Civil Services (Main) Examination, 2003

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.

SECTION 'A'

1. Attempt any three of the following parts (Answer to each part should not exceed 200 words):- **20×3=60**

(a) A solar- powered refrigeration system is run by heat transfer Q_H from solar collector at temperature 400 K and rejects Q_A heat at 300 K. It receives heat Q_C from cold space at 200 K. Assuming the cycle to be reversible, and using I^{st} law of thermodynamics and Clausius inequality, find the ratio Q_C/Q_H.

(b) Calculate the decrease in available energy when 25 kg of water at 97°C is mixed with 35 kg of water at 47°C, the pressure being constant and temperature of surrounding is 25°C. Specific heat of water is $C_p = 4.2\,kJ/kg\text{-}K$.

(c) Describe various stages of combustion in C.I. engine by illustrating on pressure-crank angle diagram. Discuss the effect of following operating variables on the first stage of combustion (i) ignition advance (ii) compression ratio (iii) speed

(d) The brake thermal efficiency of a diesel engine is 30%. If the air to fuel ratio by weight is 20 and the calorific value of fuel is 41800 kJ/kg, find brake mean effective pressure at S.T.P. (15°C and 760 mm of Hg).

2. **(a)** Air at 17°C and 1.1 bar occupies 0.05 m^3. The air is first heated at constant volume until the pressure is 4.4 bar and then cooled at constant pressure back to original temperature. Calculate (i) the net heat transfer to or from the air and (ii) the net entropy change. Given that for air $C_p = 1.005$ and $C_v = 0.718\,kJ/kg\text{-}K$. **30**

(b) Two reversible heat engines A and B are arranged in series. Heat engine A rejects heat directly to B. Engine A receives 300 kJ of heat at a temperature of 427°C from a high temperature source while engine B rejects heat to a cold sink at 7°C. If the work output of A is two times that of B, find (i) intermediate temperature between A and B, (ii) efficiency of each engine, (iii) heat rejected by engine A and received by engine B and (iv) heat rejected to the sink. **30**

3. **(a)** A six cylinder, four stroke petrol engine with a bore of 120 mm and stroke of 180 mm under test, is supplied petrol of composition: C = 82% and H_2 = 18% by mass. The Orsat gas analysis indicated that CO_2 = 12%, O_2 = 4% and N_2 = 84% by volume. Determine (i) that air-fuel ratio and (ii) the percentage of excess air. Also calculate the volumetric efficiency of engine based on intake conditions when the mass flow rate of petrol 32 kg/min at 1600 RPM. Intake conditions are 1 bar

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and 17°C. Consider the density of petrol vapour to be 3.5 times that of air at same temperature and pressure. Air contains 23% oxygen by mass. **30**

(b) The venturi of a sample carburettor has a throat diameter of 20 mm and the fuel orifice has a diameter of 1.12 mm. The level of petrol surface in the float chamber is 6.0 mm below the throat venturi. Coefficients of discharge for venturi and fuel orifice are 0.85 and 0.78 respectively. Specific gravity of petrol is 0.75. Calculate (i) the air-fuel ratio for a pressure drop of 0.08 bar, (ii) petrol consumption in kg/hr and (iii) the critical air velocity. The intake conditions are 1.0 bar and 17°C. For air $C_p = 1.005$ and $C_v = 0.718\, kJ/kg\text{-}K$ **30**

4. (a) An eight cylinder automobile engine of 80 mm diameter and 90 mm stroke with a compression ratio of 7, is tested at 4000 RPM on a dynamometer of 600 mm arm length. During a ten minutes test period at a dynamometer scale reading of 450 N, 4.8 kg of gasoline having a calorific value of 45000 kJ/kg was burnt and air at 27°C and 1.0 bar was supplied to the carburettor at the rate of 6.6 kg/min. Find (i) the brake power delivered, (ii) the brake mean effective pressure, (iii) the brake specific fuel consumption, (iv) brake thermal efficiency, (v) the volumetric efficiency and (vi) the air-fuel ratio. **40**

(b) A salesman reports that he has a steam turbine that delivers 3 MW. The steam enters the turbine at 6.0 bas, 260°C and leaves the turbine at 0.15 bar and the required rate of steam flow is 12000 kg/hr. (i) Find the maximum power output of turbine to justify his claim. (ii) Also, verify his claim if the steam flow rate is 20,000 kg/hr **20**

SECTION 'B'

5. Answer any three of the following parts (Answer to each part should not exceed 200 words) **20×3=60**

(a) Show that the effectiveness of a parallel flow heat exchanger is given by

$$\varepsilon = \frac{1 - \exp\left\{-NTU\left(1 + C_{min}/C_{max}\right)\right\}}{1 + C_{min}/C_{max}}$$

(b) Define Reynolds number, Prandtl number, Stanton number and Nusselt number, and give their physical significance. What is meant by fully developed flow in a pipe? Illustrate it with the help of a figure. State the parameters upon which the entrance length depends.

