MECHANICAL ENGINEERING

Paper – II

Time Allowed : ***Three*** *Hours*

Maximum Marks : ***200***

Question Paper Specific Instructions

Please read each of the following instructions carefully before attempting questions :

There are ***EIGHT*** *questions in all, out of which* ***FIVE*** *are to be attempted.*

Questions no. ***1*** *and* ***5*** *are* ***compulsory****. Out of the remaining* ***SIX*** *questions,* ***THREE*** *are to be attempted selecting at least* ***ONE*** *question from each of the two Sections A and B.*

Attempts of questions shall be counted in sequential 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 Question-cum-Answer Booklet must be clearly struck off.

All questions carry equal marks. The number of marks carried by a question/part is indicated against it.

Answers must be written in ***ENGLISH*** *only.*

Unless otherwise mentioned, symbols and notations have their usual standard meanings.

Assume suitable data, if necessary and indicate the same clearly.

Neat sketches may be drawn, wherever required.

Newton may be converted to kgf using the equality 1 kilonewton (1 kN) ---- 100 kgf, if found necessary.

All answers should be in SI units.

Take : $1\ kcal = 4{\cdot}187\ kJ$ *and* $1\ kg/cm^2 - 0{\cdot}98\ bar$

$1\ bar = 10^5$ *pascals*

Universal gas constant = $8314{\cdot}6\ J/kmol\text{-}K$

Psychrometric chart is enclosed.

SECTION A

Q1. (a) A non-flow quasi-static process occurs for which P = – 3V + 16 bar, where V is the volume in m^3. What is the work done when V changes from 2 m^3 to 6 m^3 ? *8*

(b) Air flows steadily at the rate of 1 kg/s through an air compressor. The properties of air at entry are velocity 7 m/s, pressure 105 kPa, specific volume 0·95 m^3/kg. The properties at exit are velocity 5 m/s, pressure 700 kPa, specific volume 0·19 m^3/kg. The internal energy of the air increases by 95 kJ/kg, as it flows through the compressor. Cooling water in the compressor jacket removes heat from the air at the rate of 60 kW.

(i) Compute the rate of shaft work input to the air, in kW.

(ii) Find the ratio of inlet pipe diameter to outlet pipe diameter. *8*

(c) Define specific speed of a turbine. Derive its expression in terms of speed, power and head. *8*

(d) Explain what you understand by Similitude. Further, explain the following : *8*

(i) Geometric Similarity

(ii) Kinematic Similarity

(iii) Dynamic Similarity

(e) Sketch and describe a natural circulation high pressure boiler. *8*

Q2. (a) A system at 500 K receives 7000 kJ/min from a source at 1000 K. The temperature of atmosphere is 300 K. Assuming that the temperature of the system and source remain constant during heat transfer, find out :

(i) The entropy produced during heat transfer

(ii) The decrease in available energy of source after heat transfer and increase in available energy of the system.

Show the process on the T-s diagram and mark the increase in unavailable energy. *20*

(b) Twenty people attend a cocktail party in a small room which measures 9·1 m by 7·6 m and 2·4 m ceiling. Each person generates about 131 W of heat. Assuming that the room is completely sealed off and well insulated, calculate the air temperature rise occurring within 15 minutes if the room temperature is 21°C. Volume occupied by each person is 0·07 m^3. The atmospheric pressure is 1·01325 bar. Take C_v of the air as 718 J/kg K. *10*

(c) Derive an equation describing a Fanno curve. Clearly mention the various assumptions made. Further, prove that at the maximum entropy point Mach number is unity and all processes approach this point. *10*

Q3. (a) A centrifugal compressor compresses air at ambient temperature and pressure of 288 K and 1·01 bar respectively. The impeller tip speed is 364 m/s, the radial velocity at the exit from the impeller is 28 m/s, and the slip factor is 0·891. Calculate the Mach number of the flow at the impeller tip. If the impeller total-to-total efficiency is 0·881 and the flow area from the impeller is 0·085 m^2, calculate the mass flow rate of air. Assume an axial entrance at the impeller eye and radial blades. Take isentropic index of air as 1·4, specific heat at constant pressure as 1005 J/kg K. *20*

