Indian Institute of Technology Kharagpur
Department of Chemical Engineering
Mid Semester Examination, Autumn 2015
Subject: Chemical Process Calculations (CH21103)

Sept 14, 2015
Time: 2 Hrs
Full Marks: 30
No. of Students: 127

Instructions: Closed book, closed notes examination. Answer all questions. Use a single answer book for both the parts. All questions of a part must be answered together. Assume any missing data suitably. State all assumptions clearly and explicitly. If there is any correction to the question, that will be announced in due time. No question/clarification will be entertained during the examination. **Required pages of steam table is attached. No additional table/chart is required.**

Part A

1. (3 marks) Heat capacity of a certain substance is given by:

$$C_p \left(\frac{\text{Btu}}{\text{lb}_m\,^\circ\text{F}} \right) = 0.487 + 2.29 \times 10^{-4} (^\circ\text{F}).$$

Determine the expression for C_p in J/(g. $^\circ$C).

2. (3 marks) An incline manometer is a device used for measuring small pressure difference. As shown in the figure below, the small pressure difference between two points which would otherwise result in a very small height difference will result in a measurable length difference if inclined to a sufficiently small angle. If the manometer fluid is water and the process fluid is
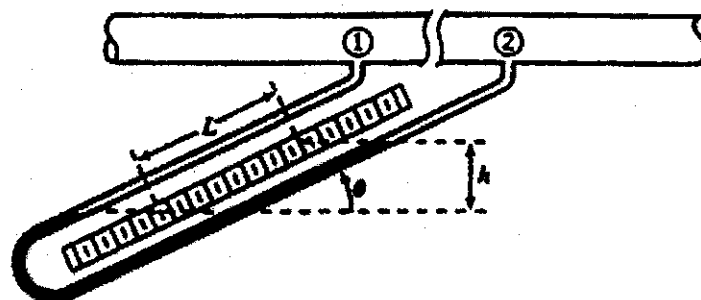
air, and the tilt angle (θ) is 15°, and the reading L = 9 cm, what is the pressure difference between point 1 and 2 in psia?

3. (4 marks) An aqueous solution containing 35% Na_2CO_3 weighs 5000 lb.

   (a) (2 marks) To what temperature the solution must be cooled to recover 98% of the Na_2CO_3?

   (b) (2 marks) What will be the weight of the crystal recovered and to the residual mother liquor?

   Data: Na_2CO_3 crystallizes as decahydrate and the solubility is given by:

Temperature ($^\circ$C)	Solubility (g Na_2CO_3/100 g solution)
0	7
10	11
20	18
30	28

4. (5 marks) The reaction between ethylene (C_2H_4) and hydrogen bromide to form ethylene bromide is carried out in a continuous reactor. The product stream is analyzed and found to contain 51.7 mol % C_2H_5Br and 17.3% HBr. The feed to the reactor contains only ethylene and hydrogen bromide. Calculate:

(a) (2 marks) The fractional conversion of the limiting reactant.

(b) (2 marks) Percent excess of the other reactant used.

(c) (1 mark) If the molar flow rate of the feed stream is 165 mol/s what is the extent of reaction?

Part B

5. (a) (2 marks) Can a nuclear reaction be explained by First Law of Thermodynamics? Justify.

(b) (2 marks) Suppose you are told to write the Energy Balance of a Plug Flow Reactor (PFR), what modification would you need to incorporate in the classical form of First Law of Thermodynamics? (For the time being, neglect the effect of heat of reaction).

(c) (1 mark) Why heat of vaporization is much higher that heat of fusion?

(d) (2 marks) What is enthalpy? Qualitatively discuss a system that is better described by enthalpy than internal energy.

(e) (1 mark) What is a Stokesian Fluid?

6. 3.05 kg of steam initially at 3.5 MPa ($\tilde{V}= 0.09557$ m3/kg, $\tilde{V}$ is specific volume) is used for heating another liquid in a steam chest. After heating of the liquid is accomplished, the steam is found to be at a pressure of 1.5 MPa, T = 111.37 °C and $\tilde{V} = 1.0$ m^3/kg. Find out the following:

(a) (1 mark) What is the nature of steam and its initial temperature? 475

(b) (2 marks) What is the final nature of steam?

(c) (4 marks) How much liquid ($C_p = 1.3 + 0.0065T$, T in K) can be heated from 30°C to 51°C by the enthalpy that is lost by steam, considering there is a 10% heat loss to the surrounding.

Please use the attached steam table if necessary.

