BENGAL ENGINEERING AND SCIENCE UNIVERSITY, SHIBPUR
B.E. 3RD SEMESTER (AE) FINAL EXAMINATIONS, 2012
Fundamentals of Engineering Thermodynamics (AE 303)

Time: 3 hrs Full Marks: 70

(i) **Do not** write anything on this question paper

First Half

Attempt question No. 1 and any two from the rest

1. Fill in the blanks: **9**
a) Even though air is a mixture of gases, it is considered a ________________ as long as there is no ________________.
b) ____________ and ____________ of an ideal gas are functions of ____________ only.
c) Generally speaking, in a ______________ throttling process, ______________ remains constant but ______________ drops abruptly.
d) At the ________________ the saturated-liquid and saturated-vapor states are identical.

2. A cylinder fitted with a piston restrained by a linear spring (spring constant 5 kN/m) contains 2 kg of water at 400 kPa, 700°C, as shown in Fig. 1. Heat is now transferred from the water to the surroundings until a final pressure of 150 kPa is reached. If the piston cross-sectional area is 0.1 m^2, determine the final state of water and the heat transfer for the process. **13**

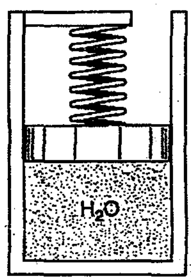

Fig 1

3. Air enters a compressor operating at steady state at a pressure of 1 bar, a temperature of 290 K and a velocity of 6 m/s through an inlet area of 0.1 m^2. At the exit the pressure is 7 bar, temperature is 450 K and velocity is 2 m/s. Heat transfer from the compressor to the surroundings occurs at a rate of 180 kJ/min. Employing the ideal gas model calculate the power input to the compressor in kW and the exit area in m^2. For air, take $R = 287$ J/kg.K and $C_p = R\left[3.653 - 1.337\times10^{-3}T + 3.294\times10^{-6}T^2 - 1.913\times10^{-9}T^3 + 0.276\times10^{-12}T^4\right]$. **13**

4. A 1 m^3 rigid steel tank contains air at 5 bar, and both tank and air are at 20° C, initially. The tank is connected to a large supply line carrying air at 20° C, 20 bar, by a valve. The valve is opened, allowing air to flow into the tank until the pressure reaches 15 bar, and is then closed. The steel tank, which has a mass of 40 kg, is always at the same temperature as the air in the tank. Final temperature of the tank and the air in the tank is 35° C. The specific heat of the steel is $c = 460$ J/kg.K. Assuming constant specific heats for air, determine (a) the initial and final mass of air within the tank, and (b) the heat transfer to the surroundings from the tank and its contents, ignoring kinetic and potential energy effects. For air, take $R = 287$ J/kg.K, $C_v = 716.5$ J/kg.K, $C_p = 1003.5$ J/kg.K. **13**

Saturated water: Pressure table

P bar	T °C	Spec. vol. m^3/kg Sat. liq. v_f X1000	Spec. vol. m^3/kg Sat. vap. v_g	Int. Energy kJ/kg Sat. liq. u_f	Int. Energy kJ/kg Sat. vap. u_g	Enthalpy kJ/kg Sat. liq. h_f	Enthalpy kJ/kg Sat. vap. h_g
0.04	28.96	1.004	34.80	121.4	2415	121.4	2554
0.06	36.15	1.006	23.75	151.5	2425	151.5	2567
0.08	41.5	1.008	18.11	173.8	2432	173.8	2577
0.1	45.8	1.010	14.68	191.8	2438	191.8	2585
0.2	60.07	1.017	7.649	251.4	2457	251.4	2610
0.3	69.11	1.023	5.229	289.2	2468	289.2	2625
0.4	75.87	1.026	3.994	317.5	2477	317.6	2637
0.5	81.33	1.030	3.240	340.4	2484	340.5	2646
0.6	85.94	1.033	2.732	359.8	2490	359.9	2653
0.7	89.95	1.036	2.365	376.6	2494	376.7	2660
0.8	93.5	1.039	2.087	391.6	2499	391.7	2666
0.9	96.71	1.041	1.870	405.1	2503	405.1	2671
1	99.62	1.043	1.694	417.3	2506	417.4	2675
1.5	111.4	1.053	1.159	466.9	2520	467.1	2694
2	120.2	1.061	0.886	504.5	2530	504.7	2707
3	133.6	1.073	0.606	561.1	2544	561.5	2725
4	143.6	1.084	0.463	604.3	2554	604.8	2739

