hole.

Take σ (Stefan-Boltzmann's constant) as $5{\cdot}67 \times 10^{-8}$ W/m^{2}K^4. *15*

(b) An ammonia refrigeration plant operates between a condensing temperature of 40°C and an evaporating temperature of – 10°C. The vapour is dry saturated at the end of compression. The properties of ammonia are given in the table.

Temperature (t)	Enthalpy of liquid (h_f)	Enthalpy of vapour (h_g)	Entropy of liquid (s_f)
°C	kJ/kg	kJ/kg	kJ/kg K
40°	371·5	1473	1·36
– 10°	135·4	1433	0·544

The specific heat of NH_3 vapour is 2·1897 kJ/kg K. Calculate the theoretical COP of the cycle. Also calculate the COP of the cycle if dry saturated vapour enters the compressor. Draw P-H diagram also. *15*

(c) State the effects of variation of blade angles on head and degree of reaction in the case of radial flow machines. *10*

Q7. (a) The power output of a Francis turbine is 1100 kW at an overall efficiency of 90% without using any draft tube. The available head at the inlet to the turbine is 26 m, and the level of the turbine is 2·3 m above the tailrace. The flow coefficient of the turbine is 0·3. Assess the effect on power output when using (i) a straight cylindrical draft tube, and (ii) a draft tube with the half cone angle of 5° at the exit of the turbine. The efficiency of the draft tube in both the cases may be taken as 94%. The atmospheric pressure head may be taken as 10 m. *15*

(b) (i) What are the various thermodynamic, chemical and physical requirements for the selection of a refrigerant ? *10*

(ii) Give the differences between azeotropic and zeotropic refrigerants. Give one example of each type. *5*

(c) Explain the working of co-generation power plant with a back pressure turbine with the help of a neat schematic diagram and T-s plot. *10*

Q8. (a) (i) The steam generated by a boiler is at a pressure of 15 bar and is superheated to 350°C. [h = 3149 kJ/kg]

The feed water temperature is 65°C. The boiler is oil fired and the calorific value (net) is 47,000 kJ/kg. The ultimate analysis of the fuel is C = 85%, H_2 = 15%.

Determine :

I. the minimum mass of air required for complete combustion of the fuel.

II. overall efficiency of the boiler if the steaming rate is 12·2 kg per kg of fuel fired.

Assume the latent heat of water vapour in the flue gas as 2500 kJ/kg and the C_p for feed water as 4·1868 kJ/kg K. *10*

(ii) Two ideal vapour power cycles are coupled in series. The thermal efficiency of the top cycle is η_t and that of the bottom cycle is η_b. Obtain an expression for the two coupled cycles in terms of these efficiencies. *5*

(b) 25 kg/min of air is initially at DBT of 10°C, and 5°C WBT. It is preheated sensibly to a DBT of 46°C, passed through a recirculated spray washer followed by reheating sensibly to 35°C DBT and 39% RH. Show the scheme of processes on a skeleton psychrometric chart.

Calculate :

