UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING
FINAL EXAMINATIONS, April, 2001
CHE 410S – Advanced Separation Processes
Examiner – O. Trass

Books and personal notes may be used.
Three diagrams are supplied.

MARKS

A scheme to separate a solution of benzene and ethyl alcohol has been proposed. It involves three operations: (i) continuous distillation in a tray tower to give alcohol as the bottoms product, (ii) counter-current extraction of alcohol with water from the nearly azeotropic overhead product, followed by (iii) batch distillation to recover most of the alcohol from the water (extract) solution. Perform the calculations requested below.

15 1. The feed, saturated vapour, is supplied continuously at a rate of 10,000 kg/day. The tray tower to be designed should yield a bottoms product containing 99 mole % alcohol, and an overhead product containing 53 mole % benzene. The feed composition is 24 mole % (34.8 wt %) benzene. Calculate

(a) the product rates, kg/day, and

(b) the number of theoretical trays required for this separation. The operating reflux ratio is to be twice the minimum value.

20 2. The overhead product will be cooled to 25°C and fed to a packed extraction column for counter-current contacting with water to reduce the alcohol content to 2 % by weight. Determine:

(a) the lower limit to the amount of water (kg/day) which can be used to carry out the separation in this case.

(b) the number of theoretical stages which the packing must be equivalent to if the amount of water used is 0.65 kg/kg of feed. (Likely H.E.T.S. data are available, or you would have been asked to calculate the number of transfer units), and

(c) the amount, kg/day, and composition of the resulting extract solution.

15 3. The ethanol solution from the extraction is allowed to accumulate in a hold-up tank and is distilled batchwise once a day. A still, equipped with a column containing five trays (equivalent to three theoretical trays) is available. It will be operated at a constant reflux ratio of three.

(a) What is the pot composition, x_w, when the distillate coming off is 85 wt % alcohol? Do this sample calculation only, showing all construction lines.

(b) Describe how you would prepare a graph of the average composition of the distillate vs. amount distilled. Indicate how you would obtain the required information.

It is proposed to recycle the water from the batch rectifier via a holding tank and a heat exchanger to the extraction unit.

15 4. By now you are perhaps thinking that, even though this proposed separation will work, it could stand much improvement. Suggest, preferably sketching a flow-sheet, and entering streams and their compositions, what changes you think may be profitable, and why. You may wish to consider product specifications, equipment, energy savings, operating conditions and/or the overall scheme.
(Bonus marks available for more than two good suggestions.)

20 5. Answer the following questions concisely.

(a) Regarding possible applications and limitations of the use of heat-mass momentum transfer analogies, give one example each for (i) cases where analogies may be used successfully, and (ii) cases where they fail (and state why).

(b) Consider the general correlations for HTU values. Regarding the influence of fluid flow rates, why is it that the HTU_L values are influenced by the liquid flow rate L′ only while the HTU_G values are influence by both L′ and the gas flow rate G′?

(c) In a gas absorption problem $k_ya = 10$ mol/s.m^3 and $k_xa = 50$ mol/s.m^3 with $m_{yx} = 10$. What is the overall volumetric mass transfer coefficient $K_{ox}a$?

(d) Using the k-values from part c), estimate the interfacial concentration of solute A, as mole fraction x_{Ai}, at the top of an absorption column where the bulk liquid concentration is zero, pressure is atmospheric and the partial pressure of A in the bulk gas is 0.05 atm.

(e) The feed to a distillation column may enter as liquid below its boiling point, at its boiling point, or as part (or wholly) vapour. Recalling the analogy between binary distillation and extraction, viz. that heat corresponds to solvent, the more volatile component to solute and the less volatile one to diluent, can you think of comparable possibilities in extraction? If so, what might they be?

15 6.