Superheated steam table (S.I units)

Pressure MPa (Sat. T)		Temperature—Degrees Celsius 150	200	250	300	350	400	450	500	550	600	700
0.30	*v*	0.6340	0.7164	0.7965	0.8753	0.9536	1.0315	1.1092	1.1867	1.2641	1.3414	1.4958
(133.53)	*h*	2761.2	2866.0	2967.9	3069.6	3172.0	3275.4	3380.2	3486.6	3594.5	3704.0	3928.2
	s	7.0791	7.3132	7.5181	7.7037	7.8749	8.0346	8.1848	8.3269	8.4622	8.5914	8.8344
0.35	*v*	0.5408	0.6124	0.6815	0.7494	0.8167	0.8836	0.9503	1.0168	1.0832	1.1495	1.2819
(138.86)	*h*	2757.1	2863.5	2966.3	3068.4	3171.0	3274.6	3379.6	3486.0	3594.0	3703.6	3927.9
	s	7.0002	7.2381	7.4445	7.6310	7.8026	7.9626	8.1130	8.2553	8.3906	8.5199	8.7630
0.40	*v*	0.4709	0.5343	0.5952	0.6549	0.7139	0.7726	0.8311	0.8894	0.9475	1.0056	1.1215
(143.61)	*h*	2752.8	2861.0	2964.6	3067.1	3170.0	3273.9	3379.0	3485.5	3593.6	3703.2	3927.6
	s	6.9305	7.1724	7.3805	7.5677	7.7398	7.9001	8.0507	8.1931	8.3286	8.4579	8.7012
0.45	*v*	0.4164	0.4736	0.5281	0.5814	0.6341	0.6863	0.7384	0.7902	0.8420	0.8936	0.9968
(147.91)	*h*	2748.3	2858.5	2962.8	3065.9	3169.0	3273.1	3378.3	3484.9	3593.1	3702.8	3927.3
	s	6.8677	7.1139	7.3237	7.5117	7.6843	7.8449	7.9957	8.1383	8.2738	8.4032	8.6466

v = specific volume, m^3/kg *h* = enthalpy, kJ/kg *s* = entropy, kJ/(kg•K)

SECOND HALF

Answer Question 6 and any two from the remaining questions.

6. a) Show that entropy is a property of a system.
b) Establish the inequality of Clausius.
c) Insulated tank A shown in Fig. Q6(c) has a volume of 0.6 m^3 and is initially filled with steam at 1.4 MPa, 300°C. Tank B is uninsulated, has A volume of 0.3 m^3 and is initially filled with steam at 0.2 MPa, 200°C. A valve interconnecting the two tanks is then opened and steam flows from A to B until the temperature in A is , 250°C, at which time the valve is closed. During this time, heat is transferred from B to the surroundings at 25°C such that the temperature in B remains at 200°C. It may be assumed that the steam remaining in A has undergone a reversible adiabatic process. Determine i) the final pressure in each of the tanks, ii) the final mass in B, and iii) the net entropy change for the process (system plus surroundings).
See table 6C for required data. (2+4+7)

7. a) Give the Kelvin-Planck statement and the Clausius statement of the second law of thermodynamics.
b) A reversible engine works between three reservoirs A, B and C. The engine absorbs an equal amount of heat from the thermal reservoirs A and B kept at temperatures T_A and T_B respectively, and rejects heat to the thermal reservoir C kept at temperature T_C. The efficiency of the engine is α times the efficiency of the reversible engine, which works between the two reservoirs A and C.
Prove that $\frac{T_A}{T_B} = (2\alpha - 1) + 2(1-\alpha)\frac{T_A}{T_C}$. (4+7)

8. a) Prove that the violation of the Clausius statement implies the violation of the Kelvin-Planck statement of the second law of thermodynamics.
b) A reversible power cycle is used to drive a reversible heat pump cycle. The power cycle takes in Q_1 heat units at T_1 and rejects Q_2 at T_2. The heat pump abstracts Q_4 from the sink at T_4 and discharges Q_3 at T_3. Develop an expression for the ratio Q_4/Q_1 in terms of the four temperatures.
(4+7)

9. a) Air flows at 1500 K and 100 kPa through a constant-pressure heat exchanger giving energy to a heat engine and comes out at 500 K. At what constant temperature should the same heat transfer be delivered to provide the same availability?
b) Air enters the turbocharger compressor (Fig. Q9(b)) of an automotive engine at 100 kPa, 30°C and exits at 170 kPa. The air is cooled by 50°C in an intercooler before entering the engine. The isentropic efficiency of the compressor is 75%. Determine the temperature of the air entering the engine and the irreversibility of the compressor-cooling system. (5+6)