(b) The incremental fuel costs for two generating units a and b of a power plant are given by the following relations :

$$\frac{dF_a}{dP_a} = 0 \cdot 07\ P_a + 55$$

$$\frac{dF_b}{dP_b} = 0 \cdot 08\ P_b + 50$$

where F is the fuel cost in rupees per hour and P is the power output in MW. Calculate,

(i) the economic loading of the two units when the total load supplied by the power plants is 500 MW.

(ii) the loss in fuel cost per hour if the load is equally shared by both the units. *10*

(c) Air at 15°C and 1·03 bar occupies 0·02 m^3. The air is heated at constant volume until the pressure is 4·2 bar and then cooled at constant pressure to initial temperature 15°C. Calculate the net heat flow to or from the air and the net entropy change of air. Treat air as ideal gas. Take C_p of air as 1·005 kJ/kg K and C_v as 0·718 kJ/kg K. *10*

Q4. (a) Determine the value of compressibility factor at critical point for gases following Van der Waal's equation of state. *15*

(b) The power P developed by a water turbine depends on the rotational speed N, operating head H, gravity g, diameter D and breadth B of the runner, density ρ and viscosity μ of water. Show by using Buckingham's π-theorem method,

$$P = \rho D^5 N^3 \phi \left[\frac{H}{D}, \frac{D}{B}, \frac{\rho D^2 N}{\mu}, \frac{ND}{\sqrt{gH}} \right].$$ *15*

(c) The following particulars refer to an experimental determination of the calorific value of a sample of fuel containing 88% C and 4·2% H_2. Mass of fuel is 0·848 gm. Mass of fuse wire 0·027 gm, of calorific value 6700 J/gm. Mass of water in the calorimeter is 1950 gm. Water equivalent of calorimeter is 380 gm. It is observed that rise in temperature is 3·06°C. The cooling correction is 0·017°C.

Find the higher calorific value of the fuel. Take C_p of water as 4·18 kJ/kg K. *10*

SECTION B

Q5. (a) Define (i) fin effectiveness ε_f, and (ii) fin efficiency η_f. Obtain expressions for ε_f and η_f for an infinitely long fin of uniform cross-section. Also, from the expression derived for ε_f, enumerate the conditions under which use of fins can be justified. *8*

(b) Liquid nitrogen is stored in a thin walled spherical container of 100 cm diameter. The system is insulated by an evacuated space between the inner sphere and the surroundings with 105 cm concentric sphere. Both the spheres are made of aluminium and have an emittance of 0·03. The inner surface of the sphere is maintained at 77·4 K and the temperature of the outer sphere is 280 K. The latent heat of vaporization of nitrogen is 200 kJ/kg.

