332005

COMBINED COMPETITIVE EXAMINATION (MAIN)

MECHANICAL ENGINEERING

Paper–II

Time : 3 Hours *Full Marks* : 200

Note : (1) The figures in the right-hand margin indicate full marks for the questions.

(2) Attempt five questions in all.

(3) Question No. 1 is compulsory.

1. Answer any ***ten*** questions from the following : $4 \times 10 = 40$

(a) What do you mean by nonflow and flow systems in thermodynamics? Give examples of each type.

(b) Define a reversible process and explain why most of the natural processes are irreversible. What are internal and external irreversibilities?

(c) State and explain the Clausius statement of the second law of thermodynamics.

(d) Explain with the help of a schematic, a cyclic heat engine giving suitable example.

(e) What is the effect of boiler pressure on thermal efficiency of a Rankine cycle? Why is reheat cycle employed in a steam power plant?

(f) Why is gas cycle refrigeration perferred in aircraft? How is it possible to achieve very low temperature in gas refrigeration cycle?

(g) What is an MPFI engine? How does it overcome the problems related with carburetted engine?

(h) Define Biot number. How is it different from Nusselt number? What is a lumped system? What is the limiting value of Biot number for which the lumped system model is valid?

(i) Give the definition of specific speed separately for pump and turbine. What is the physical significance of specific speed?

(j) Explain with a suitable diagram, the working principle of a Francis turbine.

(k) What do you understand by hydrodynamically developing and hydrodynamically developed laminar incompressible flow in a circular pipe? How does Nusselt number vary for these two flow types?

(l) Differentiate between Fanno and Rayleight flows.

2. Answer any ***four*** questions from the following : 10×4=40

(a) What is refrigeration? Name various methods which are used for producing refrigerating effect. Explain the vapour compression refrigeration cycle with the help of a schematic and the corresponding *T-s* and *p-h* diagram. Is this a reversible cycle? Comment giving proper justification.

(b) Derive an expression for the mass flow rate for one dimensional steady isentropic flow through a nozzle. What is critical pressure ratio? Hence find the critical pressure ratio and the expression for the maximum mass flow rate through the nozzle.

(c) State the principle of operation of an impulse and a reaction turbine. Show that the degree of reaction for Parson's reaction turbine is 50%.

(d) Why is compounding of steam turbines necessary? Discuss with suitable diagrams, the salient features of *(i)* pressure, and *(ii)* velocity compounding of steam turbine.

(e) Consider an engine operating on the ideal Diesel cycle with air as the working fluid. The volume of the cylinder is 1200 cm^3 at the beginning of the compression process, 75 cm^3 at the end and 150 cm^3 after the heat-addition process. Air is at 17°C and 100 kPa at the beginning of the compression process. Determine *(i)* the pressure at the beginning of the heat-rejection process, and *(ii)* the net work done per cycle in kJ. Assume $C_P = 1.005$ kJ/kg-K, $C_V = 0.718$ kJ/kg-K and $\gamma = 1.4$.

(f) A petrol engine has a compression ratio of 6 and it uses a fuel of calorific value 44000 kJ/kg. The air fuel ratio is 15 : 1. The pressure and temperature of the charge at the end of suction stroke are 1 bar and 60°C, respectively. Find the maximum pressure in the cylinder if the index of compression is 1.32 and the specific heat at constant volume is temperature dependent as given by $C_V = 0.71 + 20 \times 10^{-5} T$ kJ/kg-K where T is in Kelvin. Compare the result with that of a constant $C_V = 0.71$ kJ/kg-K.

3. Answer any ***five*** questions from the following : 8×5=40

(a) What are the limitations of steam as a working fluid? Draw the schematic of a mercury-steam binary vapour cycle and explain how it improves the performance of a steam power plant.

(b) What is an ideal regnerative vapour power cycle? Draw its *T-s* diagram and show that it has the same thermal efficiency as the Carnot cycle.

(c) The net work output and the thermal efficiency for the Carnot and the simple ideal Rankine cycles with steam as the working fluid are to be calculated and compared.

Steam enters the turbine in both cases at 10 MPa as a saturated vapour, and the condenser pressure is 20 kPa. In the Rankine cycle, the condenser exit state is saturated liquid and in the Carnot cycle, the boiler inlet state is saturated liquid. Draw the *T-s* diagrams for both the cycles and give the comparison.

(d) A single-acting reciprocating pump has a piston diameter of 200 mm and stroke of 300 mm. The suction and delivery heads are 4 m and 20 m respectively. The pump operates at 120 rpm. If the motor efficiency is 75%, determine the power required by the pump.

(e) Show with the help of *p-V* and *T-s* diagram that $\eta_{Diesel} > \eta_{Dual} \geq \eta_{Otto}$ for the same inlet conditions and peak pressure. Why are the analysis of peak pressure and the rate of pressure rise important in engine study.

