MECHANICAL ENGINEERING PAPER I

Time allowed: 3 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 and printed both in **HINDI** and in **ENGLISH**. Candidate has to attempt **FIVE** questions in all.*

Question Nos. 1 and 5 are compulsory and out of the remaining, THREE are to be attempted choosing at least ONE from each section.

The number of marks carried by a question/part is indicated against it.

Answers must be written in the medium authorized in the Admission certificate which must be stated clearly on the cover of this Question-cum-Answer (QCA) booklet in the space provided.

No marks will be given for answers written in medium other than the authorized one.

Wherever any assumptions are made for answering a question, they must be clearly indicated.

Diagrams/Figures, wherever required, shall be drawn in the space provided for answering the question itself.

Unless otherwise mentioned, symbols and notations carry their usual standard meaning. Attempts of questions shall be counted in chronological 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 answer book must be clearly struck off.

SECTION—A

Q. 1(a) A particle of mass m is resting at point B on a smooth semicircular cylinder of radius *r*, tied to a point a vertically above the centre of the cylinder at a height of 2*r*, with a string of length 1.1*r* as shown in Fig. 1(a). If the string is cut, find the angle θ defining the position C of the particle where it jumps off the cylinder. 10

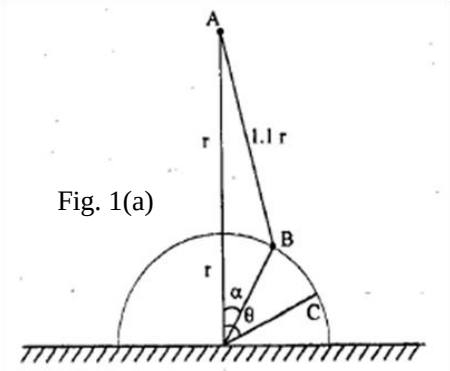


Fig. 1(a)

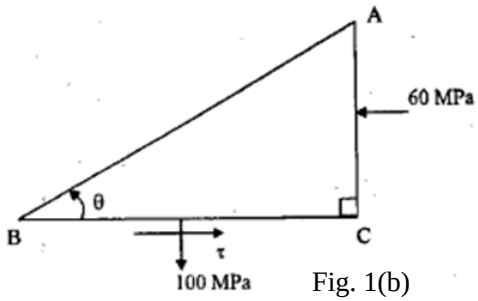


Fig. 1(b)

Q. 1(b) Stresses at a point are shown in Fig. 1(b). What is the shear stress on plane AC, if τ on plane BC is 40 MPa? What is the magnitude of angle θ if AB is a principal plane? What is the maximum shear stress at the point? 10

Q. 1(c) Describe different crystal systems in Materials. 10

Q. 1(d) A pinion having 30 teeth drives a gear having 80 teeth. The profile of the gears is involute with 20° pressure angle, 12 mm module and 10 mm addendum. Find the length of path of contact, arc of contact and contact ratio. 10

Q. 1(e) The vibrations of a machine of mass 76 kg are damped by a viscous dashpot which diminishes amplitude of vibrations from 17.2 mm to 3.2 mm in two complete oscillations. The machine is mounted on four springs each of stiffness 7.5 N/mm. Assuming that the damping force varies as the velocity, determine:

(i) the damping coefficient,

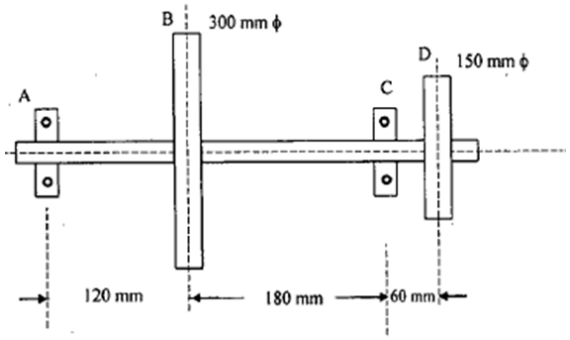
(ii) the ratio of frequencies of damped and undamped vibrations, and
(iii) the periodic time of damped vibrations. 10