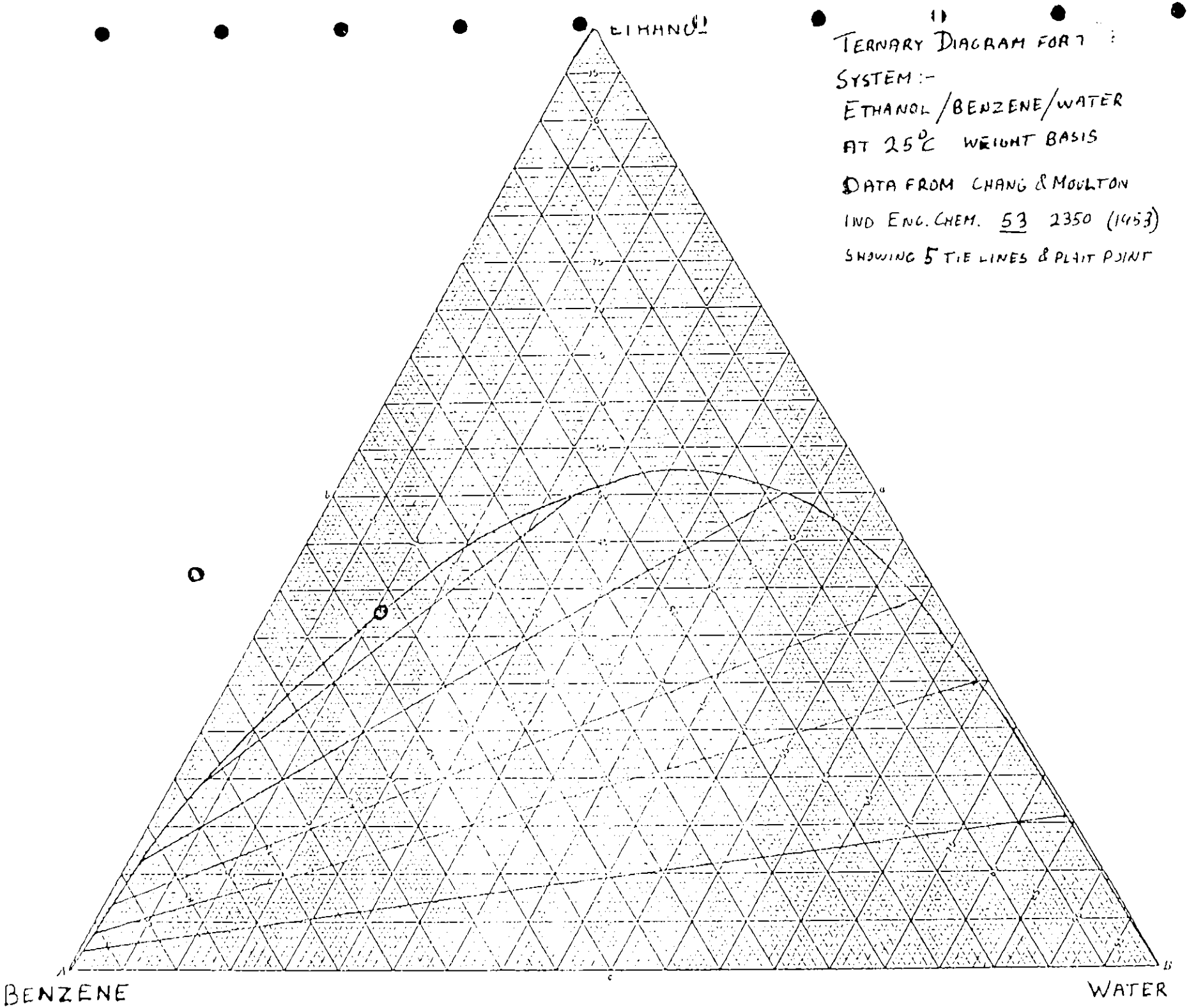
(a) Assume that you are faced with the problem of separating a binary solution into relatively pure components. The vapour-liquid equilibrium data at atmospheric pressure indicate a very difficult separation by distillation since the relative volatility, α, is close to unity.
What reasonable alternatives may you have and in which order would you prefer to investigate them?
What are the most important considerations, in general and/or for each alternative?

(b) Why is it usually undesirable to introduce the solvent for extractive distillation at the top of the column?

