इन्जीनियरिंग सेवा परीक्षा, 2009
Engineering Service Examination.

Sl. No. 30395

A-FTF-J-NFA

MECHANICAL ENGINEERING

Paper I

(Conventional)

Time Allowed : Three Hours | *Maximum Marks : 200*

INSTRUCTIONS

Candidates should attempt FIVE questions.

Each question carries 40 marks.

The number of marks carried by each subdivision of a question is indicated at the end of the subdivision.

All subdivisions within a question are to be attempted, wherever the question is attempted.

Answers must be written in ENGLISH.

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

For air $R = 0{\cdot}287$ kJ/kg-K, $C_p = 1{\cdot}005$ kJ/kg-K, $\gamma = 1{\cdot}4$, $M = 28{\cdot}966$ kg/kg-mole.

Unless indicated otherwise, symbols and notations have their usual meaning.

1. (a) The heat capacity at constant pressure of a certain system is a function of temperature only and may be expressed as

$$C_p = 2{\cdot}093 + \frac{41{\cdot}87}{t+100} \text{ J/}^\circ\text{C}$$

where t is the temperature in °C. The system is heated while it is maintained at a pressure of 1 atmosphere until its volume increases from 2000 cm^3 to 2400 cm^3 and its temperature increases from 0°C to 100°C.

(i) Find the magnitude of heat interaction.

(ii) How much does the internal energy of the system increase ? 5+5=10

(b) Derive the equations :

(i) $C_p = T\left[\frac{\partial V}{\partial T}\right]_p \left(\frac{\partial P}{\partial T}\right)_s$

(ii) $\left[\frac{\partial P}{\partial T}\right]_s = \frac{C_p}{V\beta T}$

(iii) $\dfrac{\left(\frac{\partial P}{\partial T}\right)_s}{\left(\frac{\partial P}{\partial T}\right)_v} = \frac{\gamma}{\gamma - 1}$ 5+5+5=15

(c) Show that for an ideal gas, the slope of the constant volume line on the T–s diagram is more than that of the constant pressure line. 5

(d) Explain the phenomenon of boundary layer separation. Describe four methods of controlling of boundary layer separation. 4+6=10

2. (a) Derive an expression for air/fuel ratio of a carburettor by

(i) neglecting compressibility of air

(ii) taking compressibility effects into account. 8+7=15

(b) A four stroke diesel engine of 3000 cc capacity develops 14 kW per m^3 of free air induced per minute. When running at 3500 rev/min it has a volumetric efficiency of 85 per cent 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 pressure ratio 1·7 and isentropic efficiency of 80 per cent. Assuming that at the end of induction the cylinders contain a volume of charge equal to the swept volume, at the pressure and temperature of the delivery from the blower, estimate the increase in bp to be expected from the engine. Take overall mechanical efficiency as 80 per cent. r for air = 1·4, $R = 0{\cdot}287$ kJ/kg K. 13

(c) A liquid fuel C_7H_{16} is burned with 10% more air than the stoichiometric air. Assuming complete combustion, calculate

(i) the mass of air supplied per kg of fuel and

(ii) the volumetric analysis of the dry products of combustion. Assume air contains 21 per cent O_2 by volume. 12

3. (a) In a refrigeration system brine solution having a viscosity 16·5 N-s/m^2 and thermal conductivity 0·85 W/mk is flowing through a long pipe 2·5 cm inner diameter at a velocity of 6·1 m/s. Under these conditions the heat transfer coefficient was found to be 1135 W/m^{2}k for a brine temperature of –1°C and pipe temperature of 18·3°C. Find the temperature rise of brine per metre length of pipe if the velocity is doubled and same heat transfer takes place. Assume sp. heat of brine is 3768 J/kg K and density is 1000 kg/m^3. Assume fully developed flow. 8

(b) A solid sphere of diameter 10 cm is heated to 1000°C and suspended in a room whose walls are at 30°C. Compute the following :

(i) Rate of heat transfer due to radiation only neglecting other losses.