(f) Using the Maxwell relations, determine a relation for $\left(\frac{\partial S}{\partial P}\right)_T$ for a gas whose equation of state is $P(V-b) = RT$.

4. Answer any ***four*** questions from the following : 10×4=40

(a) For laminar forced convection over a flat plate, show by dimensional analysis that the Nusselt number Nu = *f*(Re, Pr), where Re is the Reynolds number and Pr is the Prandtl number.

(b) (i) How is the compressible flow different from incompressible flow? Under what circumstances gas flow can be considered incompressible?

(ii) Show that for 1-D steady isentropic compressible flow through a duct is :

$\frac{dV}{V} = \frac{dA}{A}\frac{1}{Ma^2-1} = \frac{dP}{\rho V^2}$. Explain its implication in the design of nozzle and diffuser.

(c) For steady adiabatic flow of an ideal gas through a nozzle or diffuser, show that $\frac{T_0}{T} = 1 + \left(\frac{\gamma-1}{2}\right)M^2$; where T_o and T are the stagnation and static temperatures; γ is the ratio of specific heat and M is the Mach number.

(d) A Pelton wheel operates with a jet of 15 cm diameter under a head of 500 m. Its mean runner diameter is 2.25 m and it rotates with a speed of 375 rpm. The angle of bucket tip at the outlet is 15°, coefficient of velocity is 0.98, mechanical losses equal to 3% of power supplied and the reduction in relative velocity of water while passing through the bucket is 15%. Find *(i)* the force of jet on the bucket, *(ii)* the power developed, *(iii)* bucket efficiency, and *(iv)* overall efficiency.

(e) The impeller of a centrifugal pump has an eye and tip radius of 51 mm and 406 mm respectively. It rotates at 900 rpm. The blade angles $\beta_1 = 75°$ and $\beta_2 = 83°$ measured from radial flow direction. The width of the blade is 64 mm. Calculate volumetric flow rate through the impeller, static pressure rise, input power to the impeller assuming zero whirl at the inlet and a hydraulic efficiency of 89%.

(f) A Francis turbine has a wheel diameter of 1.2 m at the entrance and 0.6 m at the exit. The blade angle at the entrance is 90° and the guide vane angle is 15°. The water at the exit leaves the blades without any tangential velocity. The available head is 30 m and the radial component of flow velocity is constant. What will be the speed of the wheel in RPM and blade angle at exit? Neglect friction.

5. Answer any ***four*** questions from the following : 10×4=40

(a) Derive the equation for temperature distribution for a circular pin fin with an insulated tip. The base temperature is T_b and the surrounding medium has an average heat transfer coefficient h and a temperature of T_a. Also obtain the expression for conduction heat transfer rate at the base of the fin.

(b) Consider a 0.8 m high and 1.5 m wide double-pane window consisting of two 4 mm thick layers of glass ($k = 0.78$ W/m°C) separated by a 10 mm wide stagnant air space ($k = 0.026$ W/m°C). Determine the steady rate of heat transfer through this double-pane window and the temperature of its inner surface for a day during which the room is maintained at 20°C while the temperature of the outdoors is –10°C. Take the convection heat transfer coefficients on the inner and outer surfaces of the window to be $h_1 = 10$ W/m²°C and $h_2 =$ W/m²°C, which includes the effects of radiation.

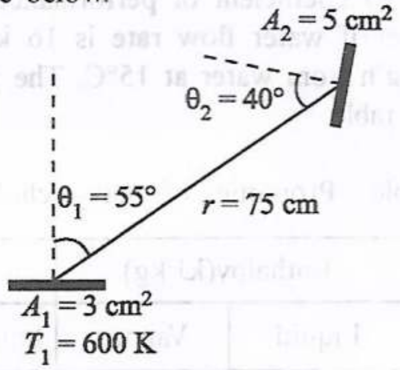
(c) Show that the critical radius of insulation for a cylindrical pipe is given by $r_{crit} = \dfrac{k}{h}$; where k is the thermal conductivity of the insulating material and h is the heat transfer coefficient of the surrounding medium.

(d) Water enters a 2.5 cm internal diameter thin copper tube of a heat exchanger at 15°C at a rate of 0.3 kg/s and is heated by steam condensing outside at 120°C. If the average heat transfer coefficient is 800 W/m²°C, determine the length of the tube required in order to heat the water to 115°C. The specific heat of water at the bulk mean temperature of 65°C is 4.187 kJ/kg°C. The heat of condensation of steam at 120°C is 2203 kJ/kg.

