21CH10079

Indian Institute of Technology Kharagpur
Department of Chemical Engineering
End Autumn Semester Examination, 2022-23
Sub: **Chemical Engineering Thermodynamics**
Subject Number: CH21008/21201

Nov 2022
Time: 3 Hrs.
Full Marks: 50
No. of Students: 130

Instructions: Answer all questions. Closed book, closed notes examination. All symbols carry their usual meaning. Assume missing data suitably. Follow the five step problem solving methodology. Data required are included in the question paper.

1. A refrigerator (operates cyclically) is designed to maintain a temperature of 5 °C inside it. The heat extraction rate from food items (as cold reservoir/sink) kept inside refrigerator is 10,000 kJ/h. If the power input to refrigerator is 4000 kJ/h and the outside environment temperature is 25 °C. Calculate:
   (a) (4 marks) the lost work due to thermodynamically imperfect design of the refrigerator
   (b) (1½ marks) the coefficient of performance (COP) of the refrigerator.

   Now imagine an ideal scenario where the above operation is conducted in reversible manner between the same hot and cold reservoir as well as with same rate of heat extraction (10000 kJ/h) from items kept inside the refrigerator. For this ideal schenario:
   (c) (2 marks) Calculate the power input required.
   (d) (1½ marks) Calculate the Co-efficient of performance (COP) of the refrigerator.
   (e) (1 mark) Compare the COP for two scenarios mentioned above and comment very briefly.

2. *(10 marks) Consider a mixture of n-pentane(1), cyclohexane(2), n-hexane(3) and n-heptane(4). Complete the Bubble T calculation considering* P = 1 bar and $y = [0.2 \quad 0.3 \quad 0.4 \quad 0.1]$. Show only two iterations.

3. (12 marks) Consider a mixture of CO_2 (1) and benzene (2) at 313 K with $x_1 = 0.1$. Calculate ϕ_1^v, ϕ_2^v, $\hat{\phi}_1^v$, $\hat{\phi}_2^v$ for this system.

4. (10 marks) Determine the fugacity of component a in a binary mixture of a and b which contains 1 mol of a and 4 mols of b at 30 kPa and 20 °C. At this temperature the saturation pressure of pure a is 50 kPa. The excess Gibbs energy for this mixture is given by:

$$\frac{g^E}{RT} = (0.25x_a + 0.5x_b)x_a x_b$$

5. (8 marks) Compute the Poynting correction factor for benzene at 500 K and 250 bar. Density of benzene under these conditions is 876 kg/m ^{3} which may be considered to be approximately independent of pressure.

§ *FORMULAE AND DATA* §

$$\phi_i^v = \exp\left[(b - a/RT)\frac{P}{RT}\right] \qquad \hat{\phi}_i^v = \phi_i^v \exp\left[\frac{(\sqrt{a_a} - \sqrt{a_b})^2 y_b^2 P}{(RT)^2}\right]$$

$$y_i P \hat{\phi}_i^v = x_i \gamma_i \phi_i^{sat} P_i^{sat} \exp\left[\int_{P_i^{sat}}^{P} v_i^l/(RT)dP\right]$$

$$a = \frac{27(RT_c)^2}{64P_c} \quad \text{and} \quad b = \frac{RT_c}{8Pc}$$

$$\ln(P^{sat}[bar]) = A - \frac{B}{T[K] + C}$$

$$P = \frac{RT}{v - b} - \frac{a}{v^2}$$

Component	A	B	C	T_c [K]	P_c [bar]
n-pentane	9.2131	2477.07	-39.94	469.6	33.74
cyclohexane	9.1325	2766.63	-50.50	553.4	40.73
n-hexane	9.2164	2697.55	-48.78	507.4	29.69
n-heptane	9.2535	2911.32	-56.51	540.2	27.36
toluene	9.3935	3096.52	-53.67	591.7	41.14
propanol	10.9237	3166.38	-80.15	536.7	51.68
CO_2	15.9696	3103.39	-0.16	304.2	73.76
Benzene	9.2806	2788.51	- 52.36	562.1	48.94