Estimate

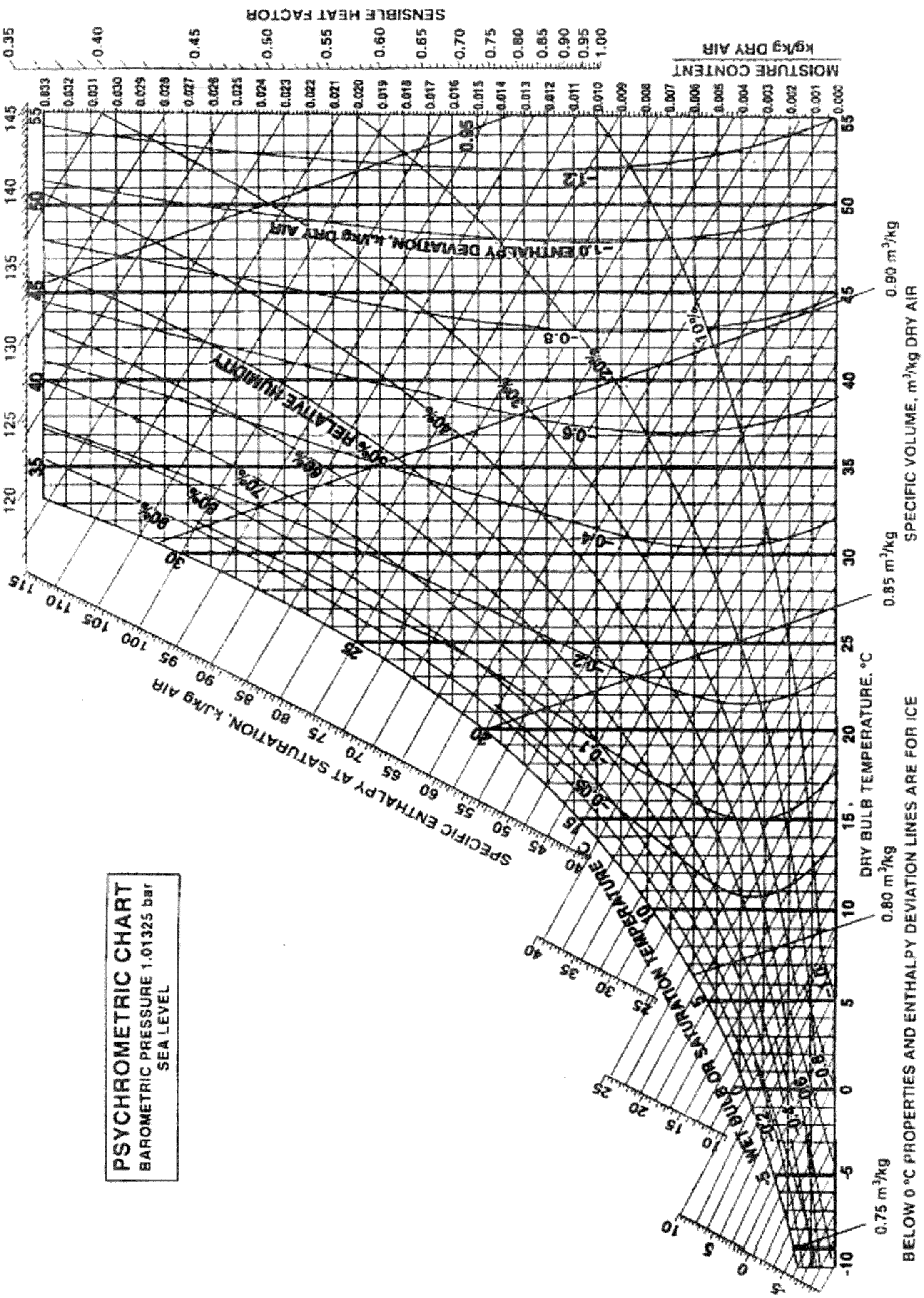
(i) the rate of heat flow by radiation to the nitrogen in the container, and

(ii) the nitrogen boil-off rate. *8*

(c) A room is to be kept at a temperature of 20°C and a pressure of 1·013 bar. The moist air at 430 m^3/hr is drawn from a supply at 5°C, 1·013 bar and 70% relative humidity, and is saturated with water vapour in a sprayer. Determine the amount of water added per hour at 5°C. *8*

Partial pressure of water vapour at 5°C = 0·0061 bar.
For air, R = 287 J/kJ K.

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



(d) Mention which factors affect the octane requirement of an engine. *8*

(e) Draw the schematic representation of disintegration of fuel jet in CI engine without swirl and with swirl. *8*

Q6. (a) A vapour compression refrigeration system of 2400 kJ/min capacity works at an evaporator temperature of –10°C and a condenser temperature of 50°C. The refrigerant R134a is subcooled by 5°C before entering the expansion valve and the vapour is superheated by 5°C before leaving the evaporator. The compression of the refrigerant is reversible adiabatic. The refrigeration compressor is having two cylinders, single acting with stroke equal to 1·5 times the bore and runs at 1000 rpm. Determine : (i) Refrigeration effect per kg of refrigerant, (ii) Mass of refrigerant circulated per minute, (iii) Theoretical piston displacement per minute, (iv) Power required to run the compressor, and (v) Bore by stroke of the compressor cylinder. Thermodynamic properties of R134a are attached. *15*

