SUBJECT: MECHANICAL ENGINEERING: PAPER I (Set A)

Time: 3 hours | Full marks: 200

Note: Answer Question No. 1 and any four from the rest. All questions carry equal marks.

Q. No. 1. Attempt any 10 (ten) $10 \times 4 = 40$

a. What is an adiabatic process? How is it different from an isentropic process?

b. Write the Kelvin Planck and Clausius statements of second law of thermodynamics.

c. Why is the second law of thermodynamics called a directional law of nature? Explain.

d. Define entropy. Show that for an irreversible process, $\oint ds > \oint \frac{dQ}{T}$.

e. Differentiate between the critical and triple point of water.

f. How is a cyclic heat pump different from that of cyclic refrigerator? Explain with suitable diagrams.

g. How does the boiling process at supercritical pressures differ from the boiling process at subcritical pressures?

h. Differentiate between laminar and turbulent flow. Define critical Reynolds number.

i. Define Biot number related to conduction heat transfer. What is its physical significance?

j. Write the conditions of stable, unstable and neutral equilibrium of a submerged body.

k. Write the differences between a nozzle and a diffuser for both subsonic and supersonic flow conditions.

l. Differentiate between impulse and reaction turbines giving examples of each type.

Q. No. 2. Attempt any 8 (eight) $8 \times 5 = 40$

a. A new temperature scale °N is divided in such a way that the freezing point of ice is 100°N and the boiling point is 400 °N. What is the temperature reading on this new scale when the temperature is 150 °C? At what temperature both the Celsius and the new temperature scale reading would be the same?

b. A fluid transfers 2000 kJ of heat to the environment at 300 K. The change in entropy of the fluid is -5 kJ/K, determine the overall change in entropy and comment on the nature of the process whether possible/impossible and reversible/irreversible.

c. A gas undergoes a thermodynamic cycle consisting of the following processes.

(i) A constant pressure process 1-2 at p=1.4 bar with V_1=0.028 m^3, W_{1-2}=10.5 kJ.

(ii) An isothermal compression process 2-3 with $U_3 = U_2$

(iii) A constant volume process 3-1 with $U_1 - U_3 = -26.4$ kJ. Neglect changes in KE and PE. Calculate the net work done during the cycle and the heat transfer for the process 1-2.

d. A heat pump, working on a reversed Carnot cycle takes in energy from a reservoir maintained at 3 °C and delivers it to another reservoir where temperature is 77 °C. The heat pump derives power for its operation from a reversible engine operating within the higher and the lower temperature limits of 1077 °C and 77 °C. For 100 kW of energy supplied to the reservoir at 77 °C, estimate the energy taken from the reservoir at 1077 °C.

e. Show that the efficiency of a diesel cycle is lower than that of Otto cycle for the same compression ratio (CR). Higher efficiency of Otto cycle compared to diesel cycle for the same CR is only of academic interest not of practical importance. Comment why.

f. A closed vessel of 0.2 m^3 capacity contains steam at 10 bar and 250 °C. The vessel is cooled till the pressure falls to 3.5 bar. Find the final temperature, dryness fraction and the heat transferred during the process.

g. Draw T-s diagram of an ideal regenerative cycle, show that it has the same thermal efficiency as the Carnot cycle.

h. A sphere of 1219 mm diameter floats half submerged in salt water (ρ=1025 kg/m^3). What minimum mass of concrete (ρ=2043 kg/m^3) has to be used as an anchor to submerge the sphere completely?

i. Consider a slab of thickness $2L$ initially $(t = 0)$ at a uniform temperature T_i is suddenly immerged in a cold medium at T_∞ with constant heat transfer coefficient h. How will the temperature vary in the slab after a certain time period of $t = t_1$ when (i) Biot number, $Bi << 1$ and (ii) $Bi >> 1$. Explain with help of diagrams.

j. A reversible absorption refrigeration consists of a reversible heat engine and a reversible refrigerator. The system removes heat from a cooled space at -10 °C at a rate of 22 kW. The refrigerator operates in an environment at 25 °C. If the heat is supplied to the system by condensing saturated steam at 200 °C, determine (a) the rate at which steam condenses (b) the power input to the refrigerator.