Q. 2(a) Derive expressions for longitudinal and hoop stresses in a thin walled pressure vessel. Using the above expressions, determine hoop and longitudinal stresses in a household LPG cylinder, assuming it to be a thin walled pressure vessel with following dimensions: OD = 315 mm thickness: 2.8 mm. Take end caps to be flat and the pressure in the cylinder is 1.4 MPa at room temperature. 20

Q. 2(b) Describe Austempering of steel with help of TTT diagram. 10

Q. 2(c) A cam drives a flat reciprocating follower in the following manner:
During first 120° rotation of the cam, the follower moves outwards through a distance of 20 mm with simple harmonic motion. The follower dwells during next 30° of cam rotation. During next 120° of cam rotation, the follower moves inwards with simple harmonic motion. The follower dwells for the next 90° of cam rotation. The minimum radius of the cam is 25 mm.
Draw the profile of the cam. 20

Q. 3(a) A shaft is to transmit 2 kW at 750 R.P.M. The shaft is supported in bearings A and C, 300 mm apart. Two pulleys of 300 mm diameter and 150 mm diameter are located at B and D as shown in Fig. 3(a). Assume that the belt tensions are vertical for both pulleys. Ratio of belt tensions for both pulleys is 3. Neglect weight of pulleys and shaft. Take combined fatigue and shock factor in bending and twisting equal to K_b = 1.5, K_t = 1.0, respectively.
Determine uniform diameter of the shaft if allowable tensile stress is 110 MPa and allowable shear stress is 65 MPa. (Take shaft diameter in steps of 5 mm.) 20



Q. 3(b) What are polymeric materials? Distinguish between two polymer types. 10

Q. 3(c) Because of nature of its operations, the load torque of a machine is intermittent as follows:
During its three quarter revolution, the load torque increases uniformly from 10 kNm to 15 kNm. Thereafter it remains constant for half revolution and then decreases uniformly in three quarter revolution to 50 kNm. After this for one revolution it remains constant. Thus the cycle is repeated.
The machine is run by a constant torque motor running at a speed of 300 rpm, in conjunction with a flywheel of mass moment of inertia of 2200 kg/m^2.
Determine:
(i) Magnitude of mean torque of motor
(ii) Power of the motor
(iii) Speed fluctuation of the system. 20

Q. 4(a) A solid circular shaft is subjected to a bending moment of 3 kN-m and a torque of 1 kN-m. The shaft is to be made in carbon steel for which σ_y = 480 MPa and τ_y = 265 MPa.

Calculate shaft diameter using:

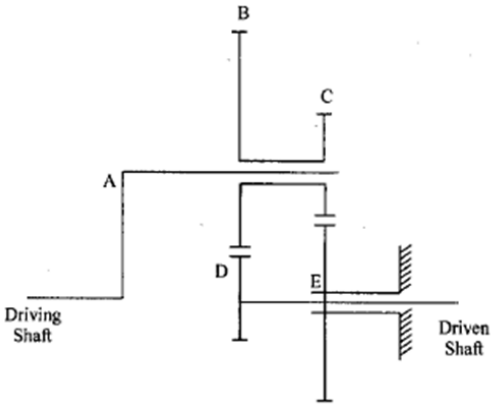
(i) Maximum normal principal stress theory

(ii) Maximum shear stress theory. 20

Q. 4(b) What are composites? How are they classified? Mention any four applications of composites. 10

Q. 4(c) An epicyclic speed reduction gear schematic is shown in Fig. 4(c). Compound wheel B-C is free to rotate on pin A connected to driving shaft. Wheel C meshes with fixed wheel 'E' and wheel B meshes with wheel D keyed to driven shaft.