(ii) Time taken by the sphere to cool to 500°C assuming emissivity for the sphere = 0·1 and density 8·68 gm/cc. Sp. heat 0·098 J/kg K. 8

(c) Find the surface area required for a surface condenser dealing with 25000 kg of saturated steam per hour at a pressure of 0·5 bar. Temperature of condensing water is 25°C. Cooling water is heated from 15°C to 25°C while passing through the condenser. Assume a heat transfer coefficient of 10 kW/m^2k. The condenser has 2 water passes with tubes of 19 mm OD and 1·2 mm thickness. Find the length and no. of tubes per pass. Assume velocity of water is 1 m/s. Assume correction factor for 2 tube pass exchanger as 0·86. At 0·5 bar saturation temperature is 32·55°C and latent heat is 2560 kJ/kg. Sp. heat of water is 4·18 kJ/kg K and density is 1000 kg/m^3. 14

(d) Estimate the coefficient of heat transfer from a vertical plate 2 m × 2 m to the surrounding air at 25°C. The plate surface temperature is 150°C. Also calculate the rate of heat transfer from the plate. For air assume the kinematic viscosity as $1{\cdot}6 \times 10^{-5}$ m^2/s. The properties of air at film temperature are density 0·972 kg/m^3, sp. heat 1·009 kJ/kg K, thermal conductivity $3{\cdot}13 \times 10^{-2}$ W/mk, Prandtl No. 0·69. The constants 'C' & 'n' in Nusselt no. equation are 0·15 and 1/3 respectively. 10

4. (a) What factors are considered in selecting a refrigerant for the following application, mentioning the name of the refrigerant in each case

(i) Household refrigerator

(ii) An ice plant

(iii) Air conditioning plant for a cinema hall. 9

(b) A dense air refrigeration machine operating on Bell-Coleman cycle operates between 3·4 bar and 17 bar. The temperature of air after the cooler is 15°C and after the refrigerator is 6°C. If the refrigeration capacity is 6 tons, calculate :

(i) temperature after compression and expansion

(ii) air circulation per min

(iii) work of compressor & expander

(iv) theoretical CoP

(v) rate of water circulation required in the cooler in kg/min if the rise in temperature is limited to 30°C. 10

(c) A simple saturation cycle using R_{12} is designed for taking a load of 10 tons. The refrigerant and ambient temperatures are 0°C and 30°C respectively. A minimum temperature difference of 5°C is required in evaporator and condenser for heat transfer. Find the

(i) mass flow rate through the system

(ii) power required in kW

(iii) cylinder dimensions assuming L/D ratio of 1·2 for a single cylinder single acting compressor if it runs at 300 rpm with a volumetric y of 0·9. The following properties are taken for R_{12}. Sp. heat of R_{12} vap = 0·95 kJ/kg K.

Sat. temp °C	Sat. pr bar	Sp. vol.		Enthalpy		Entropy	
		Sat.liq $\times 10^{-3}$	Sat.vap m^3/kg	Sat.liq kJ/kg	Sat.vap	Sat.liq kJ/kg K	Sat.vap
−5°C	2·61	0·71	0·0650	31·4	185·4	0·1251	0·6991
0°C	3·08	0·72	0·0554	36·1	187·5	0·1420	0·6966
30°C	7·45	0·77	0·0235	64·6	199·6	0·2399	0·6854
35°C	8·47	0·79	0·0206	69·5	201·5	0·2559	0·6839

10

(d) (i) What are the factors affecting comfort air conditioning ? 3

(ii) Explain the air conditioning system used in winter season. 3

(iii) Show how air washer can be used for year round air conditioning ? 3

(iv) A spray cooling coil is used to operate under the following conditions – Air inlet 28° DBT/21° WBT, Air outlet 10° DBT/6° WBT. Total air flow rate 2000 m^3/mt. Chilled water inlet and outlet temperatures are 7°C and 12°C. Find

(a) Cooling load on the coil

(b) Water flow rate through the coil.

Properties of moist air from psychometric chart are as follows : 2

DBT	WBT	Sp. humidity gm/kg	Sp. vol. m^3/kg	Enthalpy kJ/kg
28	21·0	12·95	0·87	61·0
10	6·0	4·2	0·81	21·0

5. (a) (i) Explain what do you mean by Reynold's model law. Give two examples where Reynold's model can be applied.

(ii) An oil of specific gravity 0·92 and viscosity 0·03 poise is to be transported at the rate of 2500 L/S through a 1·2 m diameter pipe. Tests were conducted on a 12 cm diameter pipe using water at 20°C. Determine,

1. Velocity of flow in the model

2. Rate of flow in the model

3+2+4+2=11

Given viscosity of water at 20°C is 0·01 poise.