(i) Capacity of preheating coil in kW

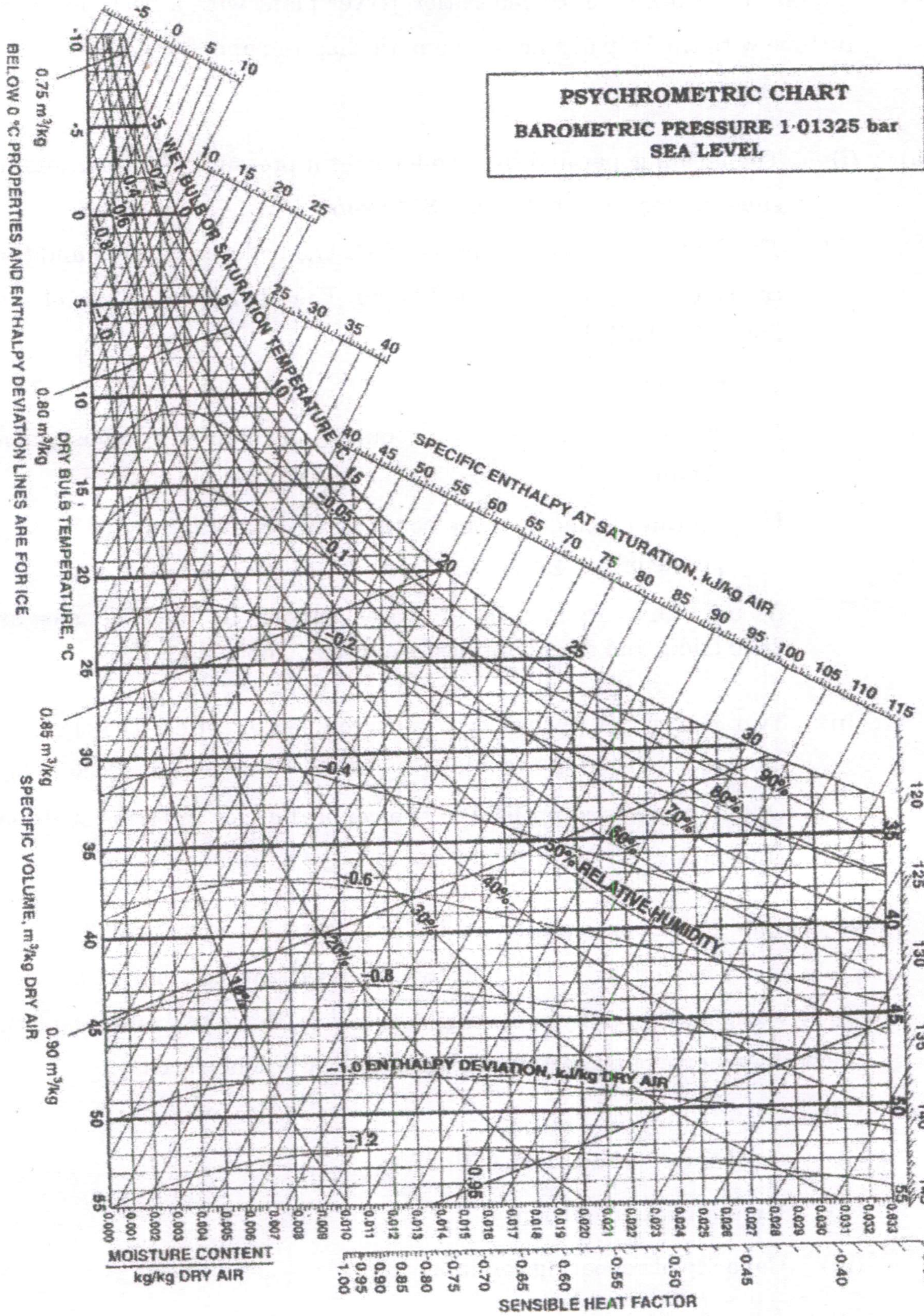
(ii) Humidification efficiency

(iii) Capacity of reheating coil in kW

(iv) Amount of water vapour added to air per hour

The psychrometric chart is attached. *15*

Question 8(b)


PSYCHROMETRIC CHART
BAROMETRIC PRESSURE 1·01325 bar
SEA LEVEL
WET BULB OR SATURATION TEMPERATURE °C
SPECIFIC ENTHALPY AT SATURATION, kJ/kg AIR
DRY BULB TEMPERATURE, °C
BELOW 0 °C PROPERTIES AND ENTHALPY DEVIATION LINES ARE FOR ICE
SPECIFIC VOLUME, m³/kg DRY AIR
0.75 m³/kg
0.80 m³/kg
0.85 m³/kg
0.90 m³/kg
50% RELATIVE HUMIDITY
-1.0 ENTHALPY DEVIATION, kJ/kg DRY AIR
MOISTURE CONTENT
kg/kg DRY AIR
SENSIBLE HEAT FACTOR

(c) Define the following with respect to the compression process in a centrifugal compressor :

(i) Isentropic compression efficiency

(ii) Slip

(iii) Pressure coefficient or Loading coefficient

(iv) Power input factor

Also establish a relationship amongst them. *10*