MEL703 Advanced Thermodynamics

Major Test

(Open Notes only: photocopies of notes and books not permitted)

Max. Marks: 60 November 24, 2008

Duration: 2 hrs

1. Consider an electric "instant" water heater operating in a steady-state steady flow process. It takes an electrical input of 2 kW, and water flows through it at a steady rate of 0.5 litre/minute, entering at 10°C and leaving at 60°C. The outer surface of the heater vessel can be taken to be at 30°C for heat loss, and ambient temperature is 10°C. Calculate the exergetic efficiency of the heater. If the overall efficiency of generation and trasmission is 0.3 kW of electricity for every kW of fuel input, compare this heater with a gas-fired heater where the 2 kW heat input is given from a burner of overall efficiency 0.8 from fuel to heat. Which is a better efficient device in terms of kW of fuel per unit exergy rise of water? Take specific heat of water to be 4.2 kJ/kg K. (15)

2. 1 kmol of CO_2 is kept in a vessel at a constant pressure and temperature of 5 bar and 2800 K. The carbon dioxide dissociates according to the reversible reaction

$$CO_2 \Leftrightarrow CO + \tfrac{1}{2} O_2$$

and reaches equilibrium corresponding to the temperature and pressure of the vessel. Using the Gibbs function of formation $g_f^o(T)$ (kJ/kmol) data given in the table below, compute the fraction of CO_2 that would have dissociated.

	Mol. Wt	2500 K	2700 K	2900 K
CO_2	44.011	-396152	-395957	-395708
CO	28.01	-327245	-343519	-359661
O_2	31.999	0	0	0

Assume all the species to behave as ideal gases. $\mathbb{R}$= 8.314 kJ/kmol K. Suppose the reaction given above is written with reactants and products interchanged, i.e.,

$$CO + \tfrac{1}{2} O_2 \Leftrightarrow CO_2$$

what would be the relation of the new equilibrium constant with the one you calculated for the original reaction? Explain. (20)

3. Liquid water containing 5% ammonia by volume is kept in a closed vessel at a constant pressure of 1 bar and 50°C, and allowed to attain phase equilibrium. If the liquid phase can be assumed to be an ideal solution and vapour phase behaves as ideal gas, compute the mole fractions of water and ammonia in the two phases. (10)

4. Natural gas, containing 90% methane and 10% ethane by volume is filled in an evacuated rigid adiabatic cylinder to 200 bar from a line at 300 bar, 20°C. Find the final temperature of the gas in the cylinder. Use Kay's rule to treat natural gas as a pseudo-pure substance, with generalized charts. Use the data in the table below and charts provided with the paper. (15)

	Molecular Weight	Specific Heat (kJ/kmol K)	Critical Temperature (K)	Critical Pressure (bar)
Methane	16.043	36.156	191.1	46.4
Ethane	30.07	53.11	305.5	44.8