(b) A rough pipe of diameter 0·1 m carries water at 20°C at the rate of 50 L/S. If the average height of the roughness projections on the pipe surface is 0·15 mm, determine the

(i) friction factor

(ii) shear stress at the pipe surface

(iii) shear velocity

(iv) maximum velocity 4+2+2+4=12

Take for water at 20°C,

γ = Kinematic viscosity = 1×10^{-6} m^2/s.

ρ = Mass density = 1000 kg/m^3

(c) Explain with the help of diagrams the phenomenon of Karman Vortex Street. How is Strouhal number, a dimensionless number, related to the above phenomenon ? 5+3=8

(d) (i) Explain what do you mean by Temporal on Local acceleration, and convective acceleration.

(ii) The velocity field in a fluid medium is given by $\overline{V} = 3xy^2\hat{i} + 2xy\hat{j} + (2zy + 3t)\hat{k}$ determine, the rotational velocity vector at (1, 2, 1) and $t = 3$. 2+2+5=9

6. (a) The velocity profile for a laminar boundary layer is given by

$$\frac{u}{U} = \sin\left(\frac{\pi}{2} \cdot \frac{Y}{\delta}\right)$$

where u is the velocity at a distance y from the plate

U is the free stream velocity

δ is the boundary layer thickness,

determine expressions in terms of Reynold's number for the following :

(i) boundary layer thickness

(ii) drag force on both sides of the plate

(iii) co-efficient of drag 15

(b) A Pitot-Static tube is used to monitor the velocity of an air stream. At the location of insertion of the probe, the static pressure is 1·5 bar and temperature is 35°C. Calculate the reading of a mercury manometer connected differentially across the static and total pressure openings of the probe, if the air stream velocity is

(i) 60 m/s

(ii) 200 m/s

(iii) 500 m/s

Take into consideration the compressibility characteristics of the flow wherever applicable. The following values may be used. 3+5+7=15

Isentropic table for perfect gas, k = 1·4

M	p/p_0
0·54	0·820
0·56	0·808
0·58	0·796
0·70	0·720
0·72	0·708
0·74	0·695

Normal shock table for perfect gas, k = 1·4

M_x	M_y	py/px	ρ_y/ρ_x
1·38	0·748	2·055	1·655
1·40	0·739	2·120	1·689
1·42	0·731	2·185	1·724
1·44	0·723	2·252	1·759

(c) Derive an expression for the area velocity relationship for a compressible fluid flow in the form of

$$\frac{dA}{A} = -\frac{dV}{V}\left[1 - M^2\right].$$

Explain properly, with the help of diagrams, what are the important conclusions derived from the above relationship. 4+6=10

7. (a) A three jet Pelton turbine is required to generate 10000 kW under a net head of 400 m. The blade angle at the outlet is 15° and the decrease in the relative velocity while passing over the blade is 5%. Determine,

(i) The diameter of the jet

(ii) The force exerted by a jet on the buckets.

Given, overall efficiency of turbine = 80%
co-efficient of velocity = 0·98
speed ratio = 0·46

Further, if the jet ratio is not to be less than 10, calculate

(iii) speed of the wheel for a frequency of 50 hertz/sec.

(iv) corresponding wheel diameter. 16

(b) A centrifugal pump is to deliver 4·5 m^3/s when running at 750 rpm. The diameter of the impeller at inlet is 53 cm and at outlet is 76 cm. It may be assumed that the air enters radially with a speed of 15 m/s. The vanes are set backwards at outlet at 70° to the tangent, and width at outlet is 10 cm. The volute casing gives at 30% recovery of the outlet velocity head. The losses in the impeller may be taken as equivalent to 25% of the outlet velocity head. Blade thickness effects may be neglected. Determine,

(i) The manometric efficiency and

(ii) The pressure at the discharge. 16

(c) Discuss how the volumetric efficiency varies with the clearance and the pressure ratio in an air compressor. 8

8. (a) With the help of a neat Schematic explain the working of a Bubbling type Fluidized Bed Boiler. What are its advantages ? 10

(b) A centrifugal compressor running at 16000 rpm takes in air at 17°C and compresses it through a pressure ratio of 4 with an isentropic efficiency of 82 per cent. The blades are radially inclined and the slip factor is 0·85. Guide vanes at inlet give the air an angle of pre-whirl of 20° to the axial direction. The mean diameter of the impeller eye is 200 mm and the absolute air velocity at inlet is 120 m/s. Calculate the impeller tip diameter. 15

(c) Explain briefly stage efficiency, internal efficiency and Reheat factor in a multistage steam turbine. Find out the relation between these three factors. 15