THERMODYNAMIC PROPERTIES OF R134a*

Saturation table of R134a

Temp. °C	Pressure MPa	Density kg/m^3 Liquid	Volume m^3/kg Vapour	Enthalpy kJ/kg		Entropy $kJ(kg. K)$		Specific Heat c_p, $kJ/(kg. K)$		c_p/c_v Vapour
				Liquid	Vapour	Liquid	Vapour	Liquid	Vapour	
– 103.30[a]	0.00039	1591.1	35.4960	71.46	334.94	0.4126	1.9639	1.184	0.585	1.164
– 100.00	0.00056	1582.4	25.1930	75.36	336.85	0.4354	1.9456	1.184	0.593	1.162
– 90.00	0.00152	1555.8	9.7698	87.23	342.76	0.5020	1.8972	1.189	0.617	1.156
– 80.00	0.00367	1529.0	4.2682	99.16	348.83	0.5654	1.8580	1.198	0.642	1.151
– 70.00	0.00798	1501.9	2.0590	111.20	355.02	0.6262	1.8264	1.210	0.667	1.148
– 60.00	0.01591	1474.3	1.0790	123.36	361.31	0.6846	1.8010	1.223	0.692	1.146
– 50.00	0.02945	1446.3	0.60620	135.67	367.65	0.7410	1.7806	1.238	0.720	1.146
– 40.00	0.05121	1417.7	0.36108	148.14	374.00	0.7956	1.7643	1.255	0.749	1.148
– 30.00	0.08438	1388.4	0.22594	160.79	380.32	0.8486	1.7515	1.273	0.781	1.152
– 28.00	0.09270	1382.4	0.20680	163.34	381.57	0.8591	1.7492	1.277	0.788	1.153
– 26.07[b]	0.10133	1376.7	0.19018	165.81	382.78	0.8690	1.7472	1.281	0.794	1.154
– 26.00	0.10167	1376.5	0.18958	165.90	382.82	0.8694	1.7471	1.281	0.794	1.154
– 24.00	0.11130	1370.4	0.17407	168.47	384.07	0.8798	1.7451	1.285	0.801	1.155
– 22.00	0.12165	1364.4	0.16006	171.05	385.32	0.8900	1.7432	1.289	0.809	1.156
– 20.00	0.13273	1358.3	0.14739	173.64	386.55	0.9002	1.7413	1.293	0.816	1.158
– 18.00	0.14460	1352.1	0.13592	176.23	387.79	0.9104	1.7396	1.297	0.823	1.159
– 16.00	0.15728	1345.9	0.12551	178.83	389.02	0.9205	1.7379	1.302	0.831	1.161
– 14.00	0.17082	1339.7	0.11605	181.44	390.24	0.9306	1.7363	1.306	0.838	1.163
– 12.00	0.18524	1333.4	0.10744	184.07	391.46	0.9407	1.7348	1.311	0.846	1.165
– 10.00	0.20060	1327.1	0.09959	186.70	392.66	0.9506	1.7334	1.316	0.854	1.167
– 8.00	0.21693	1320.8	0.09242	189.34	393.87	0.9606	1.7320	1.320	0.863	1.169
– 6.00	0.23428	1314.3	0.08587	191.99	395.06	0.9705	1.7307	1.325	0.871	1.171
– 4.00	0.25268	1307.9	0.07987	194.65	396.25	0.9804	1.7294	1.330	0.880	1.174
– 2.00	0.27217	1301.4	0.07436	197.32	397.43	0.9902	1.7282	1.336	0.888	1.176
0.00	0.29280	1294.8	0.06931	200.00	398.60	1.0000	1.7271	1.341	0.897	1.179
2.00	0.31462	1288.1	0.06466	202.69	399.77	1.0098	1.7260	1.347	0.906	1.182
4.00	0.33766	1281.4	0.06039	205.40	400.92	1.0195	1.7250	1.352	0.916	1.185
6.00	0.36198	1274.7	0.05644	208.11	402.06	1.0292	1.7240	1.358	0.925	1.189
8.00	0.38761	1267.9	0.05280	210.84	403.20	1.0388	1.7230	1.364	0.935	1.192
10.00	0.41461	1261.0	0.04944	213.58	404.32	1.0485	1.7221	1.370	0.945	1.196
12.00	0.44301	1254.0	0.04633	216.33	405.43	1.0581	1.7212	1.377	0.956	1.200
14.00	0.47288	1246.9	0.04345	219.09	406.53	1.0677	1.7204	1.383	0.967	1.204
16.00	0.50425	1239.8	0.04078	221.87	407.61	1.0772	1.7196	1.390	0.978	1.209
18.00	0.53718	1232.6	0.03830	224.66	408.69	1.0867	1.7188	1.397	0.989	1.214
20.00	0.57171	1225.3	0.03600	227.47	409.75	1.0962	1.7180	1.405	1.001	1.219
22.00	0.60789	1218.0	0.03385	230.29	410.79	1.1057	1.7173	1.413	1.013	1.224
24.00	0.64578	1210.5	0.03186	233.12	411.82	1.1152	1.7166	1.421	1.025	1.230

