Engineering Services Examination-2012

Sl. No.

C-FTF-M-NIA

MECHANICAL ENGINEERING

Paper I

(Conventional)

Time Allowed : Three Hours	*Maximum Marks : 200*

INSTRUCTIONS

Candidates should attempt any 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.

Answers must be written only 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 otherwise indicated, symbols and notations have their usual meanings.

Important : Candidates are to note that all parts and sub-parts of a question are to be attempted contiguously in the answer-book. That is, all parts and sub-parts of a question being attempted must be completed before attempting the next question.

Any pages left blank in the answer-book must be clearly struck out. Answers that follow pages left blank may not be given credit.

1. (a) For an isentropic expansion of a gas with $c_p = a + kT$, $c_v = b + kT$ and $c_p - c_v = R$, show that $T^b v^{a-b} e^{kT}$ = constant. 5

(b) A small flexible bag contains 0·1 kg ammonia at –10°C and 3 bar. The bag material is such that the pressure inside varies linearly with volume. The bag is left in open space where the incident solar radiation is 75 W. The heat energy lost to the ground and surrounding air from bag is at the rate of 25 W. After a while, it is found that the bag is heated to 30°C at which time the pressure of ammonia is 10 bar. Estimate (i) the amount of heat energy infiltrated into the bag and (ii) the elapsed time.

Properties of ammonia :

(a) Compressed liquid ammonia at –10°C, 3 bar : specific volume of saturated liquid, V_f = 0·001002 m^3/kg, specific internal energy of saturated liquid, U_f = 134 kJ/kg.

(b) Superheated ammonia vapour at 30°C, 10 bar : specific volume = 0·1321 m^3/kg, specific internal energy = 1347 kJ/kg.

10

(c) Steam enters a 15 cm diameter horizontal pipe as saturated vapour at 5 bar with a velocity of 10 m/s and exit at 4·5 bar and a quality of 0·95. Heat is transferred to surroundings at 300 K from the pipe surface which is at an average temperature of 400 K. Under the steady state operating conditions, determine

(i) the exit velocity,

(ii) the rate of heat transfer from pipe surface in kW.

(iii) the rate of entropy production in kW/K, for the control volume comprising of only pipe and its contents and

(iv) the rate of entropy production for the enlarged control volume that includes pipe, its contents and the immediate surroundings.

Properties of steam at saturation condition :

p *bar*	t_{sat} °C	*Sp. volume,* m^3/kg		*Sp. enthalpy, kJ/kg*		*Sp. entropy, kJ/kg-K*	
		liquid (v_f)	*vapour* (v_g)	*liquid* (h_f)	*vapour* (h_g)	*liquid* (s_f)	*vapour* (s_g)
4·5	147·93	0·001088	0·4140	623·5	2744	1·8207	6·8565
5·0	151·86	0·001093	0·3749	640·0	2749	1·8607	6·8213

10

(d) (i) A certain gas obeys the equation of state, $P(v-a) = RT$. Show that the ratio of its volume expansivity, β with that of an ideal gas, β_{ideal} and the ratio of its isothermal compressibility, K_T with that of an ideal gas, $K_{T,\ ideal}$ are given by

$$\frac{\beta}{\beta_{ideal}} = \frac{RT}{RT+ap} \text{ and}$$

$$\frac{K_T}{K_{T,ideal}} = 1 - \left(\frac{a}{v}\right)$$

(ii) For a substance with volume expansivity, $\beta > 0$, show that at every point of a single phase region (vapour region) on a Mollier diagram, the slope of constant pressure line is greater than the slope of constant temperature line but less than that of constant volume line. 6+9

2. (a) Explain with neat sketch, the working principle of a hybrid rocket engine. What are advantages of this engine ? 10

(b) What are the different types of combustion chambers in C.I. engine ? Explain with a neat sketch, an open combustion chamber. What are the merits and demerits of the open combustion chamber ? 10

(c) A four stroke single cylinder petrol engine mounted on a motor cycle was put to load test. The load measured on dynamometer was 30 kg with drum diameter and speed respectively at 900 mm and 2000 rpm. The engine consumed 0·15 kg of fuel in one minute, the calorific value of fuel being 43·5 MJ/kg. The fuel supply to the engine was stopped and was driven by a motor which needed 5 kW of power to keep it running at the same speed, the efficiency of the motor being 80%. The engine cylinder bore and stroke are respectively at 150 mm and 200 mm. Calculate

(i) brake power,

(ii) indicated power,

(iii) mechanical efficiency,

(iv) brake thermal efficiency,

(v) indicated thermal efficiency,

(vi) brake mean effective pressure and

(vii) indicated mean effective pressure. 10

(d) The overall thermal efficiency of a 5 MW nuclear power plant for a submarine is 30%. Calculate the amount of natural uranium, U^{235}, needed to generate the power if the average energy release per fission for U^{235} is 190 MeV. Take 1 W = $6{\cdot}241 \times 10^{12}$ MeV/s. Avogadro's Number is 6.02×10^{23}. 10