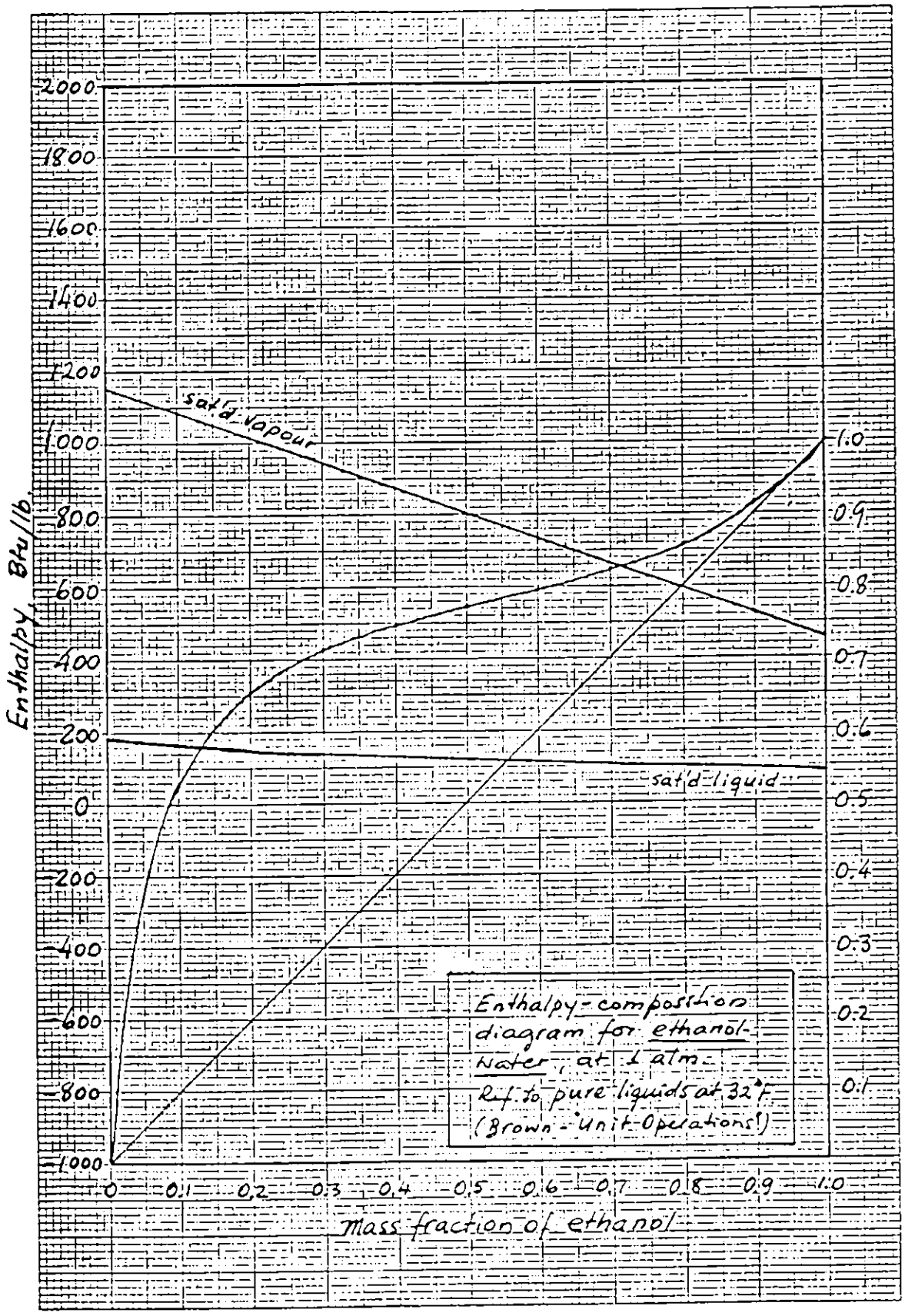
(c) What respective principles or properties are involved when species separation is accomplished by the following separation processes (i.e. what is separation based on)?

