I.F.S. EXAM-(M) 2018

FSI-D-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.

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

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.

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 a general expression for the change in entropy of a real gas obeying the van der Waals equation. *8*

(b) The boiling point of water at the top of a hill is found to be 90°C, whereas it boils at 99·6°C with the latent heat of evaporation of 2256·94 kJ/kg at the foot of the hill (where the pressure is 101·325 kPa). Assuming that the atmosphere is locally isothermal at 300 K (i.e. $pv = p_0 v_0$ is valid), estimate the height of the hill. *8*

(c) A house, that is losing heat at a rate of 50,000 kJ/h when the outside temperature drops to 4°C, is to be heated by electric resistance heaters. If the house is to be maintained at 25°C at all times, determine the reversible work input for this process and the irreversibility. *8*

(d) Determine the heat transfer rate from a rectangular fin of length 20 cm, width 40 cm and thickness 2 cm. The tip of the fin is not insulated and the fin has a thermal conductivity of 150 W/mK. The base temperature is 100°C and the fluid is at 20°C. The heat transfer coefficient between the fin and the fluid is 30 W/m^2K. *8*

(e) What purposes does an expansion device serve in a vapour compression refrigeration system ? Explain how a simple capillary tube can serve these purposes. *8*

Q2. (a) Prove that :

$$\left(\frac{\partial P}{\partial T}\right)_s = \frac{k}{k-1}\left(\frac{\partial P}{\partial T}\right)_v \text{ where } k = C_p / C_v.$$

$$\left[\text{Hint} : C_p - C_v = -T\left(\frac{\partial V}{\partial T}\right)_P^2 \left(\frac{\partial P}{\partial V}\right)_T\right]$$ *15*

(b) Three thin walled infinitely long hollow cylinders of radii 5 cm, 10 cm and 15 cm are arranged coaxially. The temperatures of the innermost and outermost cylinders are respectively 1000 K and 300 K. Calculate the steady state temperature of the middle cylinder surface and the heat flow per m^2 area of the innermost cylinder. Assume emissivity of all the cylinders to be 0·5 and vacuum in the spaces between the cylinders. Take $\sigma = 5{\cdot}67 \times 10^{-8}$ W/m^2K^4. *15*

(c) Explain, with the help of T-s diagram, that for atmospheric moist air

$T_{dry\ bulb} > T_{wet\ bulb} > T_{dew\ point}$, in unsaturated condition, and

$T_{dry\ bulb} = T_{wet\ bulb} = T_{dew\ point}$, in saturated condition. *10*

Q3. (a) A refrigeration plant operates on Reversed Carnot cycle. The saturation temperatures in the condenser and evaporator are 40°C and – 5°C respectively. The volumetric efficiencies of the compressor and expander are 100 percent each.

Calculate (i) the refrigeration effect per kg of refrigerant, (ii) the coefficient of performance, (iii) the compressor displacement per kW of refrigeration effect, and (iv) the net work input per kg of refrigerant.

Also, calculate the corresponding for a simple vapour compression refrigeration cycle. Assume no superheating either at the inlet or exit of the compressor, and no subcooling.

Show the cycles on T-s diagram.

Explain, why in practice a throttle valve is used in vapour compression refrigeration rather than an expander cylinder.

The properties of the refrigerant are as follows :

(The specific volume of the saturated liquid is negligible compared to vapour).

Saturation Temperature °C	Saturation Pressure bar	Enthalpy, kJ/kg		Entropy, kJ/kg K		Specific Volume (m^3/kg)
		h_f	h_g	s_f	s_g	v_g
40	9·6065	238·535	367·15	1·1298	1·5405	18·17
(–5)	2·6096	195·395	349·32	0·9831	1·5571	64·963

f and g refer to saturated liquid and saturated vapour respectively. *15*

(b) A piston-cylinder device contains 0·8 kg of steam at 300°C and 1 MPa. Steam is cooled at constant pressure until one-half of the mass condenses. *15*

(i) Show the process on a T – V diagram.

(ii) Find the final temperature.

(iii) Determine the volume change.

(iv) Determine the heat transfer.