P = 1.6 MPa

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg K
sat	0.12380	2595.9	2794.0	6.4217
225	0.13957	2644.5	2857.2	6.5518
250	0.14194	2692.3	2919.9	6.6732
300	0.16662	2781.0	3034.8	6.8844
350	0.17456	2866.0	3145.4	7.0693
400	0.19005	2950.1	3254.9	7.2373
450	0.19005	3031.6	3471.0	7.5990
500	0.24098	3199.3	3593.3	7.8080
600	0.20690	3284.4	4189.1	7.5980
700	0.27037	3472.7	3919.7	8.0058
800	0.29678	3460.0	4520.8	8.6098
900	0.25773	3850.5	4300.8	8.4024
1000		4040.0	4935.8	8.6906
1100	0.30081	4283.7	4987.0	8.8897
1200	0.49488	4462.3	5143.9	9.0849
1300	0.46592	4670.0	5405.0	9.5964

P = 1.8 MPa

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg K
sat	0.11042	2598.4	2797.1	6.3793
225	0.11673	2636.6	2846.7	6.4807
250	0.12497	2686.0	2911.0	6.6066
300	0.14021	2776.8	3029.2	6.8226
350	0.15457	2862.9	3141.9	7.0100
400	0.16847	2947.7	3250.9	7.1794
450	0.18190	3031.8	3359.0	7.3323
500	0.19550	3117.8	3469.7	7.4834
600	0.27450	3289.1	3682.7	7.7523
700	0.24612	3469.2	3902.1	7.9983
800	0.28150	3657.7	4151.3	8.2218
900	0.30012	3849.9	4390.1	8.4296
1000	0.34598	4048.4	4656.9	8.6250
1100	0.36180	4251.8	4906.4	8.8350
1200	0.37761	4462.7	5143.4	8.8950
1300	0.40240	4670.4	5405.6	9.1817

P = 2 MPa

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg K
sat	0.09963	2600.3	2799.5	6.3408
225	0.10377	2628.3	2835.8	6.4146
250	0.11144	2679.6	2902.5	6.5452
300	0.12547	2772.6	3023.5	6.7663
350	0.13857	2859.8	3137.0	6.9562
400	0.15120	2945.2	3247.6	7.1270
450	0.17568	3116.2	3467.6	7.4316
500	0.19860	3290.9	3690.1	7.7023
600	0.27004	3657.0	4150.4	8.1766
700	0.20933	3471.0	3917.5	7.9487
800	0.25692	3850.9	4390.4	8.3895
900	0.30633	4047.0	4634.6	8.5900
1000	0.21690	4251.7	4895.0	8.7800
1100	0.33084	4462.9	5142.9	8.9606
1200	0.36306	4670.0	5405.1	9.1328

P = 2.5 MPa

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg K
sat	0.07998	2603.1	2803.1	6.2574
225	0.08027	2605.8	2806.3	6.2638
250	0.08700	2662.6	2880.1	6.4084
300	0.09890	2761.6	3008.8	6.6437
350	0.11076	2851.9	3126.3	6.8402
400	0.12010	2939.1	3239.3	7.0147
450	0.13010	3025.0	3350.8	7.0147
500	0.15014	3205.4	3580.3	7.1745
600	0.13608	3286.0	3686.8	7.5237
700	0.16930	3462.1	3911.7	7.5084
800	0.17832	3650.6	4125.5	7.5990
900	0.19014	3852.6	4320.3	7.8429
1000	0.21500	3596.3	4148.2	8.0790
1100	0.21716	3681.6	4346.5	8.1890
1200	0.22502	4040.7	4631.6	8.4009
1300	0.99046	4677.8	5402.8	8.9442

P = 3 MPa

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg K
sat	0.06668	2604.1	2804.1	6.1869
250	0.07058	2644.0	2855.8	6.2871
300	0.08114	2750.0	2993.5	6.5390
350	0.09053	2843.7	3115.3	6.7487
400	0.09936	2932.7	3230.8	6.9211
450	0.10787	3020.4	3344.0	7.0833
500	0.11619	3107.9	3456.5	7.2337
600	0.13243	3285.0	3682.3	7.5084
700	0.14838	3466.5	3911.7	7.7571
800	0.16439	3656.2	4148.0	7.7871
900	0.18143	3853.6	4396.0	7.9962
1000	0.17840	3466.5	4395.9	8.1990
1100	0.18541	4045.4	4631.6	8.4009
1200	0.21008	4250.3	4890.3	8.5911
1300	0.25902	4680.9	5402.8	8.7719

P = 3.5 MPa

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg K
sat	0.05707	2603.7	2803.4	6.1252
250	0.05873	2623.7	2829.2	6.1748
300	0.06842	2738.0	2977.5	6.4460
350	0.07678	2835.3	3104.0	6.6578
400	0.08453	2926.4	3222.2	6.8404
450	0.09196	3015.3	3337.2	7.0051
500	0.09918	3103.7	3450.9	7.1571
600	0.11324	3282.1	3678.4	7.4338
700	0.12690	3464.4	3908.8	7.6837
800	0.14056	3651.8	4143.8	7.9135
900	0.15408	3845.0	4394.1	8.1275
1000	0.16743	4044.1	4630.1	8.3268
1100	0.18080	4249.1	4881.9	8.5191
1200	0.19415	4459.8	5139.3	8.7000
1300	0.20740	4675.5	5401.7	8.8723

