ENGINEERING SERVICES EXAMINATION-2015

A-GTD-O-NDAA

MECHANICAL ENGINEERING

Paper I

(Conventional)

Time Allowed : Three Hours *Maximum Marks : 200*

INSTRUCTIONS

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

Candidates should attempt FIVE questions in all.

Question no. ***1*** *is compulsory.*

Out of the remaining SIX questions, attempt any FOUR questions.

The number of marks carried by a part of a question is indicated against it.

Answers must be written in ENGLISH only.

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

For air $R = 0{\cdot}287\ kJ/kg\text{-}K$, $C_p = 1{\cdot}005\ kJ/kg\text{-}K$,

$\gamma = 1{\cdot}4$, $M = 28{\cdot}97\ kg/kg\text{-}mole$, *Universal gas constant*

$R = 8{\cdot}314\ kJ/kg\ mole\text{-}K$.

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

Neat sketches may be drawn, wherever required.

Attempts of questions shall be counted in chronological 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 answer book must be clearly struck off.

1. (a) An inventor claims to have designed an equipment which takes in air at 0·5 MPa and 27°C and gives two streams of equal mass of air, one hot stream at 0·1 MPa and 400 K and the other cold stream at 0·1 MPa and 200 K. It is also claimed that the equipment does not require energy either in the form of heat or work. Judge whether it is theoretically feasible or not based on the thermodynamic principles. *10*

(b) A steel pipe of diameter 8·9 cm has eight longitudinal fins of 1·5 mm thickness which extend, 30 mm from the pipe surface. If the thermal conductivity of the fin material is 45 W/mK, find the percentage increase in the rate of heat transfer for the finned surface compared to the base surface. Assume the film heat transfer coefficient as 75 W/m^2K. *10*

(c) (i) What is boundary layer separation ? Explain with neat sketches, the sufficient and necessary conditions for boundary layer separation. What are the common methods to control boundary layer separation ? *7*

(ii) For the velocity profile,

$$\frac{u}{U_\infty} = \left(\frac{y}{\delta}\right)^{1/7},$$

calculate the momentum boundary layer thickness in terms of the nominal thickness 'δ' of the boundary layer. *3*

(d) (i) Define RSHF, GSHF and ESHF. Show them on a skeleton psychrometric chart. 5

(ii) Air at a temperature of 30°C flows over a flat plate of length 2 m, which is maintained at 150°C. The air flows with a velocity of 12 m/s. Find the local heat transfer coefficient at a distance of 0·5 m from the leading edge, and at the trailing edge. What is the type of flow at these two sections ? At what length, does the flow pattern change ?

The properties of air at the mean temperature of 90°C are

$C_p = 1{\cdot}01$ kJ/kg °C, $\rho = 0{\cdot}962$ kg/m^3,

$\mu = 2{\cdot}131 \times 10^{-5}$ kg/m-s, $k = 0{\cdot}031$ W/mK.

Use the equations :

$Nu = 0{\cdot}332\, Re^{0{\cdot}5}\, Pr^{0{\cdot}33}$ for laminar flow and

$Nu = 0{\cdot}0296\, Re^{0{\cdot}8}\, Pr^{0{\cdot}33}$ for turbulent flow. 5

(e) (i) Draw the velocity triangles at the outlet and theoretical "head vs discharge" curves for a centrifugal pump with forward curved, radial and backward curved vane impellers. 5

(ii) A centrifugal pump delivers water against a head of 16 m. The external and internal diameters of the impeller are 400 mm and 200 mm respectively. Find the minimum starting speed of the pump. 5

(f) In case of turbocompressors such as centrifugal and axial flow compressors, isentropic efficiency, and in the case of reciprocating compressors, isothermal efficiency are used as the reference. Explain why. Derive an expression for the volumetric efficiency of a single stage reciprocating compressor. Explain with the help of P-V diagram, the effect of pressure ratio and clearance volume on volumetric efficiency. *10*

(g) A certain mass of air is initially at 260°C and 700 kPa and occupies 0·028 m^3. The air is expanded at constant pressure to 0·084 m^3 A polytropic process with n = 1·50 is then carried out, followed by a constant temperature process which completes the cycle. All the processes are reversible processes.

