Civil Services (Main) Examination, 2006

# MECHANICAL ENGINEERING

## (Paper II)

| Time Allowed : Three Hours | Maximum Marks : 300 |
|---|---|

**QUESTION PAPER SPECIFIC INSTRUCTIONS**

*(Please read each of the following instructions carefully before attempting questions)*

There are EIGHT questions divided in two Sections.
Candidate has to attempt FIVE questions in all.
Question Nos. 1 and 5 are compulsory and out of the remaining, any THREE are to be attempted choosing at least ONE question from each Section.
The number of marks carried by a question/part is indicated against it.
Wherever any assumptions are made for answering a question, they must be clearly indicated.
Word limit in questions, wherever specified, should be adhered to.

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## SECTION 'A'

**1.** Answer any three of the following –

**(a)** With the help of Maxwell's relation of thermodynamics, prove that Joule-Thomson coefficient, $\mu_J$ of a gas is given by the following expression:

$$\mu_J = \left(\frac{\partial T}{\partial P}\right)_h = \frac{T^2}{C_p}\left[\frac{\partial}{\partial T}\left(\frac{v}{T}\right)_p\right]$$

**20**

**(b)** A 0.8 kg metal bar kept initially at 1500°C is removed suddenly from an oven and quenched by immersing it in a closed tank containing 12 kg of water kept initially at 400°C. The metal and water can be modeled as incompressible and the specific heat of water and metal are 4.18 kJ/kg-K and 0.5 kJ/kg-K respectively. The heat transfer from the tank may be neglected. Work out the following (i) Draw the system and system boundary and list assumptions made (ii) The final temperature of metal bar and water (iii) The entropy produced **20**

**(c)** Draw the characteristic curves between the following parameters for an SI engine (i) Air standard efficiency vs Compression ratio (ii) Relative efficiency vs Air–fuel ratio (iii) Brake thermal efficiency vs Load (iv) Volumetric efficiency vs Engine speed (v) Peak–cycle temperature vs Equivalence ratio. Discuss significant points in each case in the light of design parameters. **4×5**

**(d)** A rectangular cooper plate 10 cm × 50 cm, having a mass of 1 kg and at a temperature of 100°C, is suspended vertically in still air at 20°C so that 50 cm side is vertical. Neglecting radiation effect, find heat transfer coefficient due to natural convection and initial rate of cooling of the plate in °C/minute. Take $C_p$ for copper = 383 J/kg-K. The properties of air at mean temperature 60°C are: $\rho = 1.06\,kg/m^3$, $v = 18.97 \times 10^{-6}\,m^2/s$, $Pr = 0.696$, $C_p = 1.005\,kJ/kg\text{-}K$, $k = 28.96 \times 10^{-3}\,W/m\text{-}K$, $\mu = 20.1 \times 10^{-6}\,N\text{-}s/m^2$. You may use the following correlation: $Nu = 0.1(GrPr)^{1/3}$. Will the result change if 10 cm side is vertical? Why? **20**

**2.** **(a)** A counterflow heat exchanger acting as a recuperator, of gas turbine receives compressed air operating at steady state at 650 K, 12 bars and exits at 850 K, 11.6 bars. Hot combustion from the exhaust of gas turbine enters as a separate stream at 1000 K, 1.1 bars and comes out at 1 bar. The mass flow rate of each stream is 200 kg/s. The heat transfer from the outer surface of the heat exchanger to surroundings may be neglected. The changes in kinetic and potential energy are negligible. Take $T_0 = 228\,K$ and $P_0 = 1\,bar$. Assume ideal gas model for combustion gas. Work


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out the following: (i) Draw the system and show the temperature distribution for each stream (ii) The exit temperature of combustion gas (iii) The net change in the flow energy rate from inlet to outlet for each stream (iv) The energy distribution rate (v) Comment on the results **30**

**(b)** During summer to cool water for drinking purpose, 2 kg of ice at −3°C in an insulated container which is subjected to atmospheric pressure of 1 bar. Assume specific heat of ice is 2.093 kJ/kg-K and latent heat of ice as 335 kJ/kg. Work out the following (i) Draw the system and show the process on T-Q for both ice and water (ii) The temperature of the mixture (iii) The change of entropy for instantaneous process. **30**

