-Engg. Services Exam, 2011

Serial No. 39281

D–RSR–L–ZRA

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 = 0·287 kJ/kg-K, C_p = 1·005 kJ/kg-K, γ = 1·4, M = 28·966 kg/kg-mole.

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

1. (a) A pressure cylinder of volume V contains air at pressure p_0 and temperature T_0. It is to be filled from a compressed air line maintained at constant pressure p_1 and temperature T_1. Show

that the temperature of the air in the cylinder after it has been charged to the pressure of the line is given by

$$T = \frac{\gamma T_1}{1 + \frac{p_0}{p_1}\left[\gamma \frac{T_1}{T_0} - 1\right]}$$ 10

(b) Consider an engine in outer space which operates on the Carnot Cycle. The only way in which heat can be transferred from the engine is by radiation. The rate at which heat is radiated is proportional to the fourth power of the absolute temperature and to the area of the radiating surface. Show that for a given power output and a given T_1, the area of the radiator will be a minimum when $\frac{T_2}{T_1} = \frac{3}{4}$.

10

(c) A lead storage battery used in an automobile is able to deliver 5·2 MJ of electrical energy. This energy is available for starting the car. Let compressed air be considered for doing an equivalent amount of work in starting the car. The compressed air is to be stored at

7 MPa, 25°C. What is the volume of the tank that would be required to let the compressed air have an availability of 5·2 MJ ? For air, pv = 0·287 T, where T is in K, p in kPa, and v in m^3/kg. 10

(d) Obtain an expression for the specific work output of a gas turbine unit in terms of pressure ratio, isentropic efficiencies of the compressor and turbine, and the maximum and minimum temperatures, T_3 and T_1. Hence show that the pressure ratio r_p for maximum power is given by

$$r_p = \left[\eta_T \cdot \eta_C \frac{T_3}{T_1} \right]^{\frac{\gamma}{2(\gamma-1)}}. \qquad 10$$

2. (a) An engine fitted with a single jet carburettor having a jet diameter of 1·25 mm has a fuel consumption of 6 kg/hr. The specific gravity of fuel is 0·7. The level of fuel in the float chamber is 5 mm below the top of the jet when the engine is not running. Ambient conditions are 1 bar and 17°C. The fuel jet diameter is 0·6 mm. The discharge coefficient of air is 0·85. Air-fuel ratio is 15.

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Determine the critical velocity of flow at throat and the throat diameter. Express the pressure at throat in mm of water column. Neglect compressibility effect. Assume discharge coefficient of fuel flow is 0·60. 15

(b) Find the percentage increase in the efficiency of a Diesel Cycle having a compression ratio 'r' of 16 and cut off ratio 'r_c' is 10% of the swept volume, if C_v decrease by 2%. Take C_v = 0·717 kJ/kg °K and γ = 1·4. 15

(c) Explain the knocking phenomenon in a CI engine. Compare it with that of SI engines. Discuss the effect of operating variables on delay period and diesel knock 10

3 (a) A steel pipe having internal diameter of 2 cm, outer diameter of 2·4 cm and thermal conductivity of steel of 54 W/mK carries hot water at 95°C. Heat transfer coefficient between the inner surface of steel pipe and the hot water is 600 W/m^2K An asbestos insulation with thermal conductivity of 0·2 W/mK and thickness 2 cm is put on the steel pipe. Heat is lost from the outer surface of the asbestos insulated pipe to the

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surrounding air at 30°C, heat transfer coefficient for the outer surface of the insulation being 8 W/m^2K.

Determine :

(i) The rate of heat transfer per meter length of the pipe.

(ii) Determine the temperatures at the inner, outer surfaces of the steel pipe and the outer surface of the insulation.

(iii) What do you understand by the term "critical radius of insulation" ? What is the value of critical radius in the above question ? What is the rate of heat loss, if thickness of insulation were to correspond to critical radius ? Comment on the results. 10

(b) Define and discuss the physical significance of the following :—

(i) Nusselt Number — Can it be less than 1 ?

(ii) Prandtl Number — What does it signify ?

(iii) Biot Number — How does it differ from Nusselt number ?