If number of teeth on wheels are T_b = 27, T_c = 30, T_d = 24 and T_e = 21, determine the ratio of speeds of the driving and driven shafts. 20



SECTION—B

Q. 5(a) Compare flank wear and crater wear and draw tool life versus cutting speed curves for H.S.S., Carbide, and ceramic tools. 10

Q. 5(b) Define 'Grinding Ratio'. Also explain what is meant by a grinding wheel acting soft or acting hard. Is it always desirable to obtain a high grinding ratio in practice? 10

Q. 5(c) A company studied the cost data on quality and found a relationship between the percent defective and the cost of control and cost of failure per 100 parts as under:

Cost of failure F = 1500 + 120 X

Cost of Control C = 3000/X

where X is percent defective.

What is the percent defective which minimizes the quality cost? How much is the minimum quality cost per hundred parts? 10

Q. 5(d) Fixed and variable costs for three potential manufacturing facilities for same product are shown below:

Mfg. Facility	Fixed Cost/Yr. (Rs.),	Variable Cost/Unit (Rs.)
A	1,25,000	50
B	2,00,000	40
C	2,50,000	20

(i) If the expected output is to be 8000 units per year, which facility should be selected? Explain with the help of a graph.

(ii) When is option B economical?

(iii) Comment on choice of the options. 10

Q. 5(e) Differentiate between open loop, closed loop and adaptive control systems used in NC machine tools. 10

Q. 6(a) According to the ISO system, sketch the basic size, deviation, and tolerance on a shaft and hole assembly. Why uni-lateral tolerance is preferred over bi-lateral tolerance? 10

Q. 6(b) Explain with the help of a sketch the Electric Discharge Machining (EDM) process. What are its advantages and limitations? Describe the nature of the surface obtained by EDM. Also name any three important electrode materials. 20

Q. 6(c) Explain with neat sketches the Plasma Arc Welding (PAW) process and discuss its applications and limitations. 20

Q. 7(a) List five distinct methods used to obtain high energy rates in HERF. With the help of a sketch explain the spark discharge method of High Energy Rate Forming. Also mention two advantages and three important applications of HERF method. 20

Q. 7(b) State the basic principles of plant layout. Table below lists 12 work-elements along with their immediate predecessor elements and duration in minutes. Design suitable line consisting of appropriate work-stations assuming a cycle time of 20 minutes. Compute the line efficiency, balance delay and smoothness index:

Work Element	Immediate Predecessor Element	Duration
A	—	10
B	A	6
C	B	8
D	A	6
E	B	12
F	E	10
G	F	4
H	G	12
I	F	2
J	F	8
K	G	8
L	H, I, K	14

Use the least-number-of predecessors rule. 20

Q. 7(c) A transport company assumes that the requirement of tyres used in vehicles are closely related to number of kilometres driven. Accordingly, the following data covering the last six months have been collected as follows:

Months	Tyres Used	Thousands of km driven
1	100	1500
2	150	2000
3	120	1700
4	80	1100
5	90	1200
6	180	2700

(i) Establish the relationship (linear) between the required tyres and kms driven based on data. How good is the co-relation?

(ii) If expected kms drive in a month is 32,00,000, forecast the demand for tyres. 10

Q. 8(a) Compare the concept of 'Just-in-Time' with that of 'Manufacturing Resource Planning'. A work centre uses Kanban containers which hold 200 parts. To produce enough parts to fill the container 60 minutes are needed. Moving the container to the next work-station and return of empty container takes 120 minutes. There is overall demand rate of 6 units per minute.

(i) Calculate the number of containers needed for the system.

(ii) What is maximum inventory in the system?

(iii) If the setup and runtime to fill the container is reduced to 40 minutes, can the number of containers be reduced? How much will be the inventory in system then? 20

Q. 8(b) What is understood by "process is under statistical control"? Explain clearly with the help of diagrams, illustrating out of control situations.

Plot the control charts of $\bar{X}$ and R, using the following sample data and a sample size of 5. From the chart, find out whether the process is under control.

