INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Mid-Autumn Semester 2022-23

Date of Examination: 23/09/2022 Session FN Duration 2 hrs Full Marks: 30
Subject No.: CH21103 & CH21203 Subject: CHEMICAL PROCESS CALCULATIONS
Department/: CHEMICAL ENGINEERING
Specific charts, graph paper, log book etc., required:
Special Instructions (if any): Answer all questions. Assume, if necessary, clearly stating them. No queries will be entertained during the examination.

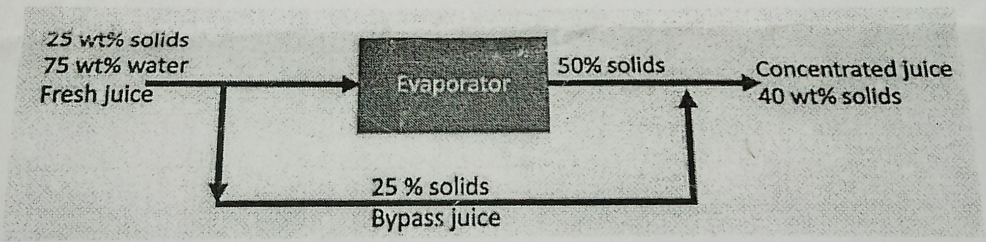
PART A

1. In the production of a bean oil, beans containing 13.0 wt% oil and 87.0% solids are ground and fed to a stirred tank (the extractor) along with a recycled stream of liquid n-hexane. The feed ratio is 3 kg hexane/kg beans. The ground beans are suspended in the liquid, and essentially all of the oil in the beans is extracted into the hexane. The extractor effluent passes to a filter. The filter cake contains 75.0 wt% bean solids and the balance bean oil and hexane, the latter two in the same ratio in which they emerge from the extractor. The filter cake is discarded and the liquid filtrate is fed to a heated evaporator in which the hexane is vaporized and the oil remains as a liquid. The oil is stored in drums and shipped. The hexane vapor is subsequently cooled and condensed, and the liquid hexane condensate is recycled to the extractor.

   a) Draw and label a flowchart of the process, do the degree-of-freedom analysis, and write in an efficient order the equations you would solve to determine all unknown stream variables, circling the variables for which you would solve. **(2+4+2)**

   b) Calculate the yield of bean oil product (kg oil/kg beans fed), the required fresh hexane feed (kg hexane/kg beans fed), and the recycle to fresh feed ratio (kg hexane recycled/kg fresh feed). **(1+1+1)**

2. Given below is a process flow chart to concentrate the solids present in fresh lime juice using an evaporator:



From the above flow chart, calculate:

a) the percentage of fresh juice that is bypassing the evaporator. **(2)**

b) the amount of concentrated juice produced in kg per 100 kg of fresh juice fed into the evaporator. **(2)**

PART B

3. **Your answer should contain logic for choice of data**

   (A) Find out the specific Enthalpy of water at P = 10.0 KPa and Sp. Volume = 10 m^3/kg. What is the temperature of water? **(1.5+0.5)**

   (B) 1 Kg of steam at P=2.5 MPa and T=1050°C undergoes a process in a closed container so that the final pressure becomes 1.4 MPa. What is the final temperature of steam? **(3)**

   (C) A closed vessel contains steam at 3.75 MPa in a 3:1 vapor - volume - to – liquid volume ratio. What is the steam quality? **(2)**

4. Draw the typical Phase diagram of water (T-P). Mark the invariant points on the graph. Please comment how the phase diagram of water is different from that of any other material. How do you justify the difference? From the graph comment on the condition under which sublimation is possible. Why it is not possible to liquefy a gas above critical temperature? **(1+1+1+2+1+2)**

Useful Data:

TABLE Superheated Water Vapor

$P = 1$ MPa

T °C	$\hat{v}$ m³/kg	$\hat{u}$ kJ/kg	$\hat{h}$ kJ/kg
sat	0.19444	2583.6	2778.1
200	0.20596	2621.9	2827.9
250	0.23268	2709.9	2942.6
300	0.25794	2793.2	3051.2
350	0.28247	2875.2	3157.7
400	0.30659	2957.3	3263.9
500	0.35411	3124.3	3478.4
600	0.40109	3296.8	3697.9
700	0.44779	3475.4	3923.1
800	0.49432	3660.5	4154.8
900	0.54075	3852.2	4392.9
1000	0.58712	4050.5	4637.6
1100	0.63345	4255.1	4888.5

