ESE (Mains), 2022

Mechanical Paper-I

SECTION 'A'

1. (a) A wooden block of specific gravity 0.75 floats in water. If the size of the block is 1mt × 0.5mt × 0.4mt, find its metacentric height. 12

1. (b) In a cold winter night with an outside ambient temperature of 2°C, a wall of house steadily loses 30 kJ per minute. If the inner and outer surface temperatures of the wall are maintained at 25°C and 8°C, respectively, determine the rate of energy destruction within the wall in watts. 12

1. (c) What are the physical assumptions necessary for a lumped capacity unsteady state heat transfer analysis to be applied? 12

1. (d) The brake fuel conversion efficiency of an engine is 30%. The mechanical and combustion efficiencies are 80% and 94%, respectively. The heat losses to the oil and coolant are 60 kW. The chemical energy of the fuel entering the engine is 190 kW. What percentage of this energy becomes (a) brake power; (b) friction power; (c) heat losses; (d) exhaust chemical energy; (e) exhaust sensible energy? 12

1. (e) Briefly explain the working principle of a vortex tube refrigeration system. 12

2. (a) The diameter of the horizontal pipe which is 300 mm is suddenly enlarged to 600 mm. The rate of flow of water through this pipe is 0.4 m^3/sec. If the intensity of pressure in the smaller pipe is 125KN/m^2, determine

(i) loss of head, due to sudden enlargement.

(ii) intensity of pressure in the larger pipe.

(iii) power lost due to enlargement. 20

2. (b) Argon at 39.85°C with a volume of 0.5 m^3 is initially contained in a pistoncylinder (cross sectional area 0.7 m^2 and height 5.7 m) system with a massless piston loaded with water at 20°C and outside atmosphere (atmospheric pressure, Po = 101.203 kPa) as shown in figure. If the piston just touches the stops, the volume of argon would be 0.8 m3. Heat is now added until the temperature of argon reaches 251.85°C. Plot the entire process on P-v diagram. Assume piston to be adiabatic, determine

(i) the final pressure inside the cylinder

(ii) work done (in kJ) and

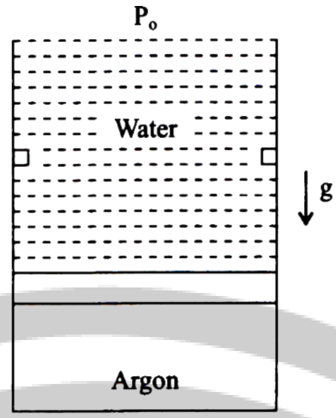
(iii) heat transfer during the process (in kJ).

Neglect the volume occupied by the piston and stops.

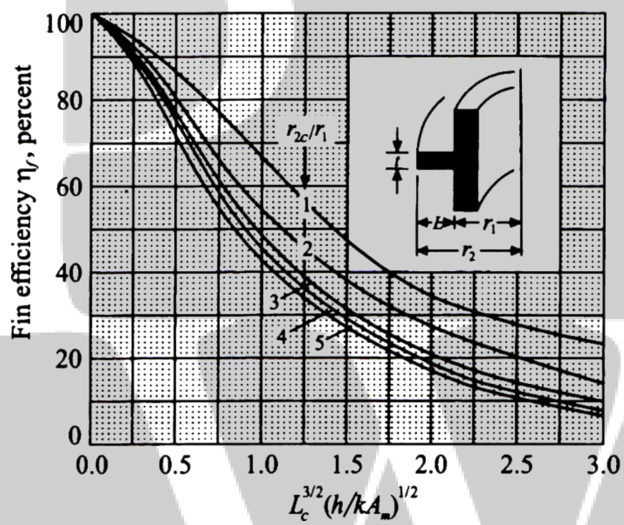
Take g = 9.807 m/s^2, specific volume of water = 0.001002 m^3/kg.

R for argon = 0.2081 kJ/kgK.