Subgroup No.	1	2	3	4	5	6	7	8	9	10
$\bar{X}$	5.004	5.204	5.014	5.008	5.009	5.016	5.030	5.010	5.016	5.010
R	0.02	0.08	0.03	0.05	0.04	0.09	0.04	0.04	0.05	0.07

The factors for estimating σ' from R and σ from statistical tables are reproduced below:

Number of observations *n*	2	3	4	5	6	7	8	9	10	11
$d_2 = \bar{R}\ /\sigma'$	1.128	1.693	2.059	2.326	2.534	2.704	2.847	2.970	3.078	3.173
$c_2 = \bar{\sigma}\ /\sigma'$	0.5642	0.7236	0.7979	0.8407	0.8686	0.8882	0.9027	0.9139	0.9227	0.9300

20

Q. 8(c) A manufacturing organisation is considering investment in two alternative equipments A and B. Equipment A costs Rs. 30,000 while the equipment B costs Rs. 50,000. The expected yearly net income for the first five years from these equipments are Rs. 10,000 and Rs. 15,000 for equipments A and B respectively. Assuming the cost of capital as 12% per annum, determine which equipment should be selected. Use net present value approach. 10

MECHANICAL ENGINEERING PAPER II

Time allowed: 3 hours **Maximum marks: 250**

QUESTION PAPER SPECIFIC INSTRUCTIONS

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

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*Candidate has to attempt **FIVE** questions in all.*

*Question Nos. 1 and 5 are compulsory and out of the remaining, **THREE** are to be attempted choosing at least **ONE** question from each Section.*

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Section—A

1. (a) In a Carnot cycle, heat is received at 480 °C and rejected at 40 °C. The entropy of the sink increases by 0.0785 kJ/kg K per cycle. Determine the work done per cycle. 10

(b) An open-cycle gas turbine plant with turbine efficiency η_t has a compressor of efficiency η_C. The minimum gas temperature is T_{min} and after heating in the combustion chamber, its temperature is T_{max}. If the pressure ratio for compression and expansion is r_p, what should be the limit for the product

$$\eta_c \eta_t \frac{T_{max}}{T_{min}}$$

Neglect pressure losses and assume that working substance is a perfect gas. 10

(c) Derive the following expression for normal shock in an ideal gas:

$$\frac{p_y}{p_x} = \frac{2\gamma}{\gamma+1} M_x^2 - \frac{\gamma-1}{\gamma+1}$$

where *x* and *y* are conditions before and after the shock, γ is ratio of specific heats and M is Mach number. 10

(d) A thin radiation shield having equal emissivities on both sides is introduced parallel to and in between two large planes with emissivities 0.8 and 0.5 respectively. Determine the emissivity of the radiation shield to reduce the heat transfer rate by 92% of the original. 10

(e) The outer and inner surfaces of a thick hollow cylinder have areas 1.25 m^2 and 0.25 m^2 respectively. The thickness of the cylinder is 10 cm and the thermal conductivity of the cylinder material is 50 W/m K. Find the radial heat transfer through the cylinder for 100 °C temperature difference at the surfaces. Derive the formula used. 10

2. (a) A reciprocating air compressor is used to fill rapidly a 3 m^3 tank at 30°C and 1 bar. The filling process is governed by $pv^{1.4}$ = const. The effects of kinetic energy are

negligible. The ratio of the final to initial mass of air in the tank is 4. Work out the following:

(i) Draw the system and show the control volume.

(ii) List the assumptions made.

(iii) What would be the work input to the compressor, if mechanical efficiency is 90%? 20

(b) A centrifugal compressor running at 1200 r.p.m. delivers 800 m3/min of free air. The air is compressed from 1 bar, 30 °C to 4.8 bar with isentropic efficiency of 0.84. The impeller blades are radial at outlet and the flow velocity of 80 m/s may be assumed constant throughout. The outer radius of the impeller is twice the inner. The slip factor may be assumed as 0.9. The blade area coefficient is equal to 0.9 at inlet.

(i) Draw inlet and outlet velocity triangles for the impeller, and show the process on a T-s diagram.