Table A.1 | Saturated water—Temperature table

Temp., T °C	Sat. press., P_{sat} kPa	Specific volume, m³/kg: Sat. liquid, v_f	Sat. vapor, v_g	Internal energy, kJ/kg: Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Enthalpy, kJ/kg: Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Entropy, kJ/kg.K: Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6113	0.001000	206.14	0.0	2375.3	2375.3	0.01	2501.3	2501.4	0.000	9.1562	9.1562
5	0.8721	0.001000	147.12	20.97	2361.3	2382.3	20.98	2489.6	2510.6	0.0761	8.9496	9.0257
10	1.2276	0.001000	106.38	42.00	2347.2	2389.2	42.01	2477.7	2519.8	0.1510	8.7498	8.9008
15	1.7051	0.001001	77.93	62.99	2333.1	2396.1	62.99	2465.9	2528.9	0.2245	8.5569	8.7814
20	2.339	0.001002	57.79	83.95	2319.0	2402.9	83.96	2454.1	2538.1	0.2966	8.3706	8.6672
25	3.169	0.001003	43.36	104.88	2304.9	2409.8	104.89	2442.3	2547.2	0.3674	8.1905	8.5580
30	4.246	0.001004	32.89	125.78	2290.8	2416.6	125.79	2430.5	2556.3	0.4369	8.0164	8.4533
35	5.628	0.001006	25.22	146.67	2276.7	2423.4	146.68	2418.6	2565.3	0.5053	7.8478	8.3531
40	7.384	0.001008	19.52	167.56	2262.6	2430.1	167.57	2406.7	2574.3	0.5725	7.6845	8.2570
45	9.593	0.001010	15.26	188.44	2248.4	2436.8	188.45	2394.8	2583.2	0.6387	7.5261	8.1648
50	12.349	0.001012	12.03	209.32	2234.2	2443.5	209.33	2382.7	2592.1	0.7038	7.3725	8.0763
55	15.758	0.001015	9.568	230.21	2219.9	2450.1	230.23	2370.7	2600.9	0.7679	7.2234	7.9913
60	19.940	0.001017	7.671	251.11	2205.5	2456.6	251.13	2358.5	2609.6	0.8312	7.0784	7.9096
65	25.03	0.001020	6.197	272.02	2191.1	2463.1	272.06	2346.2	2618.3	0.8935	6.9375	7.8310
70	31.19	0.001023	5.042	292.95	2176.6	2469.6	292.98	2333.8	2626.8	0.9549	6.8004	7.7553
75	38.58	0.001026	4.131	313.90	2162.0	2475.9	313.93	2321.4	2635.3	1.0155	6.6669	7.6824
80	47.39	0.001029	3.407	334.86	2147.4	2482.2	334.91	2308.8	2643.7	1.0753	6.5369	7.6122
85	57.83	0.001033	2.828	355.84	2132.6	2488.4	355.90	2296.0	2651.9	1.1343	6.4102	7.5445
90	70.14	0.001036	2.361	376.85	2117.7	2494.5	376.92	2283.2	2660.1	1.1925	6.2866	7.4791
95	84.55	0.001040	1.982	397.88	2102.77	2500.6	397.96	2270.2	2668.1	1.2500	6.1659	7.4159

Table A.6 | SI Saturated Ammonia

urated Ammonia (*Concluded*)