ω for argon = 0.312 kJ/kgK. 20



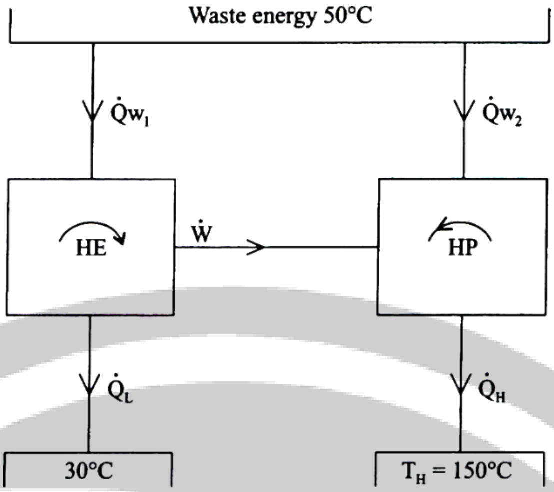
2. **(c)** Aluminum fins 1.5 cm wide and 1.0 mm thick are placed on a 2.5 cm diameter tube to dissipate the heat. The tube surface temperature is 170°C and the ambient fluid temperature is 25°C. Calculate the heat loss per fin for h = 130w/m°C. Assume k = 200w/m °C for aluminum. Use the fin-efficiency curves given below : 20



3. **(a)** A four cylinder SI engine has a stroke of 90 mm and a bore of 60 mm, with rated speed of 2800rpm. The engine is tested at the rated speed against a brake which has a torque arm of 0.356 m. The brake load is 155 N and the fuel consumption is 6.74l/hr. The specific gravity of the petrol used is 0.735 The net heating value of the petrol used is 44200 kJ/kg. A Morse test is carried out and the cylinders are cut out in the order 1, 2, 3, 4 with corresponding brake load of 111 N,106.5 N,104.2 N and 111 N, respectively. Calculate for this speed, the engine torque, the bmep, the brake thermal efficiency, the specific fuel consumption, the mechanical efficiency and the indicated mean effective pressure. 20

3. **(b)** Describe the working of steam jet-ejector refrigeration system with the help of a neat sketch. Also state the important relations for normal shock in the steam jet refrigeration system. 20

3. **(c)** A combination of a heat engine driving a heat pump as shown in figure, takes waste energy at 50°C as a source $\dot{Q}_{w_1}$, to the heat engine rejecting heat at 30°C. The remainder $\dot{Q}_{w_2}$ goes into the heat pump that delivers a $\dot{Q}_H$ at 150°C. If the total waste energy is 5MW, find the rate of energy delivered at the higher temperature. 20



4. **(a)** A room with dimensions as 3.5 m wide, 3 m high and 6 m deep, is required to be air conditioned. One of the walls (3.5 × 3 m) faces west and contains a double glazed glass window of size 2 m by 1.5 m. There are no heat gains through the rest of the walls. Calculate the sensible, latent and total heat gains. Also, calculate the room sensible heat factor and the required cooling capacity with the following data:

Inside conditions : 25° DBT, 50% RH

Outside conditions : 45° DBT, 24°C WBT

U_{wall} : 1.78 W/m^2 K

U_{roof} : 1.316 W/m^2 K

Effective Temperature Difference for wall : 25°C

Effective Temperature Difference for roof : 30°C

U_{glass} : 3.12 W/m^2 K

Solar Heat gain of glass : 300 W/m^2 K

Internal shading coefficient of glass : 0.86

Occupancy : 4 persons (90 W sensible heat per person)
(40 W latent heat per person)

Lighting load : 33 W/m^2 of floor area

Appliance load : 600 W (sensible) + 300 W (latent)

Infiltration : 0.5 Air changes per hour

State assumptions, if any.