(c) What is the role of a cooling tower in a power plant? What is meant by range and approach and what purpose does the fill serve in a cooling tower?

(d) Discuss the trends in the design of modern power plant boilers. Explain the zones of heat transfer and location of evaporators, super heaters and reheater.

6. (a) Calculate the number of tubes required for a single pass steam condenser of 2.5 m length to handle 20000 hg/hr of dry saturated steam at 60°C. The cooling water enters the tubes at 20°C and leaves at 30°C. The tubes are of 25 mm outside diameter and 22.5 mm inside diameter. The thermal conductivity of tube material is 100 W/m-K. The water velocity is 1.5 m/s. Assume that the steam side film coefficient is 4500 $W/m^2\text{-}K$. For water use, $Nu = 0.023\, Re^{0.8}\, Pr^{0.4}$ The properties of water at 25°C are $\rho = 996.95\, kg/m^3$, $C_p = 4178\, J/kg\text{-}K$, $k = 60.78 \times 10^{-2}\, W/m\text{-}K$, $v = 0.9055 \times 10^{-6}\, m^2/s$, Pr = 6.22, h_{fg} (at 60°C) = 2358.5 kJ/kg. **40**

(b) A small hemispherical oven is built of two insulating materials. The inner layer is of fire brick, 125 mm thick and outer layer of 85% magnesia, 40 mm thick. The inner surface of the oven is at 800°C and the heat transfer coefficient for the outer surface is 10 $W/m^2\text{-}K$. The room temperature is 20° C. Calculate the heat loss through hemisphere is the inside radius is 0.6 m. The thermal

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conductivities of fire brick and 85% magnesia are 0.31 and 0.05 W/m-K respectively. Also, calculate the temperature at contact between insulating materials and at the outer surface. **20**

7. (a) In a refrigeration system of 10 TR cooling capacity using $CHClF_2$, the evaporator and condenser temperatures are -10°C and 45°C respectively. Properties of $CHClF_2$ at saturation are **30**

Temperature °C	Sp. volume m^3/kg v_g	Enthalpy kJ/kg h_f	Enthalpy kJ/kg h_g	Entropy kJ/kg-K s_f	Entropy kJ/kg-K s_g
–10	0.0654	34.25	247.37	0.1374	0.9473
45	0.0133	101.76	261.95	0.3662	0.8697

Consider standard vapour compression cycle with inlet to compressor as saturated vapour and inlet to expansion valve as saturated liquid. Assume that vapour may be treated as perfect gas in desuperheating process with average specific heat of 0.9335 kJ/kg-K. Show the cycle on T-s and p-h diagrams. Find (i) compressor outlet temperature and enthalpy, (ii) mass flow rate of refrigerant, (iii) work requirement, (iv) condenser heat rejection (v) COP and (vi) swept volume of compressor in m^3/s assuming 100% volumetric efficiency.

(b) In an air-conditioning system 30 m^3/min of fresh outdoor air is introduced at 43°C dry-bulb temperature and 30% relative humidity. The remaining air is re-circulated from the room maintained at 25°C dry-bulb temperature and 50% RH. The by-pass factor of the cooling coil is 0.15 and apparatus dew point is 11.8°C. RSH = 100 kW and RLH = 15 kW. Determine (i) humidity ratios for outdoor and room condition, (ii) OASH and OALH, (iii) ERSH and ERLH, (iv) supply air temperature, (v) supply air volume flow rate using ERSH and (vi) temperature at inlet to cooling coil by assuming the density of outdoor air and re-circulated air to be the same. Given that saturation pressures of water at 25°C and 43°C are 3.1693 kPa and 8.6495 kPa respectively. Show that process on psychrometric chart schematically. Standard atmospheric pressure = 1.01325 bar. **30**

8. (a) Discuss the effect of pre-whirl on the performance of centrifugal compressors. A single sided centrifugal air compressor delivers 1800 kg of air per minute. The air enters the eye of the impeller axially at total pressure of 100 kPa and total temperature of 290 K. The overall diameter of the impeller is 700 mm and it rotates at 1600 RPM. The slip factor is 0.9 and work input factor is 1.1. Isentropic efficiency is 85%. Calculate (i) power required by the compressor, (ii) pressure coefficient and (iii) total pressure at delivery. **30**

(b) Derive an expression for the blade efficiency of a single row impulse steam turbine assuming equiangular blades in terms of nozzle angle α_1, blade velocity coefficient K and blade speed ratio. If $\alpha_1 = 20°$ and K = 0.9, what is the maximum blade efficiency and corresponding blade angles? If the blade efficiency is 85% of the maximum value, what are the possible blade speed ratios for the same nozzle angle α_1, blade velocity coefficient, K and equiangular blades? Also, find the corresponding blade angles. **30**

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