(ii) Calculate the input power needed, if mechanical efficiency is 95%.

(iii) Calculate the impeller diameters at inlet and outlet.

(iv) Calculate the impeller and diffuser blade angles at inlet. 20

(c) The vapour, at the saturation temperature of an oil flowing at the rate of 500 kg/min, enters a heat exchanger tube, at 355 K and condenses while it is cooled by water flowing at the rate of 3600 kg/min entering the concentric tube of a parallel-flow heat exchanger at 286 K. Assuming overall heat transfer coefficient of 475 W/m^2K, latent heat of oil as 600 kJ/kg K, calculate the number of tubes required of 25 mm outer diameter and 2 mm thick with a length of 4.87 m. What will be the number of tube passes, if cooling water velocity should not exceed 2 m/s? Take C_p for water as 4.18 kJ/kg K and density of water as 1000 kg/m^3. 10

3. (a) Using Buckingham's π theorem method, derive a relation for the efficiency η of a fan which depends on the following parameters: 20

Mass density ρ, Dynamic viscosity ν, Angular velocity ω, Diameter of the rotor D, Discharge Q

(b) Two long slender rods A and B, made of different materials having same diameter of 12 mm and length 1 m, are attached to a surface maintained at a temperature of 100 °C. The surfaces of the rods are exposed to ambient still air at 20 °C. By traversing along the length of the rods with a temperature sensor, it is found that the surface temperatures of rods A and B are equal at positions 15 cm and 7.5 cm respectively away from the base surface. If material of A is carbon steel with thermal conductivity 60 W/mK, what is the thermal conductivity of rod B? List the assumptions made. Assume that the average convection coefficient for air is 5 W/m^2K. Find the ratio of rate of heat transfer for rods A and B. 20

(c) A certain amount of gas is filled in a tank X until its pressure is 100 kPa and temperature is 330 K. In another tank Y, 5 times the weight of gas in X is filled raising the pressure to 500 kPa and temperature 900 K. Both the tanks X and Y are now connected through a tube having a valve which is closed. Assuming the gas is ideal and if the valve is opened till equilibrium state is achieved, find the ratio of the volumes of both tanks, equilibrium temperature and pressure. The tanks are insulated. For the gas, take R = 0.296 kJ/kgK and C_v = 0.75 kJ/kg K. 10

4. (a) Liquid N_2 enters a thin-walled 20 mm diameter tube at 77 K and flows steadily. The outer surface of the tube has an emissivity of 0.02. This tube is placed concentrically in another tube of 50 mm inner diameter, whose inner surface emissivity is 0.05. The inner surface of the outer tube is maintained at 300 K and the space in between the tubes is evacuated. Determine the heat gained by the liquid N_2 per unit length of the tube.

If a thin-walled radiation shield with emissivity 0.02 on both sides is inserted midway concentrically between inner and outer tubes, calculate the % change in heat gained by liquid N_2 per unit length of the tube. 20

(b) A fluid flowing in a tube at the rate of 0.5 kg/s is heated from 30 °C to 60 °C by hot gases entering at a temperature of 180 °C and leaving at 80 °C. The specific heats of the fluid and gases are 4.186 kJ/kg K and 1.08 kJ/kg K. Calculate the change in entropy and increase in unavailable energy for ambient temperature of surrounding of 20 °C. 20

(c) In a simple open-cycle gas turbine plant, air enters at 1 bar, 288 K and is compressed to 2 bar. It is then heated in the regenerator before entering the combustion chamber where it is heated to a temperature of 1700 K and then enters a turbine and expands to atmospheric pressure. The isentropic efficiencies of compressor and turbine are 87% and 88% respectively. The combustor and heat exchanger efficiencies are 0.97 each. Pressure loss in the combustor is 0.4 bar. Power developed by the turbine is 350 MW. Calorific value of fuel is 42 MJ/kg. Assume $C_{Pair} = C_{Pgas} = 1.005$ kJ/kg K and $\gamma = 1.4$.

