Civil Services (Main) Examination, 2013

MECHANICAL ENGINEERING

(Paper II)

Time Allowed : Three Hours	Maximum Marks : 250

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.

Attempts of questions shall be counted in sequential 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 Question-cum-Answer Booklet must be clearly struck off.

SECTION 'A'

1. **(a)** Derive an expression for entropy (S) as given below

$$dS = \left(\frac{\delta Q}{T}\right)_{rev}$$

for a closed system undergoing a reversible process. **10**

(b) Write Bernoulli's equation and the conditions for which it is valid. If a fluid obeying Bernoulli's equation has elevation, velocity and pressure at a point as 30 m, 50 m/s and 50 bar respectively, calculate the total energy per unit mass of this fluid if its density is $1000\,kg/m^3$. **10**

(c) What is the effect of Mach number on the compressibility? Derive an expression for pressure coefficient in terms of Mach number. **10**

(d) Explain Wien's displacement law. Assuming sun to be a blackbody with a constant surface temperature of 5780 K, calculate the wavelength at which it will have the maximum spectral emissive power. **10**

(e) In a standard vapour compression refrigeration cycle, the specific enthalpies of refrigerant at the end states of different processes in ascending order are 74.6 kJ/kg, 185.4 kJ/kg and 208.0 kJ/kg. If the mass flow rate of refrigerant is 30 kg/min, calculate power consumption and COP of the cycle. **10**

2. **(a)** Prove that the cyclic integral of ratio between heat transfer and temperature of any thermodynamic process is less than or equal to zero. **20**

(b) A pipe having 15.4 cm inside diameter and 3.2 m length stands vertically. Another pipe having 10.2 cm inside diameter and 4.8 m length is welded on top of this pipe. Water at 22 °C fills the smaller diameter pipe to a depth of 2.24 m. Above the water is air under an absolute pressure of 242 kPa. Determine the total force on the bottom of the larger diameter pipe. **15**

(c) Hot gases enter the blades of a gas turbine with a velocity of 550 m/s and leave with a velocity of 120 m/s. There is an increase in the enthalpy of the gases in the blade passages to the extent of 5.1 kJ/kg. The rate of gas flow is 98 kg/min. Determine the power produced. **15**

3. **(a)** Derive an expression for entropy change across a normal shock wave occurring in a nozzle. Show the trend of this entropy change (in the form of a diagram), with respect to the Mach number value before the shock. **15**

English version compiled from published transcriptions and cross-checked across sources; not a facsimile of the official UPSC question paper.

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(b) Define availability of a closed and steady-flow system. Atmospheric air is compressed steadily from 100 kPa, 27 °C to 500 kPa, 117 °C, by a compressor that is cooled only by atmospheric air. Neglecting kinetic energy changes, determine the minimum work required per kg of air compressed. **15**

(c) In a balanced counterflow heat exchanger, where $\dot{m}_c C_{p,c} = \dot{m}_h C_{p,h}$, show that– (i) $\Delta T_1 = \Delta T_2 = \Delta T$ at any section; (ii) the temperature profiles of two fluids are parallel and linear. **20**

4. **(a)** In a double-pipe heat exchanger, $\dot{m}_h C_{p,h} = 0.5 \dot{m}_c C_{p,c}$. The inlet temperatures of hot and cold fluids are $T_{h,i}$ and $T_{c,i}$. Determine an expression, in terms of $T_{h,i}$, $T_{c,i}$ and $T_{h,o}$, for the ratio of area of counterflow heat exchanger to that of parallel-flow heat exchanger, which will give same hot fluid outlet temperature $T_{h,o}$. Also find out the ratio, if $T_{h,i} = 150 \square^{\circ} C$, $T_{c,i} = 30 \square^{\circ} C$ and $T_{h,o} = 90 \square^{\circ} C$. **25**

(b) A hot plate of 100 cm height and 25 cm wide is exposed to atmospheric air at 25 °C. The surface temperature of the plate is 95 °C. Find the heat loss from both the surfaces of the plate. Also find the change in heat loss if the height of the plate is reduced to 50 cm and the width is increased to 40 cm. Use the following relations:

$$Nu = 0.59 (Gr \cdot Pr)^{0.25} \text{ if } Gr \cdot Pr < 10^9$$

$$¿ 0.10 (Gr \cdot Pr)^{0.33} \text{ if } Gr \cdot Pr > 10^9$$

The properties of air are: $\rho = 1.06 kg/m^3$, $C_p = 1004 J/kg\text{-}K$, $k = 0.029 W/m\text{-}K$, $v = 18.97 \times 10^{-6} m^2/sec$ **15**

(c) Do you think that velocity boundary layer and thermal boundary layer depend on Prandtl number? If yes, explain properly. Also explain, with the help of neat sketches, the significance of relative thickness of velocity boundary layer and thermal boundary layer for the following: (i) Liquid metals (ii) Oils **10**

SECTION 'B'