3. (a) Cooling water at a steady rate of 0·5 kg/s flows through an inner tube having inner diameter of 25 mm and length of 10 m of a tube-in-tube condenser. The mean inlet temperature of cooling water is 10°C. Saturated steam condenses in the annulus at a uniform rate such that the inner surface temperature of the tube is constant throughout the length of the tube at 40°C. The average condensing side heat transfer coefficient is 10000 W/m^2-K. Neglect the thickness of the heat exchanger tube. Calculate the effectiveness of the heat exchanger and the exit water temperature.

Properties of water are given below :

Specific heat = 4180 J/kg-K,

Density = 990 kg/m^3,

Dynamic viscosity = $0{\cdot}8 \times 10^{-3}$ Pascal.sec,

Thermal conductivity = 0·57 W/m-K.

You may use the relation,

$$Nu = 0{\cdot}023\ Re_d^{0{\cdot}8}\ Pr^{0{\cdot}4}.$$

15

(b) The net radiation from the surfaces of two parallel plates having equal emissivities of 0·8 and at different temperatures of T_1 and T_2 ($T_1 > T_2$) is to be reduced by 99%. How many numbers of radiation screens having equal emissivities of 0·05 are to be placed between the plates to achieve the reduction in heat exchange ? 15

(c) What is an expansion device ? Explain with the help of a neat sketch the working principle of a Thermostatic Expansion Device (TEV). 10

4. (a) An R-12 vapour compression plant producing 10 tonnes of refrigeration operates with condensing and evaporating temperatures of 35°C and –10°C respectively. A suction line heat exchanger is used to subcool the saturated liquid leaving the condenser. Saturated vapour leaving the evaporator is superheated in the suction line heat exchanger to the extent that a discharge temperature of 60°C is obtained after isentropic compression. Calculate

(i) The subcooling achieved in the heat exchanger,

(ii) The refrigerant flow rate in kg/s,

(iii) The cylinder dimensions of the two-cylinder compressor, if the speed is 900 rpm, stroke-to-bore ratio is 1 : 1 and the volumetric efficiency is 80%,

(iv) The COP of the plant and

(v) The power required to drive the compressor in kW.

Draw the cycles on P-h and T-s diagrams.

You may use the following table :

Temperature (°C)	*Specific Volume (m^3/kg) Vapour (v_g)*	*Specific enthalpy KJ/kg*		*Specific entropy KJ/kg-K*	
		Liquid (h_f)	*Vapour (h_g)*	*Liquid (s_f)*	*Vapour (s_g)*
–10	0·0766	190·88	347·13	0·9660	1·5600
+35	0·0206	233·50	365·92	1·1139	1·5419

Average specific heat of desuperheating vapour at condenser = 0·796 KJ/kg-K.

Average specific heat of vapour between evaporator outlet and compression suction = 0·658 KJ/kg-K. 20

(b) A rectangular fin of length 30 cm, width 30 cm and thickness 2 mm is attached to a surface at 300°C. The fin is made of aluminium (K = 204 W/m-K) and is exposed to air at 30°C. The fin end is uninsulated and can lose heat through its end also. The convection heat transfer coefficient between the fin surface and air is 15 W/m^2-K.

Determine :

(i) the temperature of the fin at 30 cm from the base,

(ii) the rate of heat transfer from the fin and

(iii) fin efficiency. 10

(c) Briefly describe the various methods of air-conditioning duct design. 10

5. (a) A tank with the vertical sides measuring 3 m × 3 m contains water to a depth of 1·2 m. An oil of density 900 kg/m^3 was poured in the tank up to a depth of 0·8 m. The vertical wall can withstand the thrust of 58 kN. Calculate the actual thrust on the wall and centre of pressure. If the oil level is increased up to 0·9 m, what will be stability of the wall ? 10

(b) For a rate of flow exceeding certain value, the co-efficient of discharge for a venturimeter used for measuring the discharge of an incompressible fluid is found to be constant. Prove that the loss of head in the convergent portion of the venturi can be expressed as KQ^2 under these conditions, where K is a constant (function of cd, areas of the venturimeter) and Q is flow rate in m^3/s. What will be the value of K, assuming the cd constant. 10

(c) A straight inclined pipeline 300 m long discharges freely at a point 50 m lower than the water surface at intake. The pipe intake projects into the reservoir ($k_e = 0{\cdot}8$). The first 200 m of the pipe is of 350 mm diameter and the remaining 100 m is of 250 mm diameter ($k_c = 0{\cdot}21$).