Given :

Tables

P (kPa)	T_{sat} (°C)	v_f (m^3/kg)	v_g (m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)
1·000	6·97	0·00100	129·19	29·303	2513·7
100·0	99·61	0·00104	1·6941	417·51	2675·0
1000·0	179·88	0·001127	0·19436	762·51	2777·1

Property :

$$\text{At } P = 1{\cdot}00 \text{ MPa and } T = 300°C$$
$$s = 7{\cdot}1246 \text{ kJ/kg-K}$$
$$v = 0{\cdot}25799 \text{ m}^3\text{/kg}$$
$$h = 3051{\cdot}6 \text{ kJ/kg}$$

(c) Water at 20°C flowing at the rate of 0·015 kg/s enters a 25 mm inner diameter tube which is maintained at a temperature of 90°C. Assuming hydrodynamically and thermally fully developed flow, determine the heat transfer coefficient and the tube length required to heat the water to 70°C.

Given water properties at 20°C; $\rho = 1000{\cdot}5$ kg/m^3, $C_p = 4181{\cdot}8$ J/kg K,

Kinematic viscosity = $1{\cdot}006 \times 10^{-6}$ m^2/s.

Properties of water at 45°C :

$\rho = 992$ kg/m^3, $C_p = 4180$ J/kg K, k = 0·638 W/mK,

Kinematic viscosity = $0{\cdot}613 \times 10^{-6}$ m^2/s.

The average Nusselt number for the tube is 3·657. *10*

Q4. (a) In a parallel flow heat exchanger, engine oil enters a heat exchanger at 150°C and leaves at 80°C. The cooling water enters at 30°C and leaves at 65°C. If the fluid flow rates and the inlet conditions are unchanged, find exit temperature of each stream in counterflow exchanger. *15*

(b) A building has the following calculated cooling loads :

RSH gain = 310 kW, RLH gain = 100 kW.

The building's inside space is maintained at the following conditions of Room DBT = 25°C and Room RH = 50%. The outdoor air is at 28°C DBT and 50% RH. And 10% by mass of air supplied to the building is outdoor air. If the air supplied to the space is not to be at a temperature lower than 18°C, find

