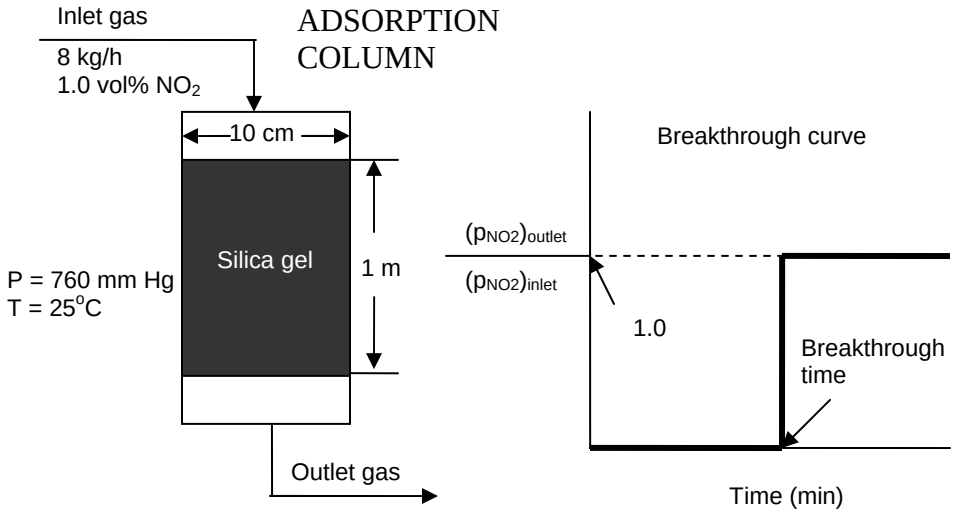
Homework 6 (Group) **Due date: 5-Mar-2007**

1. (Chapter 6, Prob. 6.100) The equilibrium for adsorption of NO_2 on silica gel at 25°C and 1 atm is adequately represented by $X(\text{kg NO2/100 kg silica gel}) = 0.140 p_{NO_2}^{1.406}$ where p is partial pressure of NO_2 in mm Hg.

   a) The adsorption column shown in figure below has an internal diameter of 10.0 cm and a bed height of 1.00 m. The bed of silica gel has a bulk density of 0.75 kg/L. The adsorber is to remove NO_2 from a stream containing 1.0 mole% NO_2 and the balance air that enters the adsorber at 8.00 kg/h. The pressure and temperature are maintained at 1 atm and 25°C. Past experience with this system has shown that a plot of the partial pressure ratio $[(p_{NO2})_{outlet}/(p_{NO2})_{inlet}]$ versus time produces a **breakthrough** with the following appearance.



   Using the isotherm given, determine the time (in min) required for breakthrough of the NO_2.

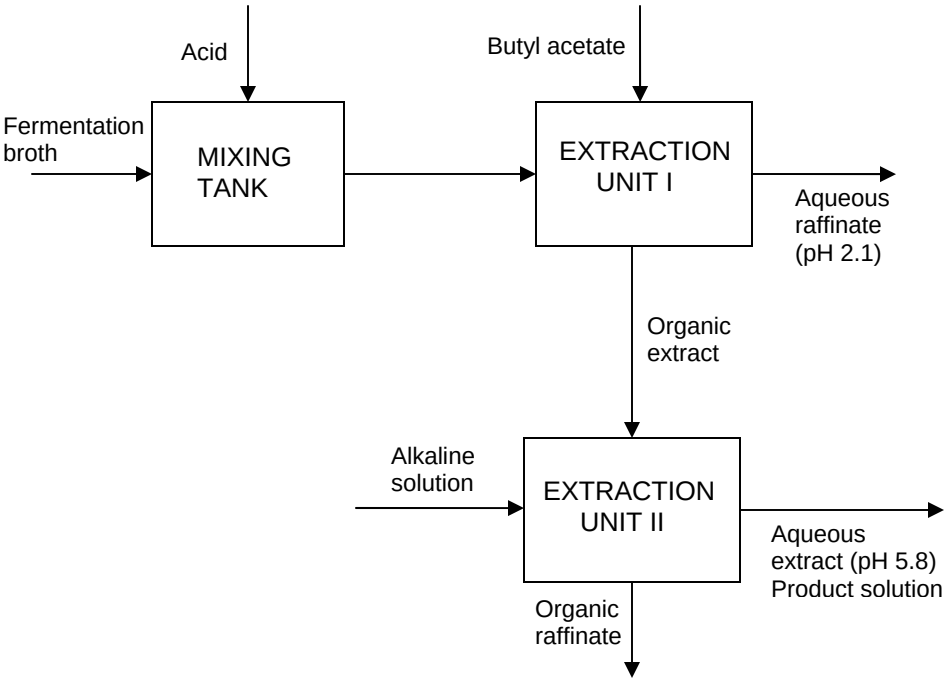
   b) Silica gel in the column can be *regenerated* (i.e., adsorbed NO_2 can be removed so that the silica gel column can be reused) by elevating the temperature and/or purging the bed with clean air. Suppose such regeneration takes 1.5 hours to accomplish. Process shutdowns can be avoided by installing several silica gel columns in parallel, using one to carry out the purification while the others are being regenerated. What is the minimum number of columns required to achieve continuous process operation?