$P = 1.4$ MPa

T °C	$\hat{v}$ m³/kg	$\hat{u}$ kJ/kg	$\hat{h}$ kJ/kg
sat	0.14084	2592.8	2790.0
200	0.14302	2603.1	2803.3
250	0.16350	2698.3	2927.2
300	0.18228	2785.2	3040.4
350	0.20026	2869.1	3149.5
400	0.21760	2952.5	3257.4
500	0.25215	3121.1	3474.1
600	0.28596	3294.4	3694.8
700	0.31947	3473.6	3920.9
800	0.35281	3659.1	4153.0
900	0.38606	3851.0	4391.5
1000	0.41924	4049.5	4636.4
1100	0.45239	4254.1	4887.5

$P = 2$ MPa

T °C	$\hat{v}$ m³/kg	$\hat{u}$ kJ/kg	$\hat{h}$ kJ/kg
sat	0.09963	2600.3	2799.5
225	0.10377	2628.3	2835.8
250	0.11144	2679.6	2902.5
300	0.12547	2772.6	3023.5
350	0.13857	2859.8	3137.0
400	0.15120	2945.2	3247.6
500	0.17568	3116.2	3467.6
600	0.19960	3290.9	3690.1
700	0.22323	3471.0	3917.5
800	0.24668	3657.0	4150.4
900	0.27004	3849.3	4389.4
1000	0.29333	4047.9	4634.6
1100	0.31659	4252.7	4885.9
1200	0.33984	4463.2	5142.9
1300	0.36306	4679.0	5405.1

$P = 2.5$ MPa

T °C	$\hat{v}$ m³/kg	$\hat{u}$ kJ/kg	$\hat{h}$ kJ/kg
sat	0.07998	2603.1	2803.1
225	0.08027	2605.6	2806.3
250	0.08700	2662.5	2880.1
300	0.09890	2761.6	3006.8
350	0.10976	2851.8	3125.2
400	0.12010	2939.0	3239.3
450	0.13014	3025.4	3350.8
500	0.13998	3112.1	3462.0
600	0.15930	3288.0	3686.2
700	0.17832	3468.8	3914.6
800	0.19716	3655.3	4148.2
900	0.21590	3847.9	4387.6
1000	0.23458	4046.7	4633.1
1100	0.25322	4251.5	4884.6
1200	0.27185	4462.1	5141.7
1300	0.29046	4677.8	5404.0

TABLE Saturated Water: Pressure Table

P kPa, MPa	T °C	$\hat{v}_f$ m³/kg	$\hat{v}_g$ m³/kg	$\hat{h}_f$ kJ/kg	$\Delta\hat{h}_{fg}$ kJ/kg	$\hat{h}_g$ kJ/kg
0.6113	0.01	0.001000	206.132	0.00	2501.3	2501.3
1.0	6.98	0.001000	129.208	29.29	2484.9	2514.2
1.5	13.03	0.001001	87.980	54.70	2470.6	2525.3
2.0	17.50	0.001001	67.004	73.47	2460.0	2533.5
2.5	21.08	0.001002	54.254	88.47	2451.6	2540.0
3.0	24.08	0.001003	45.665	101.03	2444.5	2545.5
4.0	28.96	0.001004	34.800	121.44	2432.9	2554.4
5.0	32.88	0.001005	28.193	137.79	2423.7	2561.4
7.5	40.29	0.001008	19.238	168.77	2406.0	2574.8
10.0	45.81	0.001010	14.674	191.81	2392.8	2584.6
15.0	53.97	0.001014	10.022	225.91	2373.1	2599.1
20.0	60.06	0.001017	7.649	251.38	2358.3	2609.7
25.0	64.97	0.001020	6.204	271.90	2346.3	2618.2
30.0	69.10	0.001022	5.229	289.21	2336.1	2625.3
40.0	75.87	0.001026	3.993	317.55	2319.2	2636.7
1.10	184.09	0.001133	0.17753	781.32	2000.4	2781.7
1.20	187.99	0.001139	0.16333	798.64	1986.2	2784.8
1.30	191.64	0.001144	0.15125	814.91	1972.7	2787.6
1.40	195.07	0.001149	0.14084	830.29	1959.7	2790.0
1.50	198.32	0.001154	0.13177	844.87	1947.3	2792.1
1.75	205.76	0.001166	0.11349	878.48	1918.0	2796.4
2.00	212.42	0.001177	0.09963	908.77	1890.7	2799.5
2.25	218.45	0.001187	0.08875	936.48	1865.2	2801.7
2.50	223.99	0.001197	0.07998	962.09	1841.0	2803.1
2.75	229.12	0.001207	0.07275	985.97	1817.9	2803.9
3.00	233.90	0.001216	0.06668	1008.41	1795.7	2804.1
3.25	238.38	0.001226	0.06152	1029.60	1774.4	2804.0
3.50	242.60	0.001235	0.05707	1049.73	1753.7	2803.4
4.0	250.40	0.001252	0.049778	1087.29	1714.1	2801.4
5.0	263.99	0.001286	0.039441	1154.21	1640.1	2794.3