(Contd.)

Temp. °C	Pressure MPa	Density kg/m^3 Liquid	Volume m^3/kg Vapour	Enthalpy kJ/kg		Entropy kJ(kg. K)		Specific Heat c_p, kJ/(kg. K)		c_p/c_v Vapour
				Liquid	Vapour	Liquid	Vapour	Liquid	Vapour	
26.00	0.68543	1202.9	0.03000	235.97	412.84	1.1246	1.7159	1.429	1.038	1.236
28.00	0.72688	1195.2	0.02826	238.84	413.84	1.1341	1.7152	1.437	1.052	1.243
30.00	0.77020	1187.5	0.02664	241.72	414.82	1.1435	1.7145	1.446	1.065	1.249
32.00	0.81543	1179.6	0.02513	244.62	415.78	1.1529	1.7138	1.456	1.080	1.257
34.00	0.86263	1171.6	0.02371	247.54	416.72	1.1623	1.7131	1.466	1.095	1.265
36.00	0.91185	1163.4	0.02238	250.48	417.65	1.1717	1.7124	1.476	1.111	1.273
38.00	0.96315	1155.1	0.02113	253.43	418.55	1.1811	1.7118	1.487	1.127	1.282
40.00	1.0166	1146.7	0.01997	256.41	419.43	1.1905	1.7111	1.498	1.145	1.292
42.00	1.0722	1138.2	0.01887	259.41	420.28	1.1999	1.7103	1.510	1.163	1.303
44.00	1.1301	1129.5	0.01784	262.43	421.11	1.2092	1.7096	1.523	1.182	1.314
46.00	1.1903	1120.6	0.01687	265.47	421.92	1.2186	1.7089	1.537	1.202	1.326
48.00	1.2529	1111.5	0.01595	268.53	422.69	1.2280	1.7081	1.551	1.223	1.339
50.00	1.3179	1102.3	0.01509	271.62	423.44	1.2375	1.7072	1.566	1.246	1.354
52.00	1.3854	1092.9	0.01428	274.74	424.15	1.2469	1.7064	1.582	1.270	1.369
54.00	1.4555	1083.2	0.01351	277.89	424.83	1.2563	1.7055	1.600	1.296	1.386
56.00	1.5282	1073.4	0.01278	281.06	425.47	1.2658	1.7045	1.618	1.324	1.405
58.00	1.6036	1063.2	0.01209	284.27	426.07	1.2753	1.7035	1.638	1.354	1.425
60.00	1.6818	1052.9	0.01144	287.50	426.63	1.2848	1.7024	1.660	1.387	1.448
62.00	1.7628	1042.2	0.01083	290.78	427.14	1.2944	1.7013	1.684	1.422	1.473
64.00	1.8467	1031.2	0.01024	294.09	427.61	1.3040	1.7000	1.710	1.461	1.501
66.00	1.9337	1020.0	0.00969	297.44	428.02	1.3137	1.6987	1.738	1.504	1.532
68.00	2.0237	1008.3	0.00916	300.84	428.36	1.3234	1.6972	1.769	1.552	1.567
70.00	2.1168	996.2	0.00865	304.28	428.65	1.3332	1.6956	1.804	1.605	1.607
72.00	2.2132	983.8	0.00817	307.78	428.86	1.3430	1.6939	1.843	1.665	1.653
74.00	2.3130	970.8	0.00771	311.33	429.00	1.3530	1.6920	1.887	1.734	1.705
76.00	2.4161	957.3	0.00727	314.94	429.04	1.3631	1.6899	1.938	1.812	1.766
78.00	2.5228	943.1	0.00685	318.63	428.98	1.3733	1.6876	1.996	1.904	1.838
80.00	2.6332	928.2	0.00645	322.39	428.81	1.3836	1.6850	2.065	2.012	1.924
85.00	2.9258	887.2	0.00550	332.22	427.76	1.4104	1.6771	2.306	2.397	2.232
90.00	3.2442	837.8	0.00461	342.93	425.42	1.4390	1.6662	2.756	3.121	2.820
95.00	3.5912	772.7	0.00374	355.25	420.67	1.4715	1.6492	3.938	5.020	4.369
100.00	3.9724	651.2	0.0268	373.30	407.68	1.5188	1.6109	17.59	25.35	20.81
101.06[c]	4.0593	511.9	0.00195	389.64	389.64	1.5621	1.5621	∞	∞	∞