[Psychrometric chart attached]

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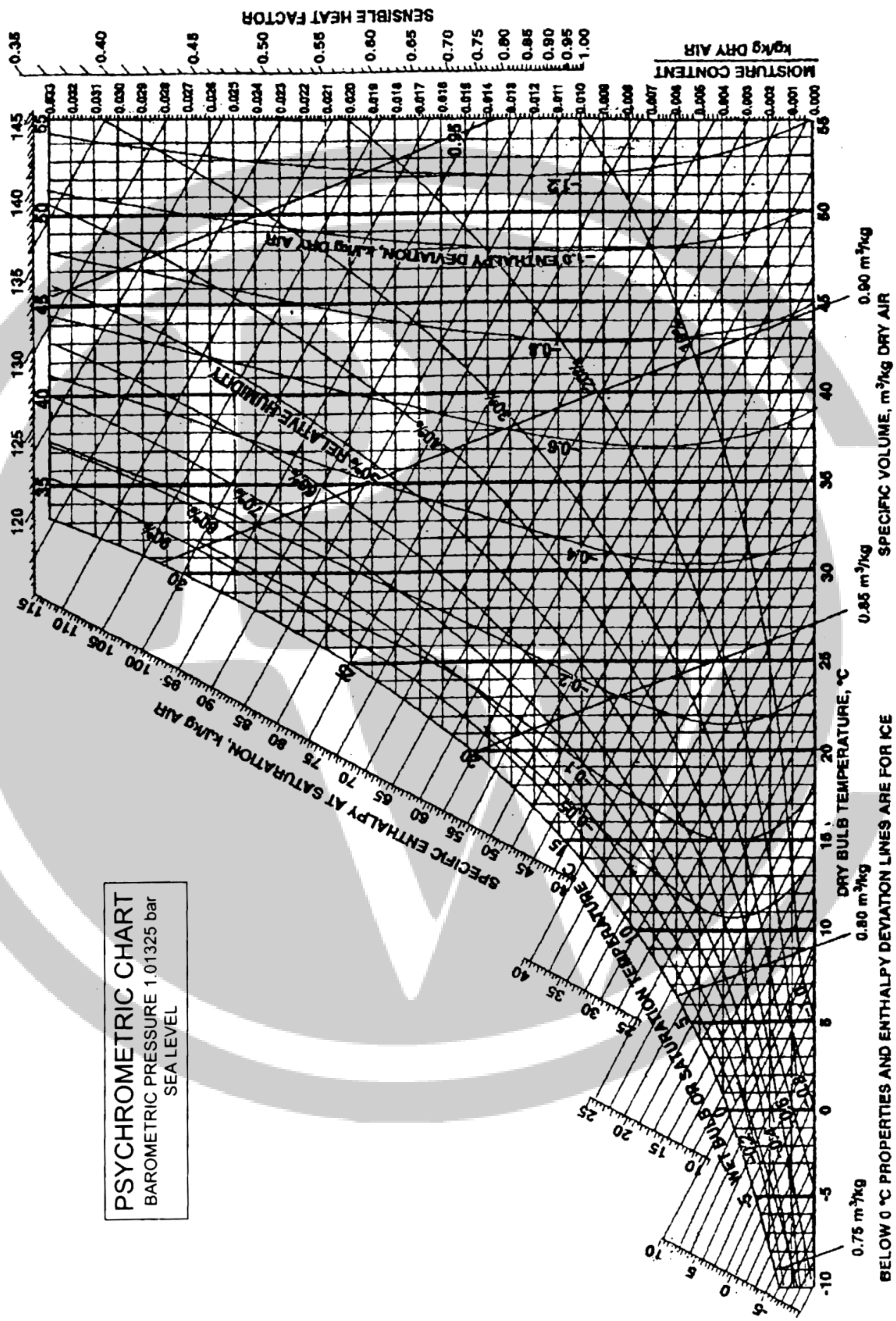
Ref. Point for S.H.F. is 25°C, 50% R.H.