(i) minimum amount of air supplied to the space in m^3/s,

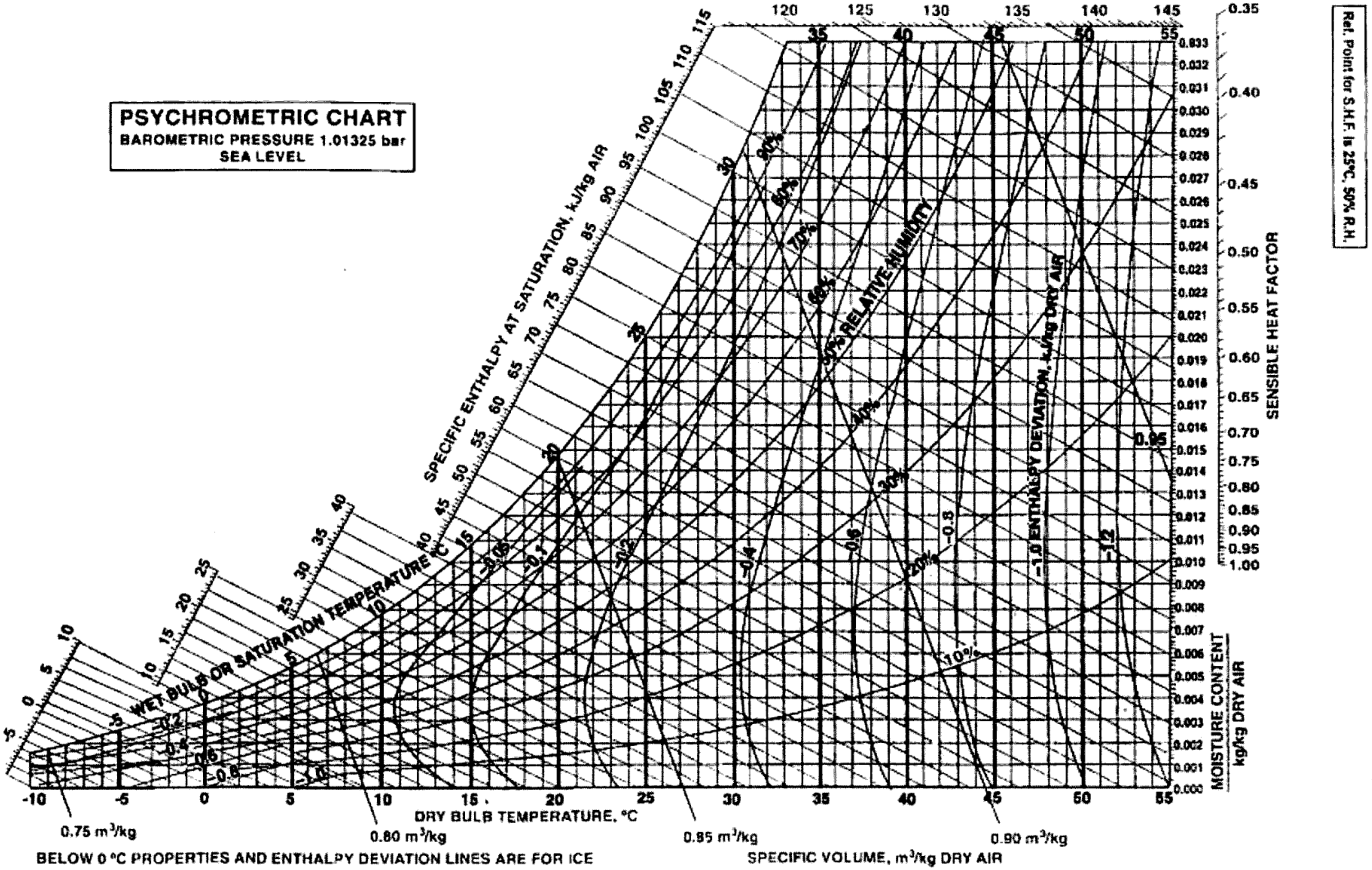
(ii) volume flow rate of air entering the coil,

(iii) capacity of the cooling coil in TR, and

(iv) ADP and bypass factor of the cooling coil.

Also, draw the layout sketch.

(Psychrometric chart is attached) *15*


PSYCHROMETRIC CHART
BAROMETRIC PRESSURE 1.01325 bar
SEA LEVEL
SPECIFIC ENTHALPY AT SATURATION, kJ/kg AIR
WET BULB OR SATURATION TEMPERATURE °C
RELATIVE HUMIDITY
ENTHALPY DEVIATION, kJ/kg DRY AIR
SENSIBLE HEAT FACTOR
MOISTURE CONTENT kg/kg DRY AIR
Ref. Point for S.H.F. is 25°C, 50% R.H.
DRY BULB TEMPERATURE, °C
0.75 m³/kg
0.80 m³/kg
0.85 m³/kg
0.90 m³/kg
BELOW 0 °C PROPERTIES AND ENTHALPY DEVIATION LINES ARE FOR ICE
SPECIFIC VOLUME, m³/kg DRY AIR

(c) In the early development of steam power plants, approximately 1·12 kg of coal is required per kilowatt hour. Assume that the mean temperature at which heat was supplied is 175°C and heat was rejected is 100°C at that time. Presently, assume that heat is supplied at a mean temperature of 380°C and rejected at 32°C. The ratio of the actual thermal efficiency to that of the Carnot cycle today is about 1·25 times that of earlier years. Assuming the same heating value for coal in both cases, calculate the amount of coal now required per kilowatt hour. *10*

SECTION B

Q5. (a) Compare the cooling effect of fuel evaporation on charge temperature in a turbocharged spark ignition engine for the following two cases :

(i) The carburettor is placed before the compressor

(ii) The carburettor is placed after the compressor

The specific heat capacity of the air and the latent heat of evaporation of the fuel are both constant. For the air/fuel ratio of 12·5 : 1, the evaporation of the fuel causes a 25 K drop in mixture temperature. The compressor efficiency is 70% for the pressure ratio of 1·5, and the ambient temperature is 15°C. Assume the following values :

for air, $C_p = 1{\cdot}01$ kJ/kgK, $\gamma = 1{\cdot}4$,

for air/fuel mixture, $C_p = 1{\cdot}05$ kJ/kgK, $\gamma = 1{\cdot}34$.