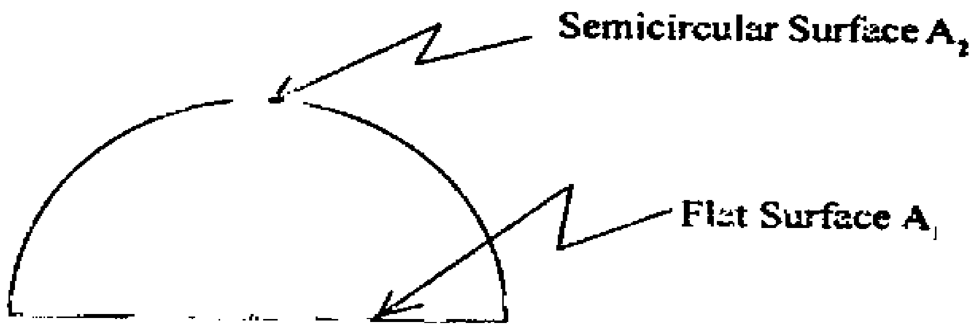
(iv) Thermal diffusivity.

(v) Fin effectiveness. 10

(c) (i) State and explain Lambert law. How is it used in radiative heat transfer calculation ? For a diffused flat surface having emissivity of 0·7 at a temperature of 800°C, calculate normal intensity of radiation.

What would be the intensity of radiation at an angle of 30° with respect to normal direction ?

(ii) For a very long semicircular duct having surface areas A_2 and A_1 as shown below :



Determine shape factors F_{12}, F_{21}, F_{22}. 10

(d) (i) What is fouling in heat exchangers ? How is it specified ? How does the fouling affect the rate of heat transfer in heat exchangers ?

(ii) Distinguish and differentiate between direct transfer heat exchangers and storage type heat exchangers with the help of simple sketches giving their advantages and disadvantages. 10

4. (a) A refrigeration system is to be designed for a cooling capacity of 7·5 tons of refrigeration at saturation pressure corresponding to –20°C. It uses refrigerant R-22. Condenser pressure is to be corresponding to saturation temperature of 40°C. The refrigeration system uses a liquid-vapour regenerative heat exchanger. The refrigerant vapours coming out of the evaporator are superheated by 5°C and then pass through the regenerative heat exchanger to cool the liquid refrigerant coming from the condenser. The temperature of the refrigerant vapours at the exit of heat exchanger is 20°C. The liquid refrigerant is subcooled to 36°C at the exit of the condenser.

Make a sketch of the system and represent it on P-h and T-S diagrams.

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The system uses two single-acting cylinders with bore to stroke ratio of 0·8, speed of compressor is 1420 rpm, clearance factor for compressors is 0·04 and polytropic index of compression is 1·1. Mechanical efficiency of the compressor is 0·8.

Determine :

(i) temperature of liquid refrigerant at the exit of regenerative heat exchanger, assuming specific heat of the liquid to be 1·37 kJ/kg K.

(ii) mass flow rate of the refrigerant.

(iii) the temperature of the refrigerant vapours at the exit of compressor, assuming ideal gas behaviour in the superheat region, specific heat of refrigerant vapours in the superheat region may be taken as 0·85 kJ/kg K.

(iv) Power input to the compressor.

(v) COP of the system.

(vi) Volumetric efficiency of the compressor, and

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(vii) Bore and stroke of the compressor.

The following properties of R-22 are given :

Sat. temp t_s (°C)	Sat. pressure P_s (bar)	Sp. Vol. of Sat. vapour (m^3/kg)	Enthalpy (kJ/kg)	
			Sat. Liquid h_f	Sat. vapour h_g
−20	2·448	0·0928	177·4	397·5
40	15·335	0·0151	249·08	415·95

For superheated refrigerant vapour at 2·448 bar and saturation temperature of −20°C

Temperature °C	Specific volume (m^3 / kg)	Enthalpy kJ / kg
−15	0·0951	400·7
20	0·1107	423·9

20

(b) (i) Discuss the measurement of wet bulb temperature by means of a wick-covered bulb of a thermometer. How is it related to dry-bulb temperature and specific humidity of moist air and on what other factors does it depend ?

(ii) Define thermodynamic wet bulb temperature. How is it determined ? How does it differ from measured wet-bulb temperature ? 10

(c) How do you define effective temperature as an index of comfort ? On what factors does it depend ? What optimum inside design conditions are recommended for comfort for summer airconditioning including ventilation requirements ? 10

5. (a) A hydraulic lift of the type commonly used for greasing automobiles consists of a 280 mm diameter ram that slides in a 280·18 mm cylinder. The annular space between the ram and cylinder is filled with oil having a kinematic viscosity of 0·00042 m^2/s and specific gravity of 0·86. If the rate of travel of the ram is 0·22 m/s, find the frictional resistance when 2 m of the ram is engaged in the cylinder. 5

(b) A solid, half-cylinder-shaped log of 0·48 M radius and 2·5 m long, floats in water with the flat face up.