4. (b) Determine the geometric shape factor for a very small disk A_1 and a large parallel disk A_2 located co-axially at a distance L directly above the smaller one. The radius of the large disk may be taken as α. 20

4. (c) An insulated 0.75 kg copper container containing 0.2 kg water, both in equilibrium at a temperature of 20°C. An experimenter now places 0.05 kg of ice at 0°C in the container. The specific heat of copper is 0.418 kJ/kgK and latent heat of fusion of ice at 0°C is 333 kJ/kg.

(i) What will be the temperature (Tf) at the equilibrium condition when all the ice has melted?

(ii) Compute the entropy generation during the process (J/K).

(iii) What will be the minimum work needed by a stirrer to bring back the temperature of water at 20°C in kJ?

Take specific heat of water as 4.187 kJ/kgK. 20

SECTION 'B'

5. (a) Explain how the use of a draft tube at the exit of a Francis turbine will increase its efficiency but may initiate the problem of cavitation. 12

5. (b) There is a limitation on maximum temperature in gas turbine as its blades have material constraints. While the usual two-wheeler internal combustion engine doesn't have any such constraints; why? Explain. How are such issues with gas turbine blades resolved? Explain with a neat sketch. 12

5. (c) What is fusible plug? Where it is used and how it works? Explain with a neat sketch. 12

5. (d) Explain the working principle of electrostatic precipitator. How can its efficiency be improved? 12

5. (e) Describe the working of Solar thermal vapour absorption air conditioning system. Also, list the advantages and limitations of $LiBr-H_2O$ and NH_3-H_2O systems. 12

6. (a) A centrifugal pump lifts water from a sump to an overhead reservoir. The static lift is 40 m out of which 3 m is suction lift. The suction and delivery pipes are both of 30 cm diameter. The friction loss in suction pipe is 2.5 m and in delivery pipe it is 7.5 m. The impeller is 0.5 m in diameter and has a width of 3 cm at the outlet. The speed of the pump is 1200rpm. The exit blade angle is 20°. If the manometric efficiency is 86%, determine the absolute pressures at the suction and delivery ends of the pump. Assume that the inlet and outlet of the pump are at the same elevation. Take atmospheric pressure as 10.10 m of water. 20

6. (b) A steam power plant has high and low pressures of 20MPa and 10kPa and one open feed water heater operating at 1MPa with the exit as saturated liquid. The maximum temperature is 800°C and the turbine has a total power output of 5MW. Find the fraction of the flow for extraction to the feedwater and the total condenser heat transfer rate. [Steam tables attached]

Saturated Water Pressure Entry

Press. (kPa)	Temp. (°C)	Specific Volume, m^3/kg		
		Sat. Liquid (v_f)	Evap. (u_{fg})	Sat.Vapor (v_g)
0.6113	0.01	0.001000	206.131	206.132
1	6.98	0.001000	129.20702	129.20802
1.5	13.03	0.001001	87.97913	87.98013
2	17.50	0.001001	67.00285	67.00385
2.5	21.08	0.001002	54.25285	54.25385
3	24.08	0.001003	45.66402	45.66502
4	28.96	0.001004	34.79915	34.80015
5	32.88	0.001005	28.19150	28.19251
7.5	40.29	0.001008	19.23674	19.23775
10	45.81	0.001010	14.67254	14.67355
15	53.97	0.001014	10.02117	10.02218
20	60.06	0.001017	7.64835	7.64937
25	64.97	0.001020	6.20322	6.20424
30	69.10	0.001022	5.22816	5.22918
40	75.87	0.001026	3.99243	3.99345
50	81.33	0.001030	3.23931	3.24034
75	91.77	0.001037	2.21607	2.21711
100	99.62	0.001043	1.69296	1.69400
125	105.99	0.001048	1.37385	1.37490
150	111.37	0.001053	1.15828	1.15933
175	116.06	0.001057	1.00257	1.00363