(e) Prove that the effectiveness of a parallel flow heat exchanger is given by.

$$\varepsilon = \frac{1-\exp\left[-NTU\left(1+\frac{C_{min}}{C_{max}}\right)\right]}{1+\frac{C_{min}}{C_{max}}}$$; where $NTU = \dfrac{UA}{C_{min}}$, U is the overall heat transfer coefficient and A, the heat transfer area.

(f) A small surface of area $A_1 = 3\ cm^2$ emits radiation as a blackbody at $T_1 = 600$ K. Part of the radiation emitted by A_1 strikes another small surface of area $A_2 = 5\ cm^2$ oriented as shown in the figure below.



Determine the solid angle subtended by A_2 when viewed from A_1, and the rate at which radiation emitted by A_1 that strikes A_2.

6. Answer any ***four*** questions from the following : 10×4=40

(a) What four processes make up the simple ideal Brayton cycle? For fixed maximum and minimum temperatures, what is the effect of pressure ratio on *(i)* the thermal efficiency, and *(ii)* the net work output of a simple ideal Brayton cycle? How is the actual gas power cycle different from the ideal Brayton cycle?

(b) Consider the ideal regenerative Brayton cycle. Determine the pressure ratio that maximizes the thermal efficiency of the cycle and compare this value with the pressure ratio that maximizes the cycle net work.

(c) A Brayton cycle with regeneration using air as the working fluid has a pressure ratio of 7. The minimum and the maximum temperatures in the cycle are 310 K and 1150 K. Assuming an isentropic efficiency of 75% for the compressor and 82% for the turbine and an effectiveness of 65% for the regenerator; determine *(i)* the air temperature at the turbine exit, *(ii)* the net work output, and *(iii)* the thermal efficiency.

(d) A heat engine operates between two reservoirs at 800°C and 20°C. One-half of the work output of the heat engine is used to drive a Carnot heat pump that removes heat from the cold surroundings at 2°C and transfers it to a house maintained at 22°C. If the house is losing heat at a rate of 62000 kJ/h, determine the minimum rate of heat supply to the heat engine required to keep the house at 22°C.

(e) What is the function of cooling tower in a steam power plant? Draw schematic of a wet cooling tower and briefly explain its working principle.

(f) A vapour compression refrigerator uses methyl chloride and works in the pressure range of 11.9 bar and 5.67 bar. At the beginning of compression, the refrigerant is 0.96 dry and at the end of isentropic compression, it has a temperature of 55°C.

The liquid refrigerant leaving the condenser is saturated. If the mass flow rate of refrigerant is 1.8 kg/min, determine *(i)* coefficient of performance, *(ii)* the rise in temperature of condenser cooling water if water flow rate is 16 kg/min and *(iii)* ice produced in evaporator at 0°C in kg/h from water at 15°C. The properties of methyl chloride are given in the following table :

Table : Properties of methyl choloride

Pressure	Temp	Enthalpy(kJ/kg)		Entropy	Entropy
(bar)	(°C)	Liquid	Vapour	liquid(kJ/kg-K)	vapour(kJ/kg-K)
11.9	–20	30.1	455.2	0.124	1.803
5.67	25	100.05	476.8	0.379	1.642

Latent heat of ice = 336 kJ/kg, Specific heat of water = 4.187 kJ/kg

7. Answer any ***four*** questions from the following : 10×4=40

(a) Draw the psychrometic chart and show in the chart, the process of *(i)* sensible cooling, and *(ii)* cooling and dehumidification. How is the dew point temperature at a specified state determined on the psychometric chart? Under what condition, the dry bulb, wet bulb and dew point temperatures are identical? What is the difference between the specific humidity and the relative humidity?

(b) Outside air at 35°C dry bulb temperature (DBT) and 70% relative humidity (RH) is passed over a cooling coil having an apparatus dew point of 10°C and 0.06 bypass factor. The cooled air is then supplied to a room to be maintained at 22°C DBT and 50% RH. The supply air rate is 4500 kg/h. Using psychrometric chart, how will you calculate the sensible and latent heat loads of the room and the heat removed in the cooling coil? Explain the solution procedure (calculation not required).

(c) Steam enters a turbine steadily at P_1 = 3 MPa and T_1 = 450°C at a rate of 8 kg/s and exits at P_2 = 0.2 MPa and T_2 = 150°C. The steam is losing heat to the surrounding air at P_0 = 100 kPa and T_0 = 25°C at a rate of 300 kW. The kinetic and potential energy changes are negligible. Determine *(i)* the actual power output, *(ii)* the maximum possible power output, *(iii)* the second-law efficiency, *(iv)* the energy destroyed, and *(v)* the energy of the steam at the inlet conditions. The properties of the steam at the inlet (P_1T_1) and exit (P_2, T_2) states and the state of the environment (P_0, T_0) are; h_1 = 3344.9 kJ/kg, s_1 = 7.0856 kJ/kg-K; h_2 = 2769.1 kJ/kg, s_2 = 7.281 kJ/kg K; h_0 = 104.83 kJ/kg s_0 = 0.3672 kJ/kg K.