(i) If the immersion depth of the lowest point is 0·3 m, what is the uniform specific weight of the log ?

(ii) The log tilts about its axis (zero net applied force), by less than 22°. Is it in stable equilibrium ? Justify your answer with a sketch and logic.

(iii) If the log tilts by 18° (left side down; zero net applied force), what is the magnitude and sense of any moment that results ? 15

(c) Air enters into a constant area frictionless duct with M = 3, P = 7 bar and T = 288 K. It is desired to reduce the flow Mach number to 2 at the exit of the duct. Determine the amount of heat added and the corresponding change in pressure. For air, C_p = 1·003 kJ/kgK.

Take :

M	T_o/T_o^*
3	·6534
2	·7934

10

(d) Show the basic elements of an electrostatic precipitator and explain its operation. 10

6. (a) A flow field is defined by $u = 2y$ and $v = xy$. Derive expressions for the acceleration components. Find the magnitude of the velocity and acceleration at the point (2, 3). Specify units in terms of L and T. 5

(b) Derive an expression for small flow rates over a spillway, in the form of a function including dimensionless quantities. Use dimensional analysis with the following parameters :

Height of spillway = P

Head of spillway = H

Viscosity of liquid = μ

Density of liquid = ρ

Surface tension = σ

Acceleration due to gravity = g. 15

(c) Assume the velocity profile for turbulent flow in a circular pipe to be approximated by a parabola from the axis to a point very close to the wall where the local velocity is $u = 0{\cdot}6\ u_m$, where u_m is the maximum velocity at the axis. The equation for this parabola is $u = u_m[1 - 0{\cdot}4(r/r_o)^2]$. Find the value of kinetic energy correction factor. 15

(d) With the help of simple schematic flow diagrams, explain the difference between once-through steam generators and the drum type steam generators. 5

7. (a) For the velocity distribution prescribed by $u/u_o = (y/\delta)^{1/7}$, show that the ratio of displacement thickness (δ^*) to momentum thickness (θ) is 1·285. 10

(b) A runner of a centrifugal pump has an outer diameter of 25 cm and runs at 1500 rpm. It has 10 blades, each of 5 mm thickness. They are backward facing at 30° to the tangent and the breath of the flow passages at outlet is 12·5 mm. Pressure gauges are fitted close to the pump casing on the suction and discharge pipes,

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both are 2·5 m above water level in supply sump. When discharge is 26 lit/s, the gauge readings are 4 m vacuum and 16·5 m of water respectively. Assume that there is no whirl at inlet and no whirl slip. If 50% of velocity head at outlet from the runner is recovered as static head in the volute, estimate :

(i) theoretical head

(ii) manometric efficiency

(iii) losses in the impeller, and

(iv) capacity of the motor to drive the pump, if mechanical efficiency is 0·9. 20

(c) Show the velocity diagrams of a 50% reaction turbine operating with maximum blade efficiency and highlight its salient features. 10

8. (a) Application of dimensional analysis technique to incompressible flow rotodynamic machines gives following dimensionless ratios :

(i) $\pi_1 = Q/ND^3$

(ii) $\pi_2 = \dfrac{gH}{N^2D^2}$

(iii) $\frac{\rho N D^2}{\mu}$

(iv) $\frac{P}{\rho N^3 D^5}$.

Using them only :

(a) Show that

(i) π_1 represents condition of kinematic similarity.

(ii) π_3 represents condition of dynamic similarity.

(b) Establish the expression of :

(i) unit speed, unit discharge and unit power for the turbine

(ii) specific speed for turbine and pump.

(c) Establish the effect of speed on discharge, head developed and power required by pump. 15

(b) A constant area circular duct is connected to the convergent divergent nozzle exit. The air enters the nozzle from a tank at a pressure of 7 bar (ab) and temp. of 127°C. The pressure at the nozzle exit is 0·19 bar. If the temperature of the air is 3°C at the end of the duct, and the duct length is 17·5 diameter of the duct, find the friction co-efficient

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of the duct. Consider flow is adiabatic through a duct and isentropic in the nozzle.

Use :

M	4fLm/D
3	·522
1·5	·136

15

(c) Explain supersaturated expansion in case of flow through nozzle and discuss, briefly, the factors causing it. Represent the phenomenon on h-s diagram indicating superheated zone. State the effects of supersaturation. 10