a) extraction
b) flotation
c) supercritical extraction

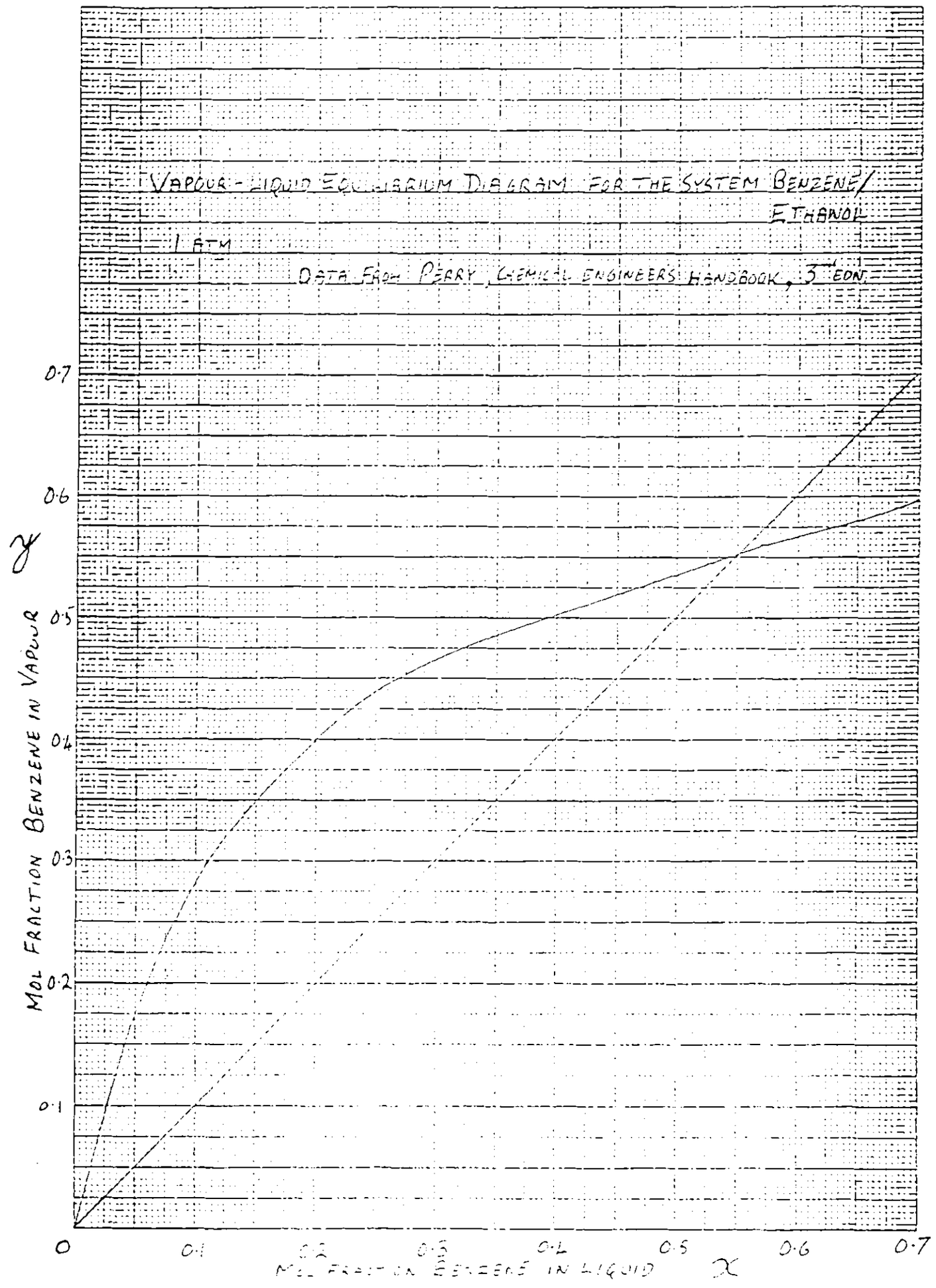
May c) also, properly, be referred to as "supercritical leaching" (although this is usually not done)?



TERNARY DIAGRAM FOR 1 SYSTEM :-
ETHANOL / BENZENE / WATER
AT 25°C WEIGHT BASIS
DATA FROM CHANG & MOULTON
IND ENG. CHEM. 53 2350 (1953)
SHOWING 5 TIE LINES & PLAIT POINT



FORM A T TECHNOLOGY STORE, M. I. T. 40 MASS AVE., CAMBRIDGE, MASS.


VAPOUR - LIQUID EQUILIBRIUM DIAGRAM FOR THE SYSTEM BENZENE/ ETHANOL
1 ATM
DATA FROM PERRY, CHEMICAL ENGINEERS HANDBOOK, 3RD EDN.
MOL FRACTION BENZENE IN VAPOUR
y
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
MOL FRACTION BENZENE IN LIQUID
x