[a]Triple point [b]NBP [c]Critical point

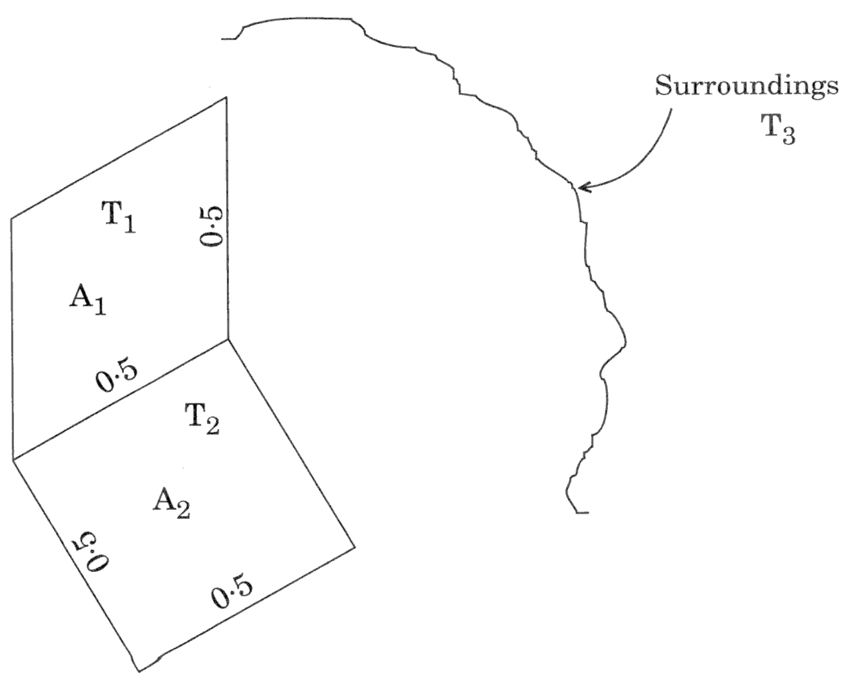
* Ashrae Handbook Fundamentals, 2005.

