Department of Chemical Engineering

CHL 351 Mass Transfer Operations: Major Exam (open book / notes)

Duration: 2 hr (8am – 10am) Max Marks: 40 2nd May 2008

Note: Each question carries 10 marks. Start answering each question on a separate page. Use separate graph sheet for each question. Write your name, entry number, and group number on every graph sheet and properly tie it to the answer sheet. No extra time would be given to do all of these.

(1) Solvent A is to be recovered by *distillation* from its water solution. It is necessary to produce an overhead product containing 95 mol % A and to recover 95 % of the A from the feed. The feed is available at the plant site in *two streams*, one containing 40 mol % A and the other 60 mol % A. Each stream will provide 50 kmol/h of component A, and each will be fed into the column as saturated liquid. Since the less volatile component is water, it has been proposed to supply the necessary heat in the form of *open steam*. For the preliminary design it has been suggested that the operating reflux ratio be 1.33 times the minimum value. A total condenser will be employed. For this system, it is estimated that the overall stage efficiency will be 70 %.

Determine the actual number of stages required, flow rate of steam, and the bottoms composition. The relative volatility may be assumed to be constant at 3.0 and the simplifying assumptions of *McCabe-Thiele* apply. Each feed should enter the column at its optimal location.

(2) A *countercurrent extraction* cascade equipped with a perfect solvent separator to provide *extract reflux* is to be used to separate 2000 kg/h of a liquid solution containing 65 wt % solute, to produce a final extract and raffinate containing 96 wt % and 10 wt % solute, respectively. All compositions are on a solvent-free basis. The feed contains no solvent and the fresh solvent is pure and enters the cascade counter-currently at a rate of 9000 kg/h.

To achieve the specified separation, determine (a) number of theoretical stages and the optimum feed stage location, (b) the extract reflux ratio, (c) the minimum extract reflux ratio, and (d) the minimum solvent rate. The equilibrium and tie line data are given below.

X	N	Y	N
0.00	0.20	0.00	5.2
0.05	0.23	0.17	4.8
0.10	0.30	0.30	4.4
0.15	0.32	0.36	4.25
0.25	0.36	0.47	3.9
0.30	0.41	0.60	3.6
0.50	0.50	0.70	3.3
0.60	0.60	0.80	3.0
0.70	0.70	0.85	2.9
0.79	0.73	0.89	2.8
0.85	0.80	0.96	2.6
1.0	0.90	1.0	2.5

(3) Consider a dry solid mixture to be leached containing 100 kg/h of NaOH and 150 kg/h of $CaCO_3$. Pure water is used as leaching solvent in a *counter-current* cascade, and it is desired to produce as overflow from the first stage a clear solution containing 9 wt % NaOH. Determine the amount of water required and the number of real stages to reduce the solute concentration to below 2 wt % in the discharged sludge. Also report the actual final concentration of the leached solids (in wt % NaOH) from the last stage. All weight percentages given here are on B-free basis.

The practical equilibrium data is given below.

x	y	N
0.090	0.092	0.50
0.070	0.076	0.53
0.047	0.061	0.57
0.033	0.045	0.60
0.021	0.030	0.62
0.012	0.020	0.65
0.007	0.014	0.66
0.005	0.010	0.67

where x and y are the tie lines corresponding to the weight fractions of NaOH (B-free basis) in clear solution (overflow) and in the settled sludge (underflow), respectively, and N is kg $CaCO_3$ per kg solution in settled sludge.

(4) An aqueous sugar cane solution containing 48 % by weight of sugar is colored by the presence of small quantities of impurities. It is to be decolorized at 80°C by treatment with an adsorptive carbon. The equilibrium data fits into the Freundlich adsorption isotherm, $Y^{*} = mX^{n}$, with constants $m = 8.325 \times 10^{-7}$ and $n = 2.17$, where Y^{*} = units of color / kg sugar and X = units of color adsorbed / kg carbon. The original solution corresponds to a color concentration of 20 units per kg sugar ($Y_0 = 20$), and it is desired to reduce the color to 2.5 % of its original value.

(a) Determine the necessary dosage of fresh carbon, for 1000 kg of solution, in a single-stage process. (b) Calculate the necessary carbon dosages per 1000 kg of solution, for a two-stage crosscurrent treatment, using the minimum total amount of fresh carbon. (c) Calculate the necessary carbon dosage per 1000 kg of solution for a two-stage counter-current treatment.