**3. (a)** Derive an expression for air-fuel ratio delivered by a simple carburetor, neglecting the effect of compressibility. Discuss the limitations of simple carburetor. What are the modifications incorporated for its use in automotive vehicles? **10+10+10**

**(b)** A four-stroke petrol engine develops 30 kW at 2600 r.p.m. The compression ratio of the engine is 8 and its fuel consumption is 8.4 kg/h with calorific value of 44 MJ/kg. The air consumption of the engine as measured by means of a sharp edge orifice is $2\,m^3$ per min. If the piston displacement volume is 2 liters, calculate (i) Volumetric efficiency (ii) Air-fuel ratio (iii) Brake mean effective pressure (iv) Brake thermal efficiency (v) Relative efficiency. The ambient temperature of air can be taken as 27°C, R for air as 287 J/kg-K and $\gamma = 1.4$. The barometer reads 755 mm of mercury. **6×5**

**4. (a)** A counterflow, concentric tubes heat exchanger is designed to heat water from 20 °C to 80°C using hot oil flowing through the annulus. The oil temperature gets reduced from 160 °C to 140 °C. The nominal diameter of the inner tube is 20 mm and the corresponding overall heat transfer coefficient is $500\,W/m^2\text{-}K$. The heat transfer rate from the oil is 3000 watts. Determine the length of the exchanger. Because of fouling after some days the outlet temperature of water reduced to 65°C for the same flow rates and same inlet conditions. Determine the outlet temperature of oil, the fouling factor and the new heat transfer rate. Sketch the heat exchanger arrangement and the temperature profiles. **30**

**(b)** The temperature of a gas flowing through a pipe was measured by a mercury-in-glass thermometer, dipped in an oil-filled steel tube welded radially to the pipeline. The thermometer indicates a temperature lower than the gas temperature. How large is the error in the temperature measurement if the thermometer reads 85 °C and the temperature of the pipe wall is 40°C? The steel tube is 125 mm long and has a 1.5 mm thick wall. The thermal conductivity of this tube material is 56 W/m-K and the local heat transfer coefficient between the gas and the tube is $23.5\,W/m^2\text{-}K$. In what way the thermometric error can be reduced? **30**

## SECTION 'B'

**5.** Write any three of the following –

**(a)** For flow through a compressor cascade, show that lift and drag coefficients are given by the following expressions

$$C_L = Z\left(\frac{s}{c}\right)\frac{\Delta C L_w}{C_m} - \zeta\left(\frac{s}{c}\right)\frac{\cos^3\alpha_m}{\cos^2\alpha_1}\tan\alpha_m$$

And

$$C_D = \zeta\left(\frac{s}{c}\right)\frac{\cos^3\alpha_m}{\cos^2\alpha_1}$$

where s/c = Pitch-chord ratio; $\Delta C_w = C_{w1} - C_{w2}$; $\alpha_m$ = Mean flow angle; $\zeta$ = Total pressure loss coefficient **20**



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**(b)** An ammonia ice plant operates on simple saturation cycle at the following temperatures: Condensing temperature = 40°C; Evaporation temperature = −15°C. It produces 10 tonnes of ice per day at −5°C from water at 30 °C. If the COP of the system is 5, determine: (i) Capacity of the refrigeration plant in tonnes of refrigeration (ii) Mass flow rate of the refrigerant, kg/min (iii) Isentropic discharge enthalpy, kJ/kg. Take: $C_p$ = 4.187 kJ/kg-K for water = 2.000 kJ/kg-K for ice; Latent heat of fusion of ice = 335 kJ/kg; Sensible enthalpy at 40°C = 600 kJ/kg; Enthalpy of sat. vapour at −15°C = 1675 kJ/kg **20**

**(c)** Explain the concept of effective temperature (ET) used in air-conditioning practice. Discuss the parameters on which it depends. **20**

**(d)** A superheater is to be designed using metallic coils (heat flux $150\,kW/m^2$) of inside diameter 50 mm and wall thickness 5 mm. The steam leaving the superheater coils is at 60 bars, 500°C and flows at a velocity of 10 m/s. If the steam mass flow rate is 90 kg/s, find the number and length of coils. For steam at 60 bars, take the following values-dry saturated steam h = 2784.3 kJ/kg, at 500°C superheated steam temperature = 3422.2 kJ/kg and specific volume $V_{sup} = 0.05665\,m^3/kg$. The steam enters the superheater as dry and saturated. **20**