(i) Draw the system flow diagram and show the processes on a T-s diagram.
(ii) Find out the mass flow rate of air and fuel.
(iii) Find out the work ratio.
(iv) Find out the thermal efficiency.
(v) Find out the specific fuel consumption. 10

Section—B

5. (a) The products of combustion of an unknown fuel C_xH_y have the following composition as measured by an Orsat apparatus:

$$CO_2 = 8.0\%,\ CO = 0.9\%,\ O_2 = 8.8\%,\ N_2 = 82.3\%$$

Determine the values of x and y, the air-fuel ratio and % of excess air used. 10

(b) Determine the expression for the ratio of chimney gas temperature to outside air temperature in terms of mass flow rate. 10

(c) At a stage in a reaction turbine, the pressure of steam is 34 kPa ($v_g = 4.65\ m^3/kg$) and dryness fraction is 0.95. For a flow rate of 36000 kg/hr, the stage develops 950 kW. The turbine runs at 3600 r.p.m. and velocity of flow is 0.72 times the blade velocity. The outlet angles of both stator and rotor blades are 20°. Determine at this stage the mean rotor diameter and height of blades. 10

(d) Mechanical air-conditioning can be used in all geographical locations, whereas desert air-coolers can be used only in some geographical locations. Explain why. Show the processes involved in both these equipments. 10

(e) It is thermodynamically advantageous to employ a heat pump rather than employing a direct electrical resistance heater for a room air heating application. Explain why. 10

6. (a) A 2-stroke oil engine was subjected to a test at room temperature of 20 °C with fuel oil of calorific value 44000 kJ/kg. Calculate the indicated and brake, power, mechanical and brake thermal efficiency, and draw the heat balance sheet using the following data:

Cylinder bore = 20 cm; Stroke-bore ratio = 1.3 : 1; Speed = 500 r.p.m.; Brake drum diameter = 120 cm; Rope diameter = 3 cm; Net brake load = 460 N; Indicated MEP = 2.8 bar; Oil consumption = 3.7 kg/hr; Jacket cooling water rate = 456 kg/hr with a rise in temperature of 27 °C; Exhaust gas temperature entering calorimeter is 320 °C and leaving 220 °C; Temperature rise in calorimeter water is 8 °C with a rate of flow 8 kg/min 20

(b) In a combined gas turbine (GT)-steam turbine (ST) plant, the exhaust from GT is used to heat steam in boiler at which a further supply of fuel is burned in the gas. Pressure ratio of GT is 8, inlet air temperature is 15°C, maximum cycle temperature is 800 °C. Combustion in boiler increases the gas temperature to 800 °C and gas leaves the boiler at 100 °C. The steam inlet in ST is at 60 bar and 600 °C (h = 3656.2 kJ/kg, s = 7.166 kJ/kg K) and condenser pressure is 0.05 bar (h_f = 137.8 kJ/kg, h_{fg} = 2423.8 kJ/kg, s_f = 0.476 kJ/kg K, s_{fg} = 7.92 kJ/kg K). Calculate flow rate of air and steam required for a total power output of 190 MW and the overall η of the combined plant. Assume that all processes are ideal. What is overall air-fuel ratio? Assume C_{Pgas} = 1.11 kJ/kg K and C_{Pair} = 1.05 kJ/kg K, and γ for gas and air as 1.33 and 1.4 respectively. Neglect mass flow rate of fuel on the airflow. Calorific value of fuel is 43.3 MJ/kg. 20

(c) Show that the enthalpy of humid air per kg of dry air is given by

$$h = C_{pm} \times DBT + 2500w$$

where C_{Pm} = humid air specific heat = (1.005 + l.88w), w = specific humidity kg/kg of dry air, h_{fg} = 2500 kJ/kg at 0 °C for water and DBT = dry-bulb temperature. 10

7. (a) (i) Derive an expression for critical pressure ratio of a nozzle. Explain the phenomenon of choking in the nozzle. 10