(i) Sketch the cycle on P-v and T-s coordinates and (ii) find the efficiency of the cycle. *10*

(h) (i) Define DBT, WBT, DPT, Relative humidity (R.H.) and Specific humidity with respect to the properties of moist air. *4*

(ii) Show a schematic sketch of a winter air-conditioning system and explain all the processes involved. *6*

2. (a) A 1 : 20 scale model of a submarine is tested in a wind tunnel to measure the drag on the proposed design. A prototype speed of 18 kmph is desired. What speed should be used in the wind tunnel for the model testing ? Estimate the ratio of drag forces between the model and the prototype. Use the following property values : *10*

Fluid	Density kg/m^3	Viscosity $N\text{-}s/m^2$
Air	1·22	1×10^{-5}
Sea water	1025	$1{\cdot}5 \times 10^{-3}$

(b) A copper wire of 5·2 mm diameter is insulated with a layer of PVC of thermal conductivity 0·43 W/mK. The wire carries current and its temperature is 60°C. Film coefficient on the air side is 11·35 W/m^2K. Calculate the critical thickness of insulation. Also calculate the heat loss from the wire with the critical thickness of insulation. Find the heat transfer for insulation thickness of 20 mm and 60 mm. Ambient air temperature is 30°C. *10*

(c) In SI engines knocking occurs near the end of combustion whereas in the CI engines knocking occurs near the beginning of combustion. Explain the factors responsible for knocking in SI engines. *10*

3. (a) A 3-jet pelton turbine is required to generate 10,000 kW under a net head of 400 m. The blade angle at outlet is 15° and the reduction in the relative velocity while passing over the blades is 5%. If the overall efficiency of the wheel is 80%, $C_V = 0{\cdot}98$ and speed ratio = 0·46, find (i) the diameter of the jet, (ii) the flow rate and (iii) the force exerted by a jet on the buckets. 10

(b) (i) The lubricating oil used in a gear box of a compressor is being recirculated through a double pipe heat exchanger for cooling. The oil is to be cooled from 70°C to 40°C using water available at 28°C. Flow rate of the oil is 1000 kg/hr. Water exit temperature should not exceed 42°C. C_P of oil is 2·05 kJ/kg-K, C_P of water is 4·17 kJ/kg-K. Calculate the required water flow rate and the area of the heat exchanger. Assume counter flow. Also assume the overall heat transfer coefficient to be 300 W/m^{2}K. 5

(ii) A refrigerator is placed near a partition wall of a room such that there is only a 4 cm gap between the wall and the refrigerator surface facing the wall. The refrigerator surface is of 1·6 m height and 0·8 m breadth and has a temperature of 22°C. The wall temperature is 30°C. Calculate the rate of heat gain by the refrigerator surface.

Assume the properties of air at 26°C :

$\nu = 1{\cdot}684 \times 10^{-5}$ m²/s, k = 0·26 W/mK,

$\alpha = 2{\cdot}21 \times 10^{-5}$ m²/s, Pr = 0·7.

Use the equation,

$$Nu = 0{\cdot}42 \, . \, Ra_w^{0{\cdot}25} \, . \, Pr^{0{\cdot}012} \, . \left(\frac{L}{W}\right)^{-0{\cdot}3}$$

(where Ra is the Rayleigh number). *5*

(c) Prove that for Van der Waals gas, C_v is a function of temperature only. Van der Waals equation is given by $P = \left(\frac{RT}{(v-b)} - \frac{a}{v^2}\right)$ *10*

4. (a) A simple R-12, heat pump, used for space heating, operates between 15°C and 50°C. Heat required to be pumped is 100 mJ/hr. Calculate the quality of the refrigerant entering the evaporator, mass flow rate of the refrigerant and discharge temperature coming out of the compressor, theoretical piston displacement, power required for the compressor and the COP.

Assume C_p of vapour as 0·8 kJ/kg-K and specific volume of saturated vapour at 15°C as 0·0354 m³/kg. *10*

Properties of R-12

t_{sat} °C	P_{sat} kPa	h_f kJ/kg	h_g	s_f kJ/kg-K	s_g
15	0·491	50·1	193·8	0·1915	0·6902
50	1·291	84·9	206·5	0·3037	0·6797

(b) In a gas turbine plant, air at 10°C and 1·0 bar is compressed to 12 bar with isentropic efficiency of 80%. The air is heated first in the regenerator and then in the combustion chamber till its temperature is raised to 1400°C, and during this process the pressure falls by 0·2 bar. The air is then expanded in the turbine, and then passes through the regenerator, which has an effectiveness of 0·75 and causes a pressure drop of 0·2 bar. Isentropic efficiency of the turbine is 85%. Determine the thermal efficiency of the plant. Assume addition of heat at constant pressure. 10

(c) Steel balls used in ball bearings are quenched by suddenly dropping the hot balls in a cold oil bath. Steel balls of 50 kg mass initially at 200°C and with specific heat 0·45 kJ/kg-K are quenched in an oil bath of initial temperature 30°C and specific heat 2·8 kJ/kg-K. During the quenching, a paddle-wheel driven by a 200 W motor is activated to stir the oil. Thermal equilibrium is established after 20 minutes, when the final temperature is 40°C. Determine the mass of the oil and the entropy generated during the process. Consider the tank containing the oil to be well insulated and of negligible mass. 10