(b) A simple jet carburettor is required to supply 6 kg of air per minute and 0·45 kg of fuel of density 740 kg/m^3. The air is initially at 1·01325 bar and 27°C. Calculate the throat diameter of the choke for a flow velocity of 92 m/s. Velocity coefficient is 0·81.

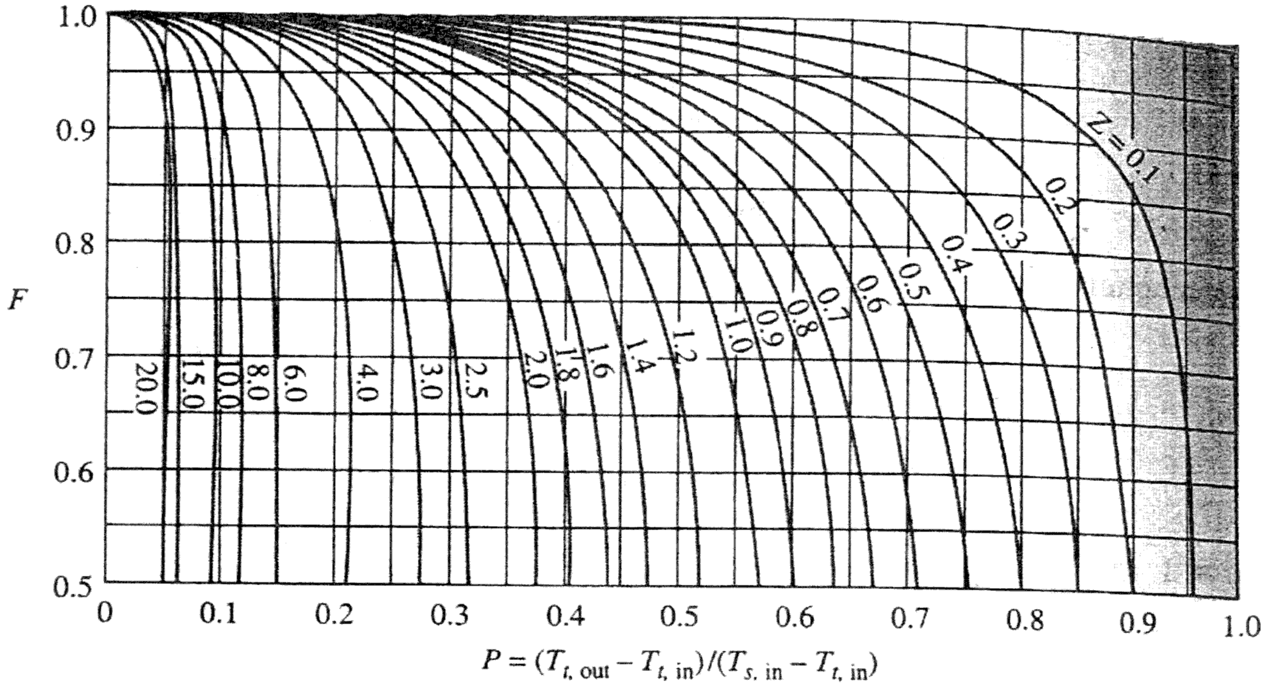
If the pressure drop across the fuel metering orifice is 0·75 of that of the choke, calculate orifice diameter assuming coefficient of discharge is 0·6. Take for air specific heat at constant pressure as 1000 J/kg K and isentropic index as 1·4. *15*

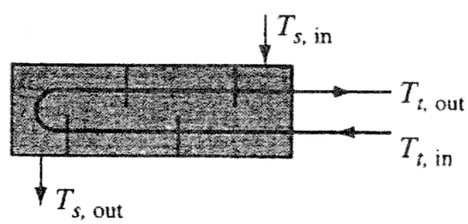
(c) Show that by Reynolds analogy for turbulent flow through a tube $St_d = \frac{f}{8}$ where f is the friction factor. *10*