TABLE B.2 Saturated Water: Pressure Table

P, kPa, bar	T, °C	v_f, m³/kg	v_g, m³/kg	u_f, kJ/kg	u_{fg}, kJ/kg	u_g, kJ/kg	h_f, kJ/kg	h_{fg}, kJ/kg	h_g, kJ/kg	s_f, kJ/kg K	s_{fg}, kJ/kg K	s_g, kJ/kg K
0.6113	0.01	0.001000	206.132	0	2375.3	2375.3	0.00	2501.3	2501.3	0	9.1562	9.1562
1.0	6.98	0.001000	129.208	29.29	2355.7	2385.0	29.29	2484.9	2514.2	0.1059	8.8697	8.9757
1.5	13.03	0.001001	87.980	54.70	2338.6	2393.3	54.70	2470.6	2525.3	0.1956	8.6322	8.8278
2.0	17.50	0.001001	67.004	73.47	2326.0	2399.5	73.47	2460.0	2533.5	0.2607	8.4629	8.7236
2.5	21.08	0.001002	54.254	88.47	2315.9	2404.4	88.47	2451.6	2540.0	0.3120	8.3311	8.6431
3.0	24.08	0.001003	45.665	101.03	2307.5	2408.5	101.03	2444.5	2545.5	0.3545	8.2231	8.5775
4.0	28.96	0.001004	34.800	121.44	2293.7	2415.2	121.44	2432.9	2554.4	0.4226	8.0520	8.4746
5.0	32.88	0.001005	28.193	137.79	2282.7	2420.5	137.79	2423.7	2561.4	0.4763	7.9187	8.3950
7.5	40.29	0.001008	19.238	168.76	2261.7	2430.5	168.77	2406.0	2574.8	0.5763	7.6751	8.2514
10.0	45.81	0.001010	14.674	191.79	2246.1	2437.9	191.81	2392.8	2584.6	0.6492	7.5010	8.1501
15.0	53.97	0.001014	10.022	225.90	2222.8	2448.7	225.91	2373.1	2599.1	0.7548	7.2536	8.0084
20.0	60.06	0.001017	7.649	251.38	2205.4	2456.7	251.39	2358.3	2609.7	0.8319	7.0766	7.9085
25.0	64.97	0.001020	6.204	271.88	2191.2	2463.1	271.90	2346.3	2618.2	0.8930	6.9383	7.8313
30.0	69.10	0.001022	5.229	289.18	2179.2	2468.4	289.21	2336.1	2625.3	0.9439	6.8247	7.7686
40.0	75.87	0.001026	3.993	317.51	2159.5	2477.0	317.55	2319.2	2636.7	1.0258	6.6441	7.6700
50.0	81.33	0.001030	3.240	340.42	2143.4	2483.8	340.47	2305.4	2645.9	1.0910	6.5029	7.5939
75.0	91.77	0.001037	2.217	384.29	2112.4	2496.7	384.36	2278.6	2663.0	1.2129	6.2434	7.4563
100.0	99.62	0.001043	1.6940	417.33	2088.7	2506.1	417.44	2258.0	2675.5	1.3025	6.0568	7.3593
125.0	105.99	0.001048	1.3749	444.16	2069.3	2513.5	444.30	2241.1	2685.3	1.3739	5.9104	7.2843
150.0	111.37	0.001053	1.1593	466.92	2052.7	2519.6	467.08	2226.5	2693.5	1.4335	5.7897	7.2232
175.0	116.06	0.001057	1.0036	486.78	2038.1	2524.9	486.97	2213.6	2700.5	1.4848	5.6868	7.1717
200.0	120.23	0.001061	0.8857	504.47	2025.0	2529.5	504.68	2201.9	2706.6	1.5300	5.5970	7.1271
225.0	124.00	0.001064	0.7933	520.45	2013.1	2533.6	520.69	2191.3	2712.0	1.5705	5.5173	7.0878
250.0	127.43	0.001067	0.7187	535.08	2002.1	2537.2	535.34	2181.5	2716.9	1.6072	5.4455	7.0526
275.0	130.60	0.001070	0.6573	548.57	1992.0	2540.5	548.87	2172.4	2721.3	1.6407	5.3801	7.0208
0.375	141.32	0.001081	0.4914	594.38	1956.9	2551.3	594.79	2140.8	2735.6	1.7587	5.1647	6.9174
0.40	143.63	0.001084	0.4625	604.30	1949.3	2553.6	604.73	2133.8	2738.5	1.7766	5.1193	6.8958
0.45	147.93	0.001088	0.4140	622.75	1934.9	2557.6	623.24	2120.7	2743.9	1.8606	5.0359	6.8565
0.50	151.86	0.001093	0.3749	639.66	1921.6	2561.2	640.21	2108.5	2748.7	1.8606	4.9606	6.8212
0.55	155.48	0.001097	0.3427	655.30	1909.2	2564.5	655.91	2097.0	2752.9	1.9073	4.8920	6.7892
0.60	158.85	0.001101	0.3157	669.88	1897.5	2567.4	670.54	2086.3	2756.8	1.9311	4.8289	6.7600
0.65	162.01	0.001104	0.2927	683.55	1886.5	2570.1	684.26	2076.0	2760.3	1.9627	4.7704	6.7330
0.70	164.97	0.001108	0.2729	696.43	1876.1	2572.5	697.20	2066.3	2763.5	1.9922	4.7158	6.7080