Press. (kPa)	Temp.(°C)	Enthalpy, kJ/kg			Entropy, kJ/kg-K		
		Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapor s_g
850	172.96	732.20	2039.43	2771.63	2.0709	4.5711	6.6421
900	175.38	742.82	2031.12	2773.94	2.0946	4.5280	6.6225
950	177.69	753.00	2023.08	2776.08	2.1171	4.4869	6.6040
1000	179.91	762.79	2015.29	2778.08	2.1386	4.4478	6.5864
1100	184.09	781.32	2000.36	2781.68	2.1791	4.3744	6.5535
1200	187.99	798.64	1986.19	2784.82	2.2165	4.3067	6.5233
1300	191.64	814.91	1972.67	2787.58	2.2514	4.2438	6.4953
1400	195.07	830.29	1959.72	2790.00	2.2842	4.1850	6.4692
1500	198.32	844.87	1947.28	2792.15	2.3150	4.1298	6.4448
1750	205.76	878.48	1917.95	2796.43	2.3851	4.0044	6.3895
2000	212.42	908.77	1890.74	2799.51	2.4473	3.8935	6.3408
2250	218.45	936.48	1865.19	2801.67	2.5034	3.7938	6.2971
2500	223.99	962.09	1840.98	2803.07	2.5546	3.7028	6.2574
2750	229.12	985.97	1817.89	2803.86	2.6018	3.6190	6.2208
3000	233.90	1008.41	1795.73	2804.14	2.6456	3.5412	6.1869
3250	238.38	1029.60	1774.37	2803.97	2.6866	3.4685	6.1551
3500	242.60	1049.73	1753.70	2803.43	2.7252	3.4000	6.1252
4000	250.40	1087.29	1714.09	2801.38	2.7963	3.2737	6.0700
5000	263.99	1154.21	1640.12	2794.33	2.9201	3.0532	5.9733
6000	275.64	1213.32	1571.00	2784.33	3.0266	2.8625	5.8891
7000	285.88	1266.97	1505.10	6.1869	3.1210	2.6922	5.8132
8000	295.06	1316.61	1441.33	2757.94	3.2067	2.5365	5.7431
9000	303.40	1363.23	1378.88	2742.11	3.2857	2.3915	5.6771
10000	311.06	1407.53	1317.14	2724.67	3.3595	2.2545	5.6140
11000	318.15	1450.05	1255.55	2705.60	3.4294	2.1233	5.5527
12000	324.75	1491.24	1193.59	2684.83	3.4961	1.9962	5.4923
13000	330.93	1531.46	1130.76	2662.22	3.5604	1.8718	5.4323
14000	336.75	1571.08	1066.47	2637.55	3.6231	1.7485	5.3716
15000	342.24	1610.45	1000.04	2610.49	3.6847	1.6250	5.3097
16000	347.43	1650.00	930.59	2580.59	3.7460	1.4995	5.2454
17000	352.37	1690.25	856.90	2547.15	3.8078	1.3698	5.1776
18000	357.06	1731.97	777.13	2509.09	3.8713	1.2330	5.1044

19000	361.54	1776.43	688.11	2464.54	3.9387	1.0841	5.0227
20000	365.81	1826.18	583.56	2409.74	4.0137	0.9132	4.9269
21000	369.89	1888.30	446.42	2334.72	4.1073	0.6942	4.8015
22000	373.80	2034.92	124.04	2158.97	4.3307	0.1917	4.5224
22089	374.14	2099.26	0	2099.26	4.4297	0	4.4297