10. a) For the same maximum pressure and temperature of the cycle and the same heat rejection, show that $\eta_{Diesel} > \eta_{Dual} > \eta_{Otto}$.

b) Show that the air standard efficiency for a cycle comprising two constant pressure processes and two isothermal processes (all reversible) is given by $\eta = \frac{(T_1 - T_2)\ln(r_p)^{(\gamma-1)/\gamma}}{T_1[1+\ln(r_p)^{(\gamma-1)\gamma}]-T_2}$ where T_1 and T_2 are the maximum and minimum temperatures of the cycle respectively, and r_p is the pressure ratio. (4+7)

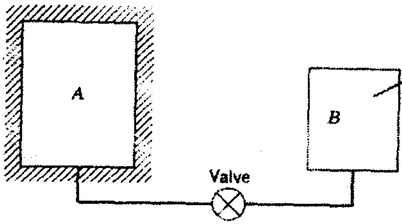

Fig. Q6(c)

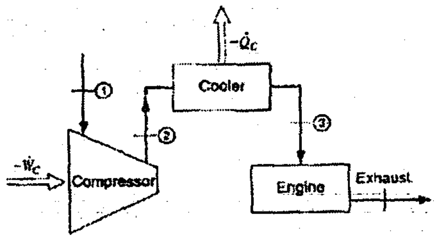

Fig. Q9(b)

Table 6C
Superheated Vapour

t °C	v m³/kg	h kJ/kg	s kJ/kg K
	p = .20 MPa (120.23)		
Sat	0.8857	2706.7	7.1272
150	0.9596	2768.8	7.2795
200	1.0803	2870.5	7.5066
250	1.1988	2971.0	7.7086
300	1.3162	3071.8	7.8926
400	1.5493	3276.6	8.2218
500	1.7814	3487.1	8.5133
600	2.013	3704.0	8.770
700	2.244	3927.6	9.0194
800	2.475	4158.2	9.2449

t(°C)	v m3/kg	h kJ/kg	s kJ/kg K	v m/kg	h kJ kg	s kJ kg K
	p = .60 MPa (158.85)			p = 0.80 MPa (170.43)		
Sat.	0.3157	2756.8	6.7600	0.2404	2769.1	6.6628
200	0.3520	2850.1	6.9665	0.2608	2839.3	6.8158
250	0.3938	2957.2	7.1816	0.2931	2950.0	7.0384
300	0.4344	3061.6	7.3724	0.3241	3056.5	7.2328
350	0.4742	3165.7	7.5464	0.3544	3161.7	7.4089
400	0.5137	3270.3	7.7079	0.3843	3267.1	7.5716
500	0.5920	3482.8	8.0021	0.4433	3480.6	7.8673
600	0.6697	3700.9	8.2674	0.5018	3699.4	8.1333
700	0.7472	3925.3	8.5107	0.5601	3924.2	8.3770
800	0.8245	4156.5	8.7367	0.6181	4155.6	8.6033

t °C	v	h	s	v	h	s	v	h	s
	p = 1.00 MPa (179.91)			p = 1.20 MPa (187.99)			p = 1.40 MPa (195.07)		
Sat	0.19444	2778.1	6.5865	0.16333	2784.8	6.5233	0.14084	2790.0	6.4693
200	0.2060	2827.9	6.6940	0.16930	2815.9	6.5898	0.14302	2803.3	6.4975
250	0.2327	2942.6	6.9247	0.19234	2935.0	6.8294	0.16350	2927.2	6.7467
300	0.2579	3051.2	7.1229	0.2138	3045.8	7.0317	0.18228	3040.4	6.9534
350	0.2825	3157.7	7.3011	0.2345	3153.6	7.2121	0.2003	3149.5	7.1360
400	0.3066	3263.9	7.4651	0.2548	3260.7	7.3774	0.2178	3257.5	7.3026
500	0.3541	3478.5	7.7622	0.2946	3476.3	7.6759	0.2521	3474.1	7.6027
600	0.4011	3697.9	8.0290	0.3339	3696.3	7.9435	0.2860	3694.8	7.8710
700	0.4478	3929.1	8.2731	0.3729	3922.0	8.1881	0.3195	3920.8	8.1160
800	0.4943	4154.7	8.4996	0.4118	4153.8	8.4148	0.3528	4153.0	8.3431