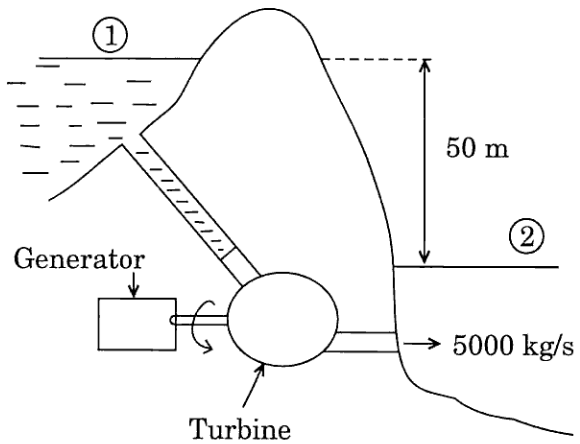
Finally, compare the compressor work in both cases. 8

(b) A Ford 2-stroke engine has a swept volume of 1·2 litres. At a speed of 5500 rpm, the full load torque is 108 Nm and the brake specific fuel consumption is 294 g/kWh. Calculate the brake mean effective pressure, and the brake thermal efficiency (assume a calorific value of 43 MJ/kg). Give at least 5 reasons why the brake thermal efficiency is lower than the value predicted by the Otto cycles analysis. 8

(c) What is meant by "work done factor" in the axial flow compressors ? Explain how the work done factor value varies with the number of stages. Why is the work done factor not considered in centrifugal compressors ? 8

(d) What is 'slip factor' for a centrifugal compressor stage ? What is its effect on the flow and the pressure ratio in the stage ? 8

(e) Water in a large lake is to be used to generate electricity by the installation of a hydraulic turbine-generator located, where the depth of water is 50 m (see Figure). Water is to be supplied at the rate of 5000 kg/s. The electric power generated is 1862 kW and the generator efficiency is 95%. Determine (i) the overall efficiency of the turbine generator, (ii) the mechanical efficiency of the turbine, and (iii) the shaft power supplied by the turbine to the generator. *8*



Density of water is 1000 kg/m^3 and gravitational acceleration is 9·81 m/s^2.

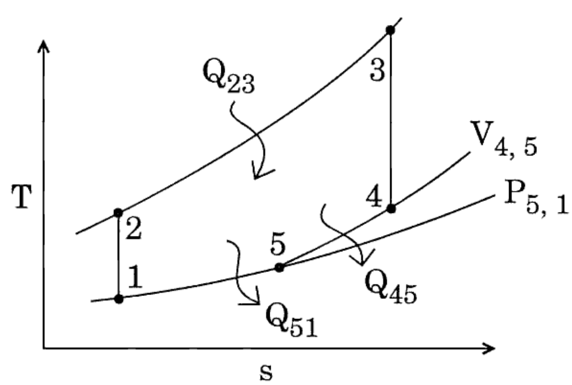
Q6. (a) Reciprocating internal combustion engines have been fitted with ingenious mechanisms that allow the expansion ratio (r_e) to be greater than the compression ratio (r_c). When such a system is modelled by an ideal gas cycle there is

(i) heat addition at constant volume,

(ii) some heat rejection at constant volume,

(iii) and some heat rejection at constant pressure, to complete the cycle.