Temp. (°C)	v (m^3/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg-K)	v (m^3/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg-K)
15000kPa (342.24°C)					20000kPa (365.81°C)			
Sat	0.01034	2455.43	2610.49	5.3097	0.00583	2293.05	2409.74	4.9269
350	0.01147	2520.36	2692.41	5.4420	-	-	-	-
400	0.01565	2740.70	2975.44	5.8810	0.00994	2619.22	2818.07	5.5539
450	0.01845	2879.47	3156.15	6.1403	0.01270	2806.16	3060.06	5.9016
500	0.02080	2996.52	3308.53	6.3442	0.01477	2942.82	3238.18	6.1400
550	0.02293	3104.71	3448.61	6.5198	0.01656	3062.34	3393.45	6.3347
600	0.02491	3208.64	3582.30	6.6775	0.01818	3174.00	3537.57	6.5048
650	0.02680	3310.37	3712.32	6.8223	0.01969	3281.46	3675.32	6.6582
700	0.02861	3410.94	3840.12	6.9572	0.02113	3386.46	3809.09	6.7993
800	0.03210	3610.99	4092.43	7.2040	0.02385	3592.73	4069.80	7.0544
900	0.03546	3811.89	4343.75	7.4279	0.02645	3797.44	4326.37	7.2830
1000	0.03875	4015.41	4596.63	7.6347	0.02897	4003.12	4582.45	7.4925
1100	0.04200	4222.55	4852.56	7.8282	0.03145	4211.30	4840.24	7.6874
1200	0.04523	4433.78	5112.27	8.0108	0.03391	4422.81	5100.96	7.8706
1300	0.04845	4649.12	5375.94	8.1839	0.03636	4637.95	5365.10	8.0441

6. **(c)** (i) A propeller-type horizontal axis wind turbine has following operating conditions:

Wind speed	:	10 m/s
Air density	:	1.226Kg/m^3
Rotor diameter	:	120 m
Rotor speed	:	50 RPM
Coefficient of performance	:	40%

Calculate :

(i) Total power density in wind system in w/m^2.

(ii) Total wind power in kW.

(iii) Maximum extractable power in kW.

(iv) Maximum torque in kN. 10

(ii) Explain the various features of wind-diesel hybrid power generation systems. Also, describe the types of operational scheduling for diesel unit. 10

7. **(a)** A single row impulse steam turbine with a blade speed of 200 m/s and mass flow rate of 4 kg/s develops 300 kW of power. Steam leaves the nozzles at 500 m/s, and the blade velocity coefficient is 0.92 If the steam leaves the turbine blade at such an angle that the absolute velocity at exit is kept minimum, determine nozzle angles, blade angles and diagram efficiency. Draw compound velocity triangles. 20

7. **(b)** An average flow rate of industrial waste water is 1000 m^3/day and 4000mg/litre of an organic substance with the composition as: $C_{50}H_{75}O_{20}N_5S$. The organic waste is processed in a mesophilic anaerobic digester at 35°C for biogas production with biodegradation efficiency of 95%. Determine the methane production rate. 20

7. **(c)** (i) What are once through boiler? How do they differ from drum boiler? 10

(ii) Why are downcomers fewer in number and bigger in diameter, while risers are more in number and smaller in diameter? 10

8. **(a)** How is the degree of reaction of a centrifugal compressor stage defined? Explain analytically how the degree of reaction varies with flow coefficient for different values of impeller exit air angle. Assume zero swirl at the entry. 20

8. **(b)** Consider a gas turbine cycle with two stages of compression and two stages of expansion. The pressure ratio across each compressor stage and each turbine stage is 8 to 1 The pressure at the entrance of the first compressor is 100kPa, the temperature entering each compressor is 20°C, the temperature entering each turbine is 1100°C. A regenerator is also incorporated into the cycle and it has an efficiency of 70%. Determine the compressor work, the turbine work and the thermal efficiency of the cycle. Take C_{po} as 1.004 kJ/kgK ratio of specific heats as 1.4 20

8. **(c)** The border region of Chattisgarh and Maharashtra has many rice mills as this region is suitable for rice crop. Suppose there is a village in this region which has many rice mills, barren land and jungle around. To meet the energy requirements of the rice mills and the village, which types of renewable energy systems would you like to propose? Justify your proposal. 20