5. (a) (i) Find the shape factors of the two surfaces, one is the hemispherical surface of same diameter and the second a flat surface of the same diameter, comprising an enclosure. 2

(ii) A steel ball of 0·3 m diameter and at 800 K is cooled by radiation only, to the ambient at 30°C. Find the time required for the ball to cool to 70°C. Assume the density and specific heat of steel as 780 kg/m^3 and 0·473 kJ/kg-K respectively. Assume the surface of the steel ball to be black. 8

(b) (i) Draw an indicator diagram showing the effect of acceleration and friction in a single stage reciprocating pump. Explain the various heads and the considerations to decide the safe speed of the pump. 5

(ii) What is an air vessel ? Give the chief advantages of fitting air vessels on the suction and delivery sides of a reciprocating pump. 5

(c) In a BWR type nuclear reactor, the heat of nuclear fission is transferred to water In a reactor, water comes out of the reactor as saturated vapour at 72 bar. The steam flows through a turbine and exhausts at 0·08 bar to a condenser. The water leaves the condenser at 0·08 bar and 40°C (h = 176·5 kJ/kg). The liquid water is again pumped through a pump to the nuclear reactor. Isentropic efficiency of the turbine is 70%. The plant has a capacity of 750 MW. Calculate the mass flow rate of steam circulated and the rate of heat generation.

Properties of steam :

P = 0·08 bar : h_f = 173·9 kJ/kg, h_{fg} = 2403·2 kJ/kg,

s_f = 0·5926 kJ/kg-K, s_{fg} = 7·6370 kJ/kg-K,

At 72 bar : h_g = 2770·9 kJ/kg, s_g = 5·8019 kJ/kg-K. *10*

6. (a) A rectangular block of material A (k = 24 W/mK) of 0·10 m thickness is sandwiched between two walls of metals, B (k = 2030 W/mK) of thickness 0·12 m, and C (k = 200 W/mK) of thickness 0·15 m respectively. Heat generation occurs in material A at a uniform rate of $2{\cdot}5 \times 10^3$ W/m^3. Develop expressions for the steady state temperature distribution in the three layers and determine the maximum temperature and its location in the assembly. The outer surfaces of 'B' and 'C' are maintained at 100°C and 150°C respectively. *10*

(b) (i) An airplane is flying at a speed of 800 kmph at an altitude of 1·5 km, where the air temperature is – 50°C. Find the maximum possible temperature on the airplane skin body. *5*

(ii) A rectangular notch of 0·8 m width and a 90° V-notch are to be used alternately for measuring an expected flow rate of 0·05 m^3/s of a liquid. Find the percentage error that would result in the two cases, if an error of 1 mm is made in the head measurement. Assume C_d = 0·6 for both the notches. *5*

(c) A process equipment has been designed to make heat continuously available at a temperature level of 260°C. The only source of energy is a continuous flow of saturated steam at 17·5 bar (h = 2794·1 kJ/kg; s = 6·3853 kJ/kg-K). Cooling water is also available in large supply at 20°C. The steam is condensed in the equipment and comes out as condensate at 1 bar and 20°C (h = 85·5 kJ/kg; s = 0·2959 kJ/kg-K). How much heat can be transferred from the process to the heat reservoir at 260°C, for every one kg of steam condensed in the process ? *10*

7. (a) (i) Show the various psychrometric processes on a skeleton psychrometric chart. *4*

(ii) Differentiate between the processes of "heating and humidification", "cooling and humidification" and "adiabatic saturation". What is the change of specific humidity and DBT in each of these processes ? Which of the processes in part (i) are possible in an air-washer ? Explain with a schematic diagram. *6*

(b) (i) Sketch neatly "Moody Diagram" — a chart showing the friction factor, $f = f(Re, E_S / D)$ for full range of Reynolds numbers in pipe flow. Can we use this chart for non-circular conduits ? If yes, how ? *4*

(ii) An oil of density 917 kg/m^3 is being pumped in a 15 cm diameter horizontal pipe. The discharge is measured as 800 litres/minute. The drop in pressure in a stretch of 800 m of pipeline is measured as 95 kPa. Estimate the absolute viscosity of the fluid. *6*

(c) The output of an engine is given as input to an agricultural pumpset. The pump is used for lifting water from a depth of 30 m at the rate of 200 litres/minute. The transmission efficiency between the engine and the pump is 100% and the pump is considered to be 100% efficient. The brake thermal efficiency of the engine is 35%, the calorific value of the fuel is 43 MJ/kg, the cost of fuel is ₹ 53·00 per litre and the density of the fuel is 780 kg/m^3. Estimate the running cost of the fuel for 1000 m^3 of water lifted. *10*