(i) Find the rate of discharge assuming $f = 0{\cdot}06$.

If the junction point C of the two sizes of the pipe is 40 m below the intake water surface level, find the pressure head.

(ii) just upstream of C and

(iii) just downstream of C.

Assume sudden contraction at C.

(iv) Verify the head loss across contraction C. 10

(d) Two pipes have length L each. One of them has a diameter of D and other d. If the pipes are arranged in parallel, the head loss is h for a discharge of Q m^3/s. When the pipes are connected in series, the head lost is H for same discharge. Find the ratio of H to h, for $D = 2{\cdot}25\ d$. (All dimensions in m) 10

6. (a) Develop (in general terms) an expression for the per cent of error in Q over a triangular weir if there is a small error in the measurement of the vertex angle. Assume there is no error in the weir coefficient. Compute the per cent error in Q, if there is a 1° error in the measurement of total vertex angle of a triangular weir which is having a total vertex angle of 60°. 10

(b) What is the hydraulic jump in the flow in open channel ? What are its types and characteristics with respect to Froude's number of flow ? 10

(c) Air flows isothermally in a long pipe. At one section the pressure is 600 kPa abs, the temperature is 25°C and the velocity is 30 m/s. At a second section (at some distance from the first section) the pressure is 100 kPa abs. Find the energy head loss due to friction and determine the thermal energy that must have been added to or taken from the fluid between the two sections. Assume the diameter of pipe to be constant. 10

(d) Researchers plan to test a 1 : 13 model of a ballistic missile in a high speed wind tunnel. The prototype missile will travel at 380 m/s through air at 23°C and 95·0 kPa (abs).

(i) If the air in the wind tunnel test section has a temperature of –20°C at a pressure of 89 kPa (abs), what must its velocity be ? and

(ii) Estimate the drag force on the prototype if the drag force on the model is 400 N. 10

7. (a) Explain the effect of vane angle on manometric efficiency in a centrifugal pump. Why is vane angle in a centrifugal pump not kept at values below 20° ? 10

(b) Fluid flows with a velocity of V_∞ over a flat plate located at $y = 0$. The leading edge of the plate is located at $x = 0$. The possible velocity profiles in the boundary layer having thickness $\delta(x)$ are as follows :

(i) $\frac{u}{V_\infty} = 2\frac{y}{\delta} - \left(\frac{y}{\delta}\right)^2$

(ii) $\frac{u}{V_\infty} = \frac{3}{2}\frac{y}{\delta} - \frac{1}{2}\left(\frac{y}{\delta}\right)^3$

(iii) $\frac{u}{V_\infty} = \frac{y}{\delta} - \frac{1}{2}\left(\frac{y}{\delta}\right)^2$

Find out which of these velocity profiles are feasible for laminar flow. Also, identify the smoothest velocity profile from these three options. 10

(c) Describe with neat sketch, the construction and working principle of Rotometer. What are its advantages ? 10

(d) A single acting reciprocating pump lifts a liquid of specific weight 9·0 kN/m^3 from a pressurised storage reservoir to an overhead container. The free surface in the supply reservoir is at an elevation of 3·5 m above the centre of the pump. The ambient pressure over the liquid surface in the supply reservoir is 27 kN/m^2 (vacuum). The other relevant data relating to the pump are as follows :

Length of the suction pipe = 6·0 m

Diameter of suction pipe = 10 cm

Minimum pressure anywhere in the system = 27 kPa (abs)

Length of stroke = 50 cm

Diameter of cylinder = 20 cm

Atmospheric pressure = 99 kN/m^2 (abs)

Determine the maximum speed admissible in rpm. 10

8. (a) Define air rate, specific power and the cycle work ratio in a gas turbine. What is the significance of these parameters ? 5

(b) Justify the selection of a turbine runner with highest specific speed possible. Derive an expression for the specific speed of a pelton wheel, for speed ratio 0·46, overall efficiency 85% and co-efficient of velocity of nozzle 0·98. 10

(c) What are the shortcomings of a fire tube boiler restricting it for limited use ? How are the impurities in feed water removed from the boiler ? 10

(d) What are the constructional features of an axial flow compressor ? How air is compressed and what is the method of getting higher compression ratio in such compressor ? 5

(e) A gas turbine utilizes two-stage centrifugal compressor. The pressure ratios for the first and second stages are 2·5 and 2·1 respectively. The flow of air is 10 kg/s, this air being drawn at 1·013 bar and 20°C. If the temperature drop in the intercooler is 60°C and the isentropic efficiency is 90% for each stage, calculate :

(i) the actual temperature at the end of each stage and

(ii) the total compressor power.

Assume $\gamma = 1{\cdot}4$ and $C_p = 1{\cdot}005$ kJ/kg K for air. 10

———