Temp. C T	Press. kPa P	Specific Volume, m³/kg: Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapor v_g	Internal Energy, kJ/kg: Sat. Liquid u_f	Evap. u_{fg}	Sat. Vapor u_g	Enthalpy, kJ/kg: Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Entropy, kJ/kg K: Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapor s_g
−50	40.9	0.001424	2.62557	2.62700	−43.82	1309.1	1265.2	−43.76	1416.3	1372.6	−0.1916	6.3470	6.1554
−45	54.5	0.001437	2.00489	2.00632	−22.01	1293.5	1271.4	−21.94	1402.8	1380.8	−0.0950	6.1484	6.0534
−40	71.7	0.001450	1.55111	1.55256	−0.10	1277.6	1277.4	0	1388.8	1388.8	0	5.9567	5.9567
−35	93.2	0.001463	1.21466	1.21613	21.93	1261.3	1283.3	22.06	1374.5	1396.5	0.0935	5.7715	5.8650
−30	119.5	0.001476	0.96192	0.96339	44.08	1244.8	1288.9	44.26	1359.8	1404.0	0.1856	5.5922	5.7778
−25	151.6	0.001490	0.76970	0.77119	66.36	1227.9	1294.3	66.58	1344.6	1411.2	0.2763	5.4185	5.6947
−20	190.2	0.001504	0.62184	0.62334	88.76	1210.7	1299.5	89.05	1329.0	1418.0	0.3657	5.2498	5.6155
−15	236.3	0.001519	0.50686	0.50838	111.30	1193.2	1304.5	111.66	1312.9	1424.6	0.4538	5.0859	5.5397
−10	290.9	0.001534	0.41655	0.41808	133.96	1175.2	1309.2	134.41	1296.4	1430.8	0.5408	4.9265	5.4673
−5	354.9	0.001550	0.34493	0.34648	156.76	1157.0	1313.7	157.31	1279.4	1436.7	0.6266	4.7711	5.3977
0	429.6	0.001566	0.28763	0.28920	179.69	1138.3	1318.0	180.36	1261.8	1442.2	0.7114	4.6195	5.3309
5	515.9	0.001583	0.24140	0.24299	202.77	1119.2	1322.0	203.58	1243.7	1447.3	0.7951	4.4715	5.2666
10	615.2	0.001600	0.20381	0.20541	225.99	1099.7	1325.7	226.97	1225.1	1452.0	0.8779	4.3266	5.2045
15	728.6	0.001619	0.17300	0.17462	249.36	1079.7	1329.1	250.54	1205.8	1456.3	0.9598	4.1846	5.1444
20	857.5	0.001638	0.14758	0.14922	272.89	1059.3	1332.2	274.30	1185.9	1460.2	1.0408	4.0452	5.0860
25	1003.2	0.001658	0.12647	0.12813	296.59	1038.4	1335.0	298.25	1165.2	1463.5	1.1210	3.9083	5.0293
30	1167.0	0.001680	0.10881	0.11049	320.46	1016.9	1337.4	322.42	1143.9	1466.3	1.2005	3.7734	4.9738
35	1350.4	0.001702	0.09397	0.09567	344.50	994.9	1339.4	346.80	1121.8	1468.6	1.2792	3.6403	4.9196
40	1554.9	0.001725	0.08141	0.08313	368.74	972.2	1341.0	371.43	1098.8	1470.2	1.3574	3.5088	4.8662
45	1782.0	0.001750	0.07073	0.07248	393.19	948.9	1342.1	396.31	1074.9	1471.2	1.4350	3.3786	4.8136
50	2033.1	0.001777	0.06159	0.06337	417.87	924.8	1342.7	421.48	1050.0	1471.5	1.5121	3.2493	4.7614
55	2310.1	0.001804	0.05375	0.05555	442.79	899.9	1342.7	446.96	1024.1	1471.0	1.5888	3.1208	4.7095
60	2614.4	0.001834	0.04697	0.04880	467.99	874.2	1342.1	472.79	997.0	1469.7	1.6652	2.9925	4.6577
65	2947.8	0.001866	0.04109	0.04296	493.51	847.4	1340.9	499.01	968.5	1467.5	1.7415	2.8642	4.6057
70	3312.0	0.001900	0.03597	0.03787	519.39	819.5	1338.9	525.69	938.7	1464.4	1.8178	2.7354	4.5533
75	3709 0	0.001937	0.03148	0.03341	545.70	790.4	1336.1	552.88	907.2	1460.1	1.8943	2.6058	4.5001
80	4140.5	0.001978	0.02753	0.02951	572.50	759.9	1332.4	580.69	873.9	1454.6	1.9712	2.4746	4.4458
85	4608.6	0.002022	0.02404	0.02606	599.90	727.8	1327.7	609.21	838.6	1447.8	2.0488	2.3413	4.3901
90	5115.3	0.002071	0.02093	0.02300	627.99	693.7	1321.7	638.59	800.8	1439.4	2.1273	2.2051	4.3325
95	5662.9	0.002126	0.01815	0.02028	656.95	657.4	1314.4	668.99	760.2	1429.2	2.2073	2.0650	4.2723
100	6253.7	0.002188	0.01565	0.01784	686.96	618.4	1305.3	700.64	716.2	1416.9	2.2893	1.9195	4.2088
105	6890.4	0.002261	0.01337	0.01564	718.30	575.9	1294.2	733.87	668.1	1402.0	2.3740	1.7667	4.1407
110	7575.7	0.002347	0.01128	0.01363	751.37	529.1	1280.5	769.15	614.6	1383.7	2.4625	1.6040	4.0665
115	8313.3	0.002452	0.00933	0.01178	786.82	476.2	1263.1	807.21	553.8	1361.0	2.5566	1.4267	3.9833
120	9107.2	0.002589	0.00744	0.01003	825.77	414.5	1240.3	849.36	482.3	1331.7	2.6593	1.2268	3.8861
125	9963.5	0.002783	0.00554	0.00833	870.69	337.7	1208.4	898.42	393.0	1291.4	2.7775	0.9870	3.7645
130	10891.6	0.003122	0.00337	0.00649	929.29	226.9	1156.2	963.29	263.7	1227.0	2.9326	0.6540	3.5866
132.3	11333.2	0.004255	0	0.00426	1037.62	0	1037.6	1085.85	0	1085.9	3.2316	0	3.2316