Q. No. 3. Attempt any 5 (eight) 5×8= 40

a. For an engine working on the ideal Dual cycle, the compression ratio is 10 and the maximum pressure is limited to 70 bar. If the total heat supplied is 1680 kJ/kg (half at constant volume and half at constant pressure) find the pressures and temperatures at the salient points of the cycle and the cycle efficiency. The pressure and temperature of air at the beginning of compression are 1 bar and 100 °C respectively. Assume C_p =1.004 kJ/kg K and C_v = 0.717 kJ/kg K.

b. With the help of a schematic and corresponding T-s diagram, describe how cooling capacity can be increased in a gas cycle refrigeration system using regeneration.

c. A rectangular barge of uniform cross section has width L and vertical draft H. Determine,

(i) metacentric height for a small tilt angle

(ii) the ratio L/H for which the barge will be in stable equilibrium if the CG is at the waterline.

d. A liquid with specific gravity (S=0.8) flows through a 150×75mm venturimeter. If the flow rate through the venturimeter is 40 litres per second and C_d = 0.96, Calculate the

(i) the pressure difference between the inlet and the throat.

(ii) the difference in levels of Hg in a U tube manometer.

e. In Couette flow, the velocity u at any y depends upon the distance h between the plates, the pressure gradient $\frac{dP}{dx}$ and the viscosity μ of the fluid. Find a relation in dimensionless form to express u in terms of independent variable using Buckingham's pi theorem.

f. What is meant by abnormal combustion? Explain the phenomenon of knock in SI engine and compare it with CI engine knock.

Q. No. 4. Attempt any 4 (four) 4×10=40

a. A gas turbine unit is to provide peaking power for an electrical utility with a net power output of 10 MW. The pressure ratio across the compressor is 7, the efficiency of the compressor and the turbine are 80% and 92% respectively. In order to conserve fuel a regenerator with an effectiveness of 85% is used. The maximum temperature in the cycle is 1200 K. The air at compressor inlet is at 20 °C, 1.1 bar. Assume the working fluid to be air which behaves as an ideal gas. Neglect pressure drops in the combustion chamber and regenerator. Determine the required air and fuel flow rate and the power plant efficiency for a fuel heating value of 42 MJ/kg and combustion efficiency of 95%.

b. Hot oil is to be cooled by water in a 1-shell-pass and 8-tube-passes heat exchanger. The tubes are thin-walled and are made of copper with an internal diameter of 1.4 cm. The length of each tube pass in the heat exchanger is 5 m, and the overall heat transfer coefficient is 310 W/m²°C. Water flows through the tubes at a rate of 0.2 kg/s, and the oil through the shell at a rate of 0.3 kg/s. The water and the oil enter at temperatures of 20 °C and 150 °C, respectively. Determine the rate of heat transfer in the heat exchanger and the outlet temperatures of the water and the oil. The following equation be used for calculating effectiveness

$$\varepsilon = 2\left[1 + c + \sqrt{1+c^2}\,\frac{1+\exp\left(-NTU\sqrt{1+c^2}\right)}{1-\exp\left(-NTU\sqrt{1+c^2}\right)}\right]^{-1}$$

c. Obtain first an expression for the velocity boundary layer thickness (δ) for steady laminal boundary layer flow over a horizontal flat plate using the momentum integral equation. Assume a parabolic velocity profile, $\frac{u}{U_\infty} = \frac{3}{2}\left(\frac{y}{\delta}\right) - \frac{1}{2}\left(\frac{y}{\delta}\right)^3$, where U_∞ is the free stream velocity.

d. The net power output of an ideal regenerative reheat steam cycle is 80 MW. Steam enters the high pressure (HP) turbine at 80 bar, 500 °C and expands till it becomes saturated vapour. Some of the steam then goes to an open feed water heater and the balance is reheated to 400 °C, after which it expands in the low pressure (LP) turbine to 0.07 bar. Compute (i) the reheat pressure, (ii) the steam flow rate to the HP turbine, and (iii) the cycle efficiency. Neglect pump work.

e. A plunger pump has a 0.127 m diameter and 5.08 cm stroke and operates at 750 rpm with 92% volumetric efficiency. (a) What is its delivery in litre/min? If the pump delivers SAE 10W oil at 20 °C against a head of 15.24 m, what horsepower is required when the overall efficiency is 84%? Take oil density as 870 kg/m³.