(ii) A steam power station uses the following cycle:

Steam boiler outlet 150 bar, 550 °C (h = 3450.4 kJ/kg, s = 6.523 kJ/kg K)

Reheat at 40 bar to 550 °C (h = 3560.34 kJ/kg, s = 7.235 kJ/kg K);

Condenser at 01 bar (h_f = 191.8 kJ/kg, h_{fg} = 2392.05 kJ/kg, s_f = 0.649 kJ/kgK, s_{fg} = 7.5 kJ/kgK)

Assuming ideal processes, find quality of steam at turbine exhaust, cycle efficiency and steam flow rate per kWh. 10

(b) The air handling unit in an AC plant supplies a total of 4500 cmm of dry air which comprises by weight 20% fresh air at 40 °C DBT, 27 °C WBT and 80% recirculated air at 25 °C DBT and 50% RH. Air leaves the cooling coil at 13 °C saturated. Calculate total cooling load and room heat gain: 20

Condition	DBT	WBT	RH	Sp. humidity	Enthalpy
	(°C)	(°C)	(%)	(kg/kg of dry air)	(kJ/kg of dry air)
Outside air	40	27		17.2	85
Room air	25		50	10.0	50.8
ADP	13		100	9.4	37.0

(c) The following data refer to a 4-stroke, 4-cylinder diesel engine:

Cylinder diameter = 36 cm; Stroke = 40 cm; Speed = 315 r.p.m.; Indicated MEP = 7 bar; Brake power = 250 kW; Fuel consumption = 80 kg/hr; Calorific value = 44 MJ/kg; Air consumption = 30 kg/min; Cooling water circulated = 90 kg/min with rise in temperature 38 °C; Exhaust gas temperature = 324 °C and Room temperature = 45 °C kJ/kg K; C_{pair} = 1.005 kJ/kgK, C_{pgas} = 1.05 kJ/kg K, C_{Psteam} = 2.093 kJ/kg K. In exhaust gases, partial pressure of steam is 0.03 bar and fuel contains 13% H_2.

Find mechanical efficiency, indicated thermal η, brake specific fuel consumption: Draw heat balance sheet for the engine in hourly basis. 10

8. (a) (i) An R12 simple saturation cycle operates at temperatures of 35°C and -15°C. Determine the COP and HP per ton of refrigeration of the system: 10

				Superheated			
				20 K		40 K	
t	h_f	h_g	s_g	h	s	h	s
°C	kJ/kg	kJ/kg	kJ/kg-K	kJ/kg	kJ/kg-K	kJ/kg	kJ/kg-K
35	69.5	201.5	0.6839	216.4	0.731	231.0	0.7741
-15	-	181.0	0.7052	193.2	0.751	205.7	0.7942

(ii) Differentiate between summer and winter air-conditioning processes. 10

(b) Even though velocity-compounded impulse turbines are less efficient, in the initial stages of high pressure turbines are normally velocity-compounded. Why? Plot the variation of pressure and velocities in velocity-compounded and pressure-compounded impulse turbines. 10

(c) A steam power plant operates on ideal regenerative Rankine cycle. Steam enters the turbine at 6 MPa, 450 °C (h = 3301.8 kJ/kg, s = 6.7193 kJ/kg K) and is condensed in the condenser at 20 kPa (h_f = 251.4 kJ/kg, h_{fg} = 2358.3 kJ/kg, v_f = 0.001 m^3/kg, s_f = 0.832 kJ/kg K, s_{fg} = 7.0766 kJ/kg K). Steam is extracted from the turbine at 0.4 MPa (h_f = 604.74 kJ/kg, v_f = 0.001 m3/kg, h_{fg} = 2133.8 kJ/kg, s_f = 1.7766 kJ/kg K, s_{fg} = 5.1193 kJ/kg K) to heat feedwater heater. Water leaves feedwater heater as saturated liquid. Show the cycle on T-s diagram and find net work output/kg of steam, the boiler and thermal efficiencies of the cycle. 20