(*d*) The fuel supplied to a petrol engine is assumed to have the composition of C_7H_{16}. Calculate the (i) stoichiometric air fuel ratio by mass, and (ii) the volumetric composition of combustion products in percentage, if 50% excess air is supplied and fuel combustion is complete. Assume that air contains 21% oxygen (O_2) by volume.

(*e*) (i) How are SI and CI engine fuels rated? How does fuel viscosity affect in a diesel engine system?

(ii) How is the fuel air cycle different from the air standard cycle? How does efficiency of a fuel air cycle vary with air fuel ratio and compression ratio?

(*f*) Why is the actual efficiency much lower than the air standard cycle efficiency? Explain various losses that occur in an IC engine in brief.

8. (*a*) What is the difference between cogeneration and regeneration? 4

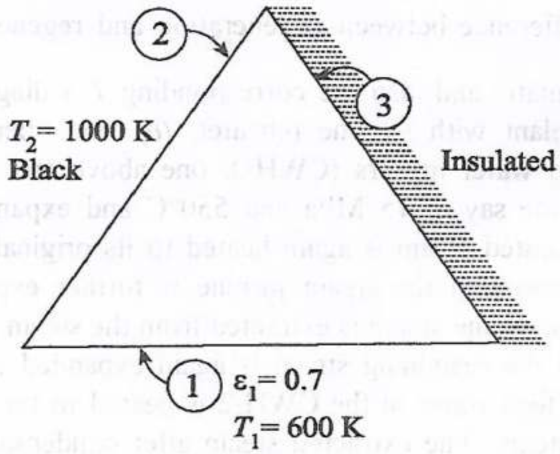
(*b*) Draw the schematic and also the corresponding *T–s* diagram of a reheat regenerative steam power plant with *(i)* one reheater, *(ii)* one open water heater (OWH), and *(iii)* two closed water heaters (CWHs), one above and one below the OWH. steam enters the tubrine say at 15 MPa and 550°C and expands until it becomes satuated vapor. The saturated steam is again heated to its original temperature in the reheater. The reheated steam in the steam turbine is further expanded to some intermediate pressure at which some steam is extracted from the steam turbine to heat the feed water in CWH-2 and the reamining steam is again expanded to some low pressure (OWH pressure). The feed water in the CWH-2 is heated to the condensation temperature of the extracted steam. The extracted steam after condensation in the CWH-2 leaves as saturated liquid which is subsequently throttled to the OWH. Again some amount of steam is extracted from the steam turbine for feed water heating in the OWH. The remaining steam is further expanded to low pressure (CWH-1 pressure) at which again some amount of steam is extracted to heat the feed water in CWH-1 and the remaining is expanded to the condenser pressure. The feed water in the CWH-1 is heated to the condensation temperature of the extracted steam. The extracted steam after condensation in the CWH-1 is throttled to the condenser. The condensed steam from the condenser is pumped to the OWH and the condensate from the OWH is subsequently pumped to the boiler by using another pump. 20

(*c*) Draw the schematic and also the corresponding *T–s* diagram of a cogeneration plant with *(i)* one reheater, *(ii)* one OWH, and (iii) one process heater. Steam enters the turbine say at 12 MPa and 500°C and expands until it becomes saturated vapour. The saturated steam is again heated to its original temperature in the reheater. The reheated steam in the steam turbine is further expanded to some intermediate pressure at which some steam from the steam turbine is extracted. A part of this extracted steam is used to heat the feed water in the OWH and the remaining steam is used for process heating which leaves the process heater as saturated liquid.

The condensate from the process heater is subsequently mixed with the perheated water from the OWH and the mixture is pumped to the boiler. The remaining steam, after some amount is extracted to the OWH and the process heater, is expanded to condenser pressure where it is condensed and the condensate is pumped to the OWH. Assume suitable process heater/OWH and condenser pressure and neglect pressure losses. 16

9. *(a)* What is the function of fuel injection system in diesel engine? What is the role of injection timing and injection pressure in diesel fuel combustion? Describe briefly with suitable diagram *(i)* the jerk pump system, *(ii)* common rail system, and *(iii)* the distributor system with their relative merits and demerits. 2+3+15=20

(b) A furnace is shaped like a long equilaternal triangular duct, as shown in the figure below :



The width of each side is 1 m. The base surface has an emissivity of 0.7 and is maintained at a uniform temperature of 600 K. The heated left-side surface closely approximates a blackbody at 1000 K. The right-side surface is well insulated. Determine the rate at which heat must be supplied to the heated side externally per unit length of the duct in order to maintain these operating conditions. 20

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