The process is shown in the following figure on a T–s plane :



Depict the processes on a P-V plane. The constant-volume temperature rise (2 → 3) is θT_1. Derive an expression for the cycle efficiency in terms of r_e, r_c and θ. State any assumptions. *15*

(b) In an ideal gas turbine cycle with reheat, air at state (P_1, T_1) is compressed to $(rp_1)_x$ in the compressor and heated to T_{3x} in the combustion chamber. The air is then expanded in two stages, each turbine having the same pressure ratio, with reheat to T_3 between the stages. Assuming the working fluid to be a perfect gas with constant specific heats, and that the compression and expansion are isentropic, show that the specific work output will be a maximum when 'r', the compressor pressure ratio is given by

$$r^{(\gamma - 1)/\gamma} = \left(\frac{T_3}{T_1}\right)^{2/3}$$

where γ is the ratio of specific heats, C_p/C_v. Draw the schematic arrangement of the cycle and the corresponding T–s diagram also. *15*

(c) $C_{12}H_{26}$ is burned at constant volume with no excess air. The initial temperature is 30°C. Assuming complete combustion, determine the theoretical maximum temperature when there is no dissociation. Use the following enthalpy values (J/mole) of different substances for the calculations : *10*

$C_{12}H_{26}$	75, 79, 383
CO_2	1, 46, 203
H_2O	1, 18, 329
N_2	88, 122

Q7. (a) In a power plant employing Rankine cycle with reheat, superheated steam at 150 bar and 500°C (h = 3310·6 kJ/kg; s = 6·3487 kJ/kg K) enters the first stage of the turbine. The condenser is maintained at 0·1 bar (v_f = 0·001 m³/kg, h_f = 191·83 kJ/kg K, h_g = 2584·8 kJ/kg, s_f = 0·6493 kJ/kg K, s_g = 8·1511 kJ/kg K). The exit steam from the first stage of turbine is reheated to 500°C before it is fed to the second stage of the turbine. Calculate the thermal efficiency of the power plant if steam expands to

(i) 90 bar in the first stage of the turbine.

(ii) 60 bar in the first stage of the turbine. *15*

From the superheated steam tables at 90 bar

T (°C)	h (kJ/kg)	s (kJ/kg K)
400	3125·5	6·3067
500	3389·2	6·6728

From the superheated steam tables at 60 bar

T (°C)	h (kJ/kg)	s (kJ/kg K)
300	2885·0	6·0692
400	3180·1	6·5462
500	3422·2	6·8818

(b) A gas engine operating on methane (CH_4) at 1500 rpm, full throttle, generates the following emissions measured on a dry volumetric basis :

CO_2	10·4%
CO	1·1%
H_2	0·6%
O_2	0·9%
NO	600 ppm
HC	1100 ppm (as methane)

If the specific fuel consumption is 250 g/kWh, calculate the specific emissions of carbon monooxide, nitrogen oxide, and unburned hydrocarbons (that is g/kWh). Why is the specific basis more relevant than a percentage basis ? *15*

(c) A model of a torpedo is tested in a water filled towing tank at a velocity of 24·4 m/s. The prototype is expected to attain a velocity of 6·1 m/s in water. What would be the model speed if tested in a wind tunnel filled with air at a pressure of 20·0 bar and constant temperature of 27°C ? The absolute viscosity of air may be assumed as $1{\cdot}845 \times 10^{-5}$ N.s/m^2, the molecular weight of air as 28·97 kg/kmol and the universal gas constant as 8·315 kJ/kg-mol K. The kinematic viscosity of water may be taken as $1{\cdot}13 \times 10^{-6}$ m^2/s. *10*

Q8. (a) Starting with the differential form of the conservation equations, show that the flow velocity increases with heat addition in subsonic Rayleigh flow, but decreases in supersonic Rayleigh flow. Also, draw the T-s diagram. *15*

(b) At the mean diameter of a gas turbine stage, the blade velocity is 350 m/s. The blade angles at the inlet and exit are 20° and 54° (respectively) with respect to axial direction. The blades at this section are designed to have a degree of reaction of 50 percent. The mean diameter of the blades is 0·432 and the mean blade height is 0·07 m. Assuming that the whirl velocity varies inversely with respect to radius, estimate :

(i) the flow velocity,

(ii) the angles of blades at the tip and at the root, and

(iii) the degree of reaction at the tip and at the root of the blades. *15*

(c) Briefly explain the stages of combustion in SI engines elaborating the flame front propagation. *10*