5. **(a)** Explain Kelvin-Planck and Clausius statements of the second law of thermodynamics and prove that both the statements are equivalent. **10**

(b) How do the following parameters influence knocking in SI engine combustion? (i) Self-ignition temperature of the fuel (ii) Air-fuel ratio (iii) Dilution by residual gas (iv) Shrouded inlet valve (v) Combustion chamber design **10**

(c) Hot gases inside a chimney are at 430 °C and the chimney height is 32 metres. The temperature of outside air is 28 °C. The furnace is supplied with 17 kg of air per kg of coal burnt. Calculate– (i) draught in mm of water; (ii) draught height in metres of hot gases. **10**

(d) What is the significance of by-pass factor? For a heating coil, derive an expression of by-pass factor. Find the expression for efficiency also for heating coil. **10**

(e) Inner and outer surfaces of a spherical shell are maintained at temperatures T_i and T_o respectively such that $T_i > T_o$. If inner and outer radii of the shell are r_i and r_o and its conductivity is k, derive an expression for the rate of heat conduction through the shell. Assume steady state and no heat generation within the shell. **10**

6. **(a)** In a 4-stroke, 2-cylinder diesel engine, the following data was collected: Piston stroke = 60 cm; Diameter of the cylinder = 40 cm; Speed of the engine = 250 r.p.m.; Indicated mean effective pressure = 8 bar; Brake power of the engine = 220 kW; Fuel consumption = 80 kg/hr; CV of fuel used = 43000 kJ/kg; Hydrogen content in fuel = 13% and remaining is carbon; Air consumption =

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30 kg/min; Cooling water circulated = 90 kg/min; Rise in temperature of cooling water = 38 °C; Piston cooling oil used = 45 kg/min; Rise in temperature of cooling oil = 23 °C; C_p of water = 4.18 kJ/kg-K; C_p of cooling oil = 2.2 kJ/kg-K; C_p of exhaust gases = 1.1 kJ/kg-K; C_p of superheated steam = 2 kJ/kg-K; Latent heat of steam = 2520 kJ/kg; Exhaust gas temperature = 450 °C; Ambient temperature = 27 °C. Find the following quantities per minute: (i) Heat converted to useful brake power (BP) (ii) Heat carried away by cooling water (iii) Heat carried away by cooling oil (iv) Heat carried away by dry exhaust gases (v) Heat carried away by steam formed (vi) Heat supplied by fuel. Draw up also a heat balance sheet on minute basis and percentage basis. **40**

(b) In the pressure crank angle diagram of normal combustion SI engine, show the point of ignition, point of combustion, angle of advance, ignition lag and combustion period. **10**

7. (a) With the help of T-s diagrams, differentiate between Carnot and Rankine vapour cycles. State the advantages of Rankine cycle and derive the expression for its thermal efficiency. **15**

(b) A combined cycle power plant operates with mercury and steam cycles. Mercury cycle is superimposed over the steam cycle operating between boiler outlet condition of 40 bar and 400 °C ($h = 3215.7\,kJ/kg$ and $s_g = 6.713\,kJ/kg\text{-}K$) and condenser temperature of 40 °C. The heat released by mercury condensing at 0.2 bar is used to impart the latent heat of vaporization to the water in steam cycle. Mercury turbine receives mercury as saturated vapour at 10 bar. Calculate the mass of mercury circulated per unit mass of water and the efficiency of this binary cycle. Properties of saturated mercury and steam are: **35**

Fluid	P (bar)	T (°C)	Enthalpy (kJ/kg) h_f	Enthalpy (kJ/kg) h_g	Entropy (kJ/kg-K) s_f	Entropy (kJ/kg-K) s_g	Sp. vol. (m^3/kg) v_f	Sp. vol. (m^3/kg) v_g
Mercury	10	515.5	72.23	363	0.1478	0.5167	80.5×10^{-6}	0.0333
Mercury	0.2	277.3	38.35	336.55	0.0967	0.6385	77.4×10^{-6}	1.163
Steam	0.074	40	167.5	2574.4	0.572	8.258	0.001	19.546

8. (a) $100\,m^3$ of air per minute at 15 °C DBT and 80% relative humidity is sensibly heated until its temperature becomes 22 °C. Saturation pressures of water vapour at 15 °C and 22 °C are 0.017 bar and 0.02645 bar respectively. Find heat added to air per minute. Take atmospheric pressure = 1.013 bar. **25**

(b) An air refrigerator used for food storage provides 50 tons of refrigeration. The temperature of air entering the compressor is 7 °C and the temperature of air before entering into the expander is 27 °C. Assuming 30% more power is required than theoretical, find (i) actual COP of the cycle and (ii) kW capacity required to run the compressor. The quantity of air circulated in the system is 100 kg/min. The compression and expansion follow the law $pv^{1.3} = \text{constant}$. Take $\gamma = 1.4$ and $C_p = 1\,kJ/kg\text{-}^{\circ}C$ for air. **25**

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