

10.32
Spring 2005
EXAM 3
May 16, 2005

1. (30 points) The attached figure is a typical gas-liquid chromatogram for a feed mixture containing four aromatic hydrocarbons, A through D. The separation was obtained using helium as a carrier gas in a column that is 1.5 m long and has an inside diameter of 6.5 mm. The column was filled with small ceramic beads coated with 0.25 wt % non-volatile liquid absorbent. The density of the liquid absorbent was 0.8 g/cm^3 , the density of the beads was 2.5 g/cm^3 , and the void fraction in the column ϵ_b was 0.4. The helium flow rate was 15 mL/min measured at 25°C , and the column was maintained at 100°C .
- Estimate the number of equilibrium stages, N , for each of the four compounds.
 - Estimate the height of the equilibrium stages for each of the four compounds.
 - Estimate the equilibrium constant, K_i , for compounds A and D.
 - Earlier in the term we separated mixtures of hydrocarbons using distillation, an equilibrium staged process. We found the number of equilibrium stages to be 10 to 20 for excellent separation. In gas-liquid chromatography, another equilibrium staged process, we generally need hundreds of stages to achieve good separations. Why?
2. (30 points) Dry air at 500 standard cubic feet per minute (60°F , 1 atm) containing 0.5 mole percent hydrogen sulfide is to be treated with activated carbon in an adsorber bed. This commercial adsorber will run at 100°F and 1 atm and at a superficial gas velocity of 50 ft/min. The adsorber bed will be 4 feet long and has a void volume fraction ϵ_b of 0.6.

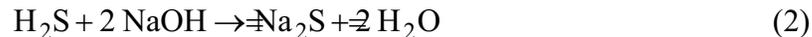
Laboratory tests with the same adsorbent material to be used in the commercial operation have been run using 1.0 mole percent H_2S in air at 100°F and 1 atm and a superficial gas velocity of 75 ft/min. A correlation for breakthrough time measured at the 2 ppm (w/w) threshold limit of the detector was

$$t_B = 1.07 L - 0.8 \quad (1)$$

In equation 1, t_B is the breakthrough time in hours and L is the length of the laboratory adsorber in feet.

You may assume that the length of the mass transfer zone is the same in the laboratory and commercial adsorber. The velocity profiles across the diameters of the adsorbers are flat. The adsorption isotherm can be expressed as $q = Kc$.

- a) What is the diameter required for the commercial adsorber?
 - b) What is the length of the unused bed LUB in the commercial adsorber?
 - c) What is the estimated breakthrough time for the commercial adsorber?
 - d) Estimate the breakthrough time if the length of the commercial adsorber is 8 feet but the cross-sectional area is reduced so that the same amount of adsorbent is used.
3. (40 points) An engineer suggests that the air stream containing 0.5mol% hydrogen sulfide in problem 2 can be contacted with an aqueous solution of 1 wt% sodium hydroxide in a small countercurrent staged column. The H_2S will react with NaOH by the reaction



The Na_2S is non-volatile and the reaction is very rapid and irreversible so that at equilibrium the concentration of H_2S in the gas phase is essentially zero.

- a) What is the minimum flow rate of the aqueous solution of 1 wt% NaOH required to remove all but 2 ppm (w/w) of H_2S from the air stream?
- b) If the flow rate of water is twice that found in part a, what is the number of theoretical equilibrium stages required? A McCabe-Thiele diagram may be helpful.
- c) If the mass transfer rate is slow so that the stage efficiency is 90% (instead of 100% as assumed on part b), how many stages are needed at the same flow rates as in part b? Again a McCabe-Thiele diagram may be useful.
- d) If a countercurrent packed column is used instead of a plate column, what is the number of transfer units, N_{OG} , for this process? The exiting air stream has a concentration of 2 ppm (w/w) H_2S and the flow rates of the air and gas streams are the same as in part b.

Notes:

(1) In thinking about the performance of the absorber, consider the mole fraction of sulfur in the water, x , to be the total of free dissolved sulfur (H_2S) plus the fixed sulfur as Na_2S .

(2) Stage efficiency ε is defined as:

$$\varepsilon = \frac{y_{n+1} - y_n}{y_{n+1} - y_n^*}$$

(3) The atomic weights of various elements are listed below:

<u>Element</u>	<u>Atomic Weight</u>
H	1
S	32
Na	23
O	16
N	14

(4) If you used a McCabe-Thiele diagram for your solution to parts b and c, please write your name on it and pass it in with your exam booklet.

Detector Output (proportional to concentration)