Q. No. 5 Attempt any 4 (four) $4\times10=40$

a. In a steam generator, water is evaporated at 260 °C, while the combustion gas (C_p =1.08 kJ/kg K) is cooled from 1300 °C to 320 °C. The surroundings are at 30 °C.

Determine the loss in available energy due to the above heat transfer per kg of water evaporated. Given, latent heat vaporization of water at 260 °C =1662.5 kJ/kg.

b. The dry and wet bulb temperatures of atmospheric air at 1 atm. are determined to be 40 °C and 36 °C respectively. Determine (i) the humidity ratio (ii) the relative humidity and (iii) dew point temperature

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

d. A two stage air compressor receives 0.238 m^3/sec of air at 1 bar and 27 °C and discharges at 10 bar. The polytropic index of compression is 1.35. Determine (i) the minimum power required (ii) power required for single stage compression to the same pressure.

e. The velocity along the centre line of Hagen-Poiseuille flow in a 0.1m diameter pipe is 2m/s. If viscosity of the fluid is 0.07 kg/m-sec and specific gravity is 0.92, calculate (i) volumetric flow rate, (ii) shear stress of the fluid at the pipe wall, (iii) local skin friction coefficient (iv) the Darcy's friction factor.

Q. No. 6. Attempt any 2 (two) 2×20=40

a. 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 maximum mass flow rate through the nozzle.

b. In a two stage reciprocating air compressor air enters the compressor at 1 bar, 27 °C and delivered at 30 bar, 150 °C with an intermediate pressure of 6 bar and intercooling up to 35 °C. Compressor delivers at the rate of 2 kg/s. Clearance volume of LP and HP cylinders are 5% and 7% of stroke volume respectively. The index of compression and expansion are same throughout. Determine the stroke volume of both the cylinders in m^3/min, amount of cooling required in the intercooler and the total power required. Take C_p=1.0032 kJ/kg K

c. Steam is generated in the boiler of a cogeneration plant at 10 MPa and 450 °C at a steady rate of 5 kg/s. In normal operation the steam expands in a turbine to a pressure of 0.5 MPa and is then routed to the process heater. Steam leaves the process heater as saturated liquid and is pumped to the boiler pressure. In this mode, no steam passes through the condenser which operates at 20 kPa.

(i) Determine the power produced and the process heat supplied in this mode

(ii) Determine the power produced and the process heat supplied if only 60% of steam is routed to the process heater and remainder is expanded to condenser pressure.

Q. No. 7. Attempt any 2 (two) $2 \times 20 = 40$

a. 300 m^3/min of air 10 °C dry bulb temperature and 90% relative humidity is to be heated and humidified to 35 °C dry bulb temperature and 22.5 °C wet bulb temperature. The required conditions are achieved by heating, humidification and then again by heating. The relative humidity of the air coming out of the humidifier is 90%. Find

(i) the heating capacity of the first heater and the bypass factor, if the surface temperature of the coil is 40 °C.

(ii) the capacity of the humidifier in kg per hour.

(iii) the heating capacity of the second heater and the coil surface temperature, if the bypass factor is 0.5.

(iv) the humidifying efficiency of humidifier.

b. A turbojet engine is flying at a speed of 268 m/s at an altitude where the ambient conditions are 0.2 bar and 220 K. The air enters an ideal diffuser and leaves the combustor at 1350 K and 1 bar. The fuel supplied has a heating value of 43000 kJ/kg. Assume all compression and expansion processes to be isentropic. Determine

(i) air fuel ratio

(ii) the specific thrust

(iii) the propulsive efficiency

Take C_p and γ for the compression process 1.005 kJ/kgK and 1.4 and for combustion and expansion processes, 1.102 and 1.33 respectively.

c. 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

(iv) overall efficiency