Q7. (a) Two square gray surfaces are oriented as shown in the figure. Surface A_1 is to be maintained at 400°C and surface A_2 at 800°C in a large surrounding whose walls are at 30°C. The surface properties are $t_1 = 0·5$ and $t_2 = 0·3$. Determine the energy supply requirements to maintain the surfaces at the given temperatures. Assume $F_{12} = F_{21} = 0·28$. Draw the equivalent network for radiation. *20*



(b) Oil is used to heat water in a 1 – 2 heat exchanger (1 shell pass and 2 tube passes). Oil enters the tube at 240°C with a mass flow rate of 7 kg/sec. The heat exchanger is to be designed so that the water leaves the heat exchanger with a minimum temperature of 80°C. The flow rate of water is 10 kg/sec and it enters the heat exchanger at 20°C. Assuming an overall heat transfer coefficient of 525 W/m^{2}K, determine heat transfer surface area required to achieve the outlet temperature of 80°C. Assume C_p of oil = 2·1 kJ/kg K. *10*





Correction factor to counterflow LMTD for heat exchanger with one shell pass and two (or a multiple of two) tube passes.

(c) The following observations were made during a test on an oil engine : Brake power is 30 kW, fuel consumed is 10 kg/hr with calorific value of 42,000 kJ/kg. The mass flow rate of water circulated in water jacket is 9 kg/min. The rise in cooling water temperature is 60°C.

The exhaust gases are passed through an exhaust gas calorimeter for determining the heat carried away by exhaust gases. The calorimeter detail are as follows : water circulated through the calorimeter is 9·5 kg/min and the rise in temperature is 40°C. The exhaust gases leave the calorimeter at 80°C. Air/fuel ratio on mass basis is 20 and the ambient temperature is 17°C. Mean specific heat of exhaust gases is 1 kJ/kg K and specific heat of water is 4·18 kJ/kg K. Draw the heat balance on kJ/min and percentage basis. *10*

Q8. (a) A spark ignition engine fuel has a composition of 86% carbon and 14% hydrogen by weight. The engine is supplied with a fuel having equivalence ratio of 1·20. Assume that all hydrogen is burnt and that the carbon burns to carbon monoxide and carbon dioxide so that there is no free carbon left. Calculate the percentage analysis of dry exhaust gases by volume. *15*

(b) A bootstrap air refrigeration system is used for an aeroplane to take 10 TR load when it is flying at an altitude of 2000 m. The ambient air conditions are 0·8 bar and 15°C. The air is rammed isentropically from 0·8 bar to 1·05 bar. The pressure of air after isentropic compression in the main compressor is 3·5 bar and this is further compressed in a secondary compressor to a pressure of 4·5 bar. The isentropic efficiencies of both the compressors are 90% and that of cooling turbine is 85%. The effectiveness of both the heat exchangers is 0·6. If the cabin is to be maintained at 20°C and the pressure in the cabin is 0·9 bar, find

(i) Mass of air passing through the cabin

(ii) Power used for the refrigeration system

(iii) COP of the system

Draw a neat sketch of the system and show the processes on T-s diagram. Take $C_p = 1$ kJ/kg K. *15*

(c) A horizontal cylinder of 50 cm length and 3 cm diameter is suspended in water at 20°C. Calculate the rate of heat transfer if the surface temperature of the cylinder is maintained at 55°C. Also, determine the rate of heat transfer if the same cylinder is kept horizontally in a bath of light oil at 55°C. *10*

Use the following properties :

	Water	Oil
ρ (kg/m^3)	992	905
μ (kg/m hr)	2·47	82·0
k (W/mK)	0·622	0·133
β (K^{-1})	$3{\cdot}96 \times 10^{-4}$	$7{\cdot}2 \times 10^{-4}$
Pr	4·64	324

Use the following table :

R_{a_D}	C	n
$10^{-10} - 10^{-2}$	0·675	0·058
$10^{-2} - 10^{2}$	1·02	0·148
$10^{2} - 10^{4}$	0·85	0·188
$10^{4} - 10^{7}$	0·48	0·25
$10^{7} - 10^{12}$	0·125	0·333