2. (Chapter 6, Prob. 6.92) In biotech industry, penicillin is produced by fermentation (certain microbes in water supplied with essential nutrients and oxygen produce penicillin). It is recovered from the resulting aqueous broth by extraction with butyl acetate. The penicillin distribution coefficient *K* (mass fraction of penicillin in the butyl acetate phase/mass fraction of penicillin in the water phase) depends strongly on the pH in the aqueous phase:

pH	2.1	4.4	5.8
K	25.0	1.38	0.10

   This dependence provides the basis for the process to be described. Water and butyl acetate ay be considered immiscible.

The extraction is performed in the following three-unit process:



- Broth from a fermentor containing dissolved penicillin, other dissolved impurities, and water is acidified in a mixing tank. The acidified broth, which contains 1.5 wt% penicillin, is contacted with liquid butyl acetate in an extraction unit consisting of a mixer, in which the aqueous and organic phases are brought into intimate contact with each other, followed by a settling tank, in which the two phases separate under the influence of gravity. The pH of the aqueous phase in the extraction unit equals 2.1. In the mixer, 90% of the penicillin in the feed broth transfers from the aqueous phase to the organic phase.

- The two streams leaving the settler are in equilibrium with each other—that is, the ratio of the penicillin mass fraction in the two phases equals the value of *K* corresponding to the pH of the aqueous phase (= 2.1 in Unit I). The impurities in the feed broth remain in the aqueous phase. The *raffinate* (by definition, the product stream containing the feed-solution solvent) leaving Extraction Unit I is sent elsewhere for further processing, and the organic *extract* (the product stream containing the extraction solvent) is sent to a second mixer-settler unit.

- In the second unit, the organic solution fed to the mixing stage is contacted with an alkaline aqueous solution that adjusts the pH of the aqueous phase in the unit to 5.8. In the mixer, 90% of the penicillin entering in the organic feed solution transfers to the aqueous phase. Once again, the two streams emerging from the settler are in equilibrium. The aqueous extract is the process product.

  a) Taking a basis of 100 kg of acidified broth to the first extraction unit, calculate the ratios (kg butyl acetate required/kg acidified broth) and (kg alkaline solution required/kg acidified broth) and the mass fraction of the penicillin in the product solution.
  b) Briefly explain the following:

i) What is the likely reason for transferring most of the penicillin from an aqueous phase to an organic phase and then transferring most of it back to an aqueous phase, when each phase transfer leads to loss of some of the drug?

ii) What is the purpose of acidifying the broth prior to the first extraction stage, and why is the extracting solution added to the second unit a base?

3. (Chapter 6, Prob. 6.65) A vapour mixture containing 30 mole% benzene and 70% toluene at 1 atm is cooled isobarically in a closed container from an initial temperature of 115^{o}C. Antoine constants for benzene and toluene are given in the following table. In the Antoine equation, temperature is in ^{o}C and vapour pressure is in mm Hg.

Species	A	B	C
Benzene	6.89272	1203.531	219.888
Toluene	6.95805	1346.773	219.263

Answer the following:

a) At what temperature does the first drop of condensate form? What is its composition?

b) At one point during the process the system temperature is 100^{o}C. Determine the mole fraction of benzene in the vapour and liquid phases at this point and calculate the ratio of moles of vapour to moles of liquid.

c) At what temperature does the last drop of condensate form? What is its composition?