**6. (a)** A VCC refrigerating machine using R-12 refrigerant produces 10 tonnes of refrigeration at 10 °C when the ambient is at 35°C. A temperature difference of minimum 5°C is required at the evaporator and condenser for spontaneous heat transfer. The refrigerant is dry saturated at the outlet and to the inlet of compressor. The adiabatic efficiency of the compressor is 90%. The enthalpy at the end of isentropic compression is estimated to be 370 kJ/kg. Determine: (i) COP (ii) Power of the compressor (iii) Capacity of the condenser. Represent the cycle on hand drawn T-S plane and show the refrigerating effect, compressor work and condenser capacity on the same. Properties of R-12 are: **30**

| Temperature (°C) | Pressure (bar) | Specific Enthalpy, kJ/kg: Sensible | Specific Enthalpy, kJ/kg: Evaporation |
|---|---|---|---|
| 5 | 3.62 | 204.64 | 148.97 |
| 10 | 4.23 | 209.32 | 146.37 |
| 15 | 4.91 | 214.10 | 143.69 |
| 30 | 7.45 | 228.54 | 135.04 |
| 35 | 8.47 | 233.50 | 131.90 |
| 40 | 9.60 | 238.53 | 128.62 |

**(b)** Explain the procedure for cooling load estimation for comfort air-conditioning in the summer. Also explain the concept of different Sensible Heat Factors (SHFs) and importance in designing an air-conditioning system. **30**

**7. (a)** Explain the concept of types of similarities between model and prototype. What do you mean by distorted model? What are its advantages? It is proposed to design a ship. The proposed ship (prototype) is having a length of 150 m and a wetted surface area of $2000\,m^2$ with a speed of 40 km/h. A model of 1:20 is to be tested in the laboratory at a velocity corresponding to the wave resistance. The total drag of the model is 50 N. Determine the following: (i) Wave resistance drag of the model (ii) Wave resistance drag of the prototype (iii) Friction drag of the prototype. Give, Friction drag, $R_f = \frac{1}{2} C_D \rho A V^2$, where A = Wetted surface area; $C_D$ = Average friction drag coefficient ¿ $\frac{0.074}{(Re)^{1/5}}$ for $Re < 2 \times 10^7$; ¿ $\frac{0.01}{(Re)^{1/5}}$ for $Re > 2 \times 10^7$; $\rho_{model} = 1000\,kg/m^3$; $\nu_{model} = 1.110 \times 10^{-6}\,m^2/s$; $\rho_{prototype} = 1020\,kg/m^3$; $\nu_{prototype} = 1.125 \times 10^{-6}\,m^2/s$ **15+25**



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**(b)** Define Rayleigh flow. Give one practical example of Rayleigh flow. Show that the Mach numbers at the maximum enthalpy and maximum entropy points on the Rayleigh line are $\frac{1}{\sqrt{\gamma}}$ and 1.0 respectively. **6+14**

**8. (a)** An axial flow compressor compresses the air up to overall stagnation pressure 10 bars with overall stagnation isentropic efficiency of 88%. The inlet stagnation pressure and temperature are 1 bar and 300 K. The mean blade speed is 200 m/s. The degree of reaction is 0.5 at the mean radius with air angles of 30° and 10° at rotor inlet and outlet with axial direction respectively. The work done factor is 0.88. The hub-tip ratio is 0.4. The mass flow rate is 50 kg/s. Work out the following: (i) Draw the inlet and outlet velocity triangles and show the compression process on T-S diagram (ii) The stagnation polytropic efficiency (iii) The number of stages (iv) The blade height in first stage of the compressor **30**

**(b)** A nuclear power plant is set up with a generating capacity of 10 MW, the capital cost being Rs 80,000 per kW. It meets the following demands: (i) Service sector: Total load 400 kW at 30% load factor (ii) Cottage industries: Total load 3.6 MW at 50% load factor (iii) Household: Total loads 6 MW at 20% load factor. The operative cost of the plant is Rs. 30,00,000 per annum and annual rate of interest and depreciation is 10%. If as per promotion policy of government, a flat rate is to be charged from all categories of consumers, calculate the overall production cost. If the power is sold at the rate of production cost estimate the loss/gain each sector consumer will get per kWh for power consumed. **30**

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