UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:-

B.Eng. *M.Eng.*

Chemical Eng E849: Mass Transfer Operations

COURSE CODE	:	**CENGE849**
UNIT VALUE	:	**0.50**
DATE	:	**23-MAY-03**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

03-C0188-3-50

Answer FOUR questions only. **Only the first four answers given will be marked.**
Each question carries a total of 25 marks distributed as shown [ ]

Additional stationery provided: graph paper

1. A hydrocarbon gas stream is to be purified by continuous counter-current contact with a liquid organic solvent. The inlet gas contains 2% by volume of toxic benzene of which 95% is to be removed. The gas flows at a rate of 0.05 kmol/s on a benzene-free basis. The organic liquid solvent initially contains 0.001 mole fraction benzene. The required solvent flowrate is to be 1.5 times the minimum.

The vapour-liquid equilibrium relationship is given by:

$$Y^* = 0.15X$$

where Y^* is the mole ratio of benzene in the gas phase and X is the mole ratio of benzene in the liquid phase.

a) Calculate the required solvent flowrate. [10]

b) Determine the required height of an absorber having a gas transfer unit height of 1.5m. [15]

2. Show that the slurry *washing ratio* for a continuous countercurrent series of n equilibrium stages at steady-state is given by:

$$\frac{x_{n+1}}{x_1} = \frac{\left(\frac{E}{R}\right)^{n+1} - 1}{\left(\frac{E}{R}\right) - 1}$$

where x is the concentration of solute in the slurry liquor, E is the mass of extracting solvent and R is the mass of retained solvent in the suspension. [10]

A particulate suspension containing 1000 kg of inert solids, I, per 1000 kg solvent, R, and 250 kg solute is washed counter-currently with 3000 kg of pure fresh solvent E in three equilibrium stages.

Assuming that $E/R = 3$ throughout

a) What is the concentration of solute in the discharge suspension? [3]

b) What are the operating conditions (compositions) of the solvent and slurry streams through the plant? [12]

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3. a) Sketch how the *moisture content* of a drying solid varies with time. [2]

b) Write equations describing the *drying rate* in terms of (i) the solid and (ii) the gas phases. [2]

c) Sketch how the batch drying rate varies with moisture content. [2]

d) Describe briefly, with reference to (a) and (c), the *constant drying rate* and *falling drying rate* periods. [2]

e) Show that the *total drying time* in a batch drier, θ_T, can be expressed by

$$\theta_T = \frac{L_S}{SN_{CR}}\left\{(X_1 - X_C) + (X_C - X^*)\ln\frac{(X_C - X^*)}{(X_2 - X^*)}\right\}$$

where X_1 and X_2 are the moisture contents of the wet feed and dried product respectively, X_C and X^* are the critical and equilibrium moisture contents respectively, L_S is the mass of dry solid, S is the drying surface area, and N_{CR} is the constant drying rate.
State clearly any assumptions that you may make. [5]

f) Five hours are required under constant drying conditions to reduce the moisture content of a wet solid from 35% to 10% with a critical moisture content of 15% and an equilibrium moisture content of 2%. How long would it take to dry a similar material from 40% to 5%? [12]

(All compositions are given on a dry basis)

4. 5000 kg/h of a mixture composed of 45 mol% heptane (C_7H_{16}) and 55 mol% ethyl-benzene (C_8H_{10}) is fed into a fractionating column to produce a distillate containing 95 mol% heptane and a residue containing 90 mol% ethyl-benzene. The column is equipped with a total condenser and a partial reboiler. Assume that the feed, the distillate and the residue are all saturated liquids.

a) What are the molar flowrates of the distillate and residue product streams? [3]

b) What percentage of the ethyl benzene in the feed is recovered in the distillate? [1]

c) With the aid of a graphical construction on the diagram provided which *must be attached to your answer book*, determine:

i) the minimum reflux ratio, R_{min}. [3]
ii) the number of theoretical stages, N, when $R = 1.5R_{min}$. [13]

d) What are the condenser and reboiler thermal duties when $R = 1.5R_{min}$? [5]

DATA: Enthalpy concentration diagram for the heptane-ethyl-benzene system.

TURN OVER

5. A multicomponent light hydrocarbons mixture is to be fed as saturated liquid into a tray tower operating at 15 atm in conjunction with a total condenser and a partial reboiler. The composition of the feed is given in Table 1. The distillate will contain 93% of the fed n-butane (light key) and have negligible n-hexane. The bottom product (residue) will contain 96% of the fed n-pentane (heavy key) and negligible propane.

Table 1

All compositions are given in molar fractions	
	Feed (x_F)
1) propane	0.10
2) n-butane	0.40
3) n-pentane	0.36
4) n-hexane	0.14

Find the following:

a) composition of distillate and residue [4]

b) bubble point temperature of residue, and dew point temperature of distillate [15]

c) minimum number of theoretical stages [6]

Data:

Relevant Antoine's constants are given in Table 2:

Table 2

	A	B	C
propane	15.72600	1872.46000	-25.16000
n-butane	15.67820	2154.90000	-34.42000
n-pentane	15.83330	2477.07000	-39.94000
n-hexane	15.83360	2697.55000	-48.78000

Antoine's Law: $ln(P°)=A-(B/(T+C))$

where: $[P°=mmHg]$ $[T=K]$

$1\ atm = 760\ mmHg$

Fenske's Equation:

$$N_M = \frac{ln\left[\left(\frac{x_{LK}}{x_{HK}}\right)_D \left(\frac{x_{HK}}{x_{LK}}\right)_B\right]}{ln(\alpha_{LK})}$$

where:

N_M = minimum number of theoretical stages in column

α = relative volatility with respect to heavy key, computed as geometric mean of relative volatities of distillate and residue streams

x = liquid mol fraction

D, B = distillate and residue respectively

LK, HK = light key and heavy key respectively

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6. a) From first principles, and with reference to a labelled sketch, show that the height of clear liquid (H) in the downcomer of a sieve tray is given by the expression:

$$H = h_0 + 2(h_w + h_{ow}) + h_{da}$$

where h denotes an equivalent head of clear liquid and the subscripts o, w, ow and da refer to dry holes, outlet weir, crest over outlet weir and downcomer apron respectively. The effects of hydraulic gradient, surface tension and vapour-in-liquid entrainment may be neglected. [10]

b) Single pass cross-flow sieve trays are to be used in a column where the liquid flowrate and density are 7,000 kg/h and 950 kg/m^3 respectively, and the vapour flowrate and density are 14,000 kg/h and 5 kg/m^3 respectively. On a basis of 80 percent of the tray flooding velocity, together with the tray data given below, calculate:

i) the tray diameter (m) [7]
ii) the downcomer liquid residence time (s) [8]

DATA Chart supplied showing tray flooding correlation.
Tray spacing = 0.457m. *Vertical splash baffles will be used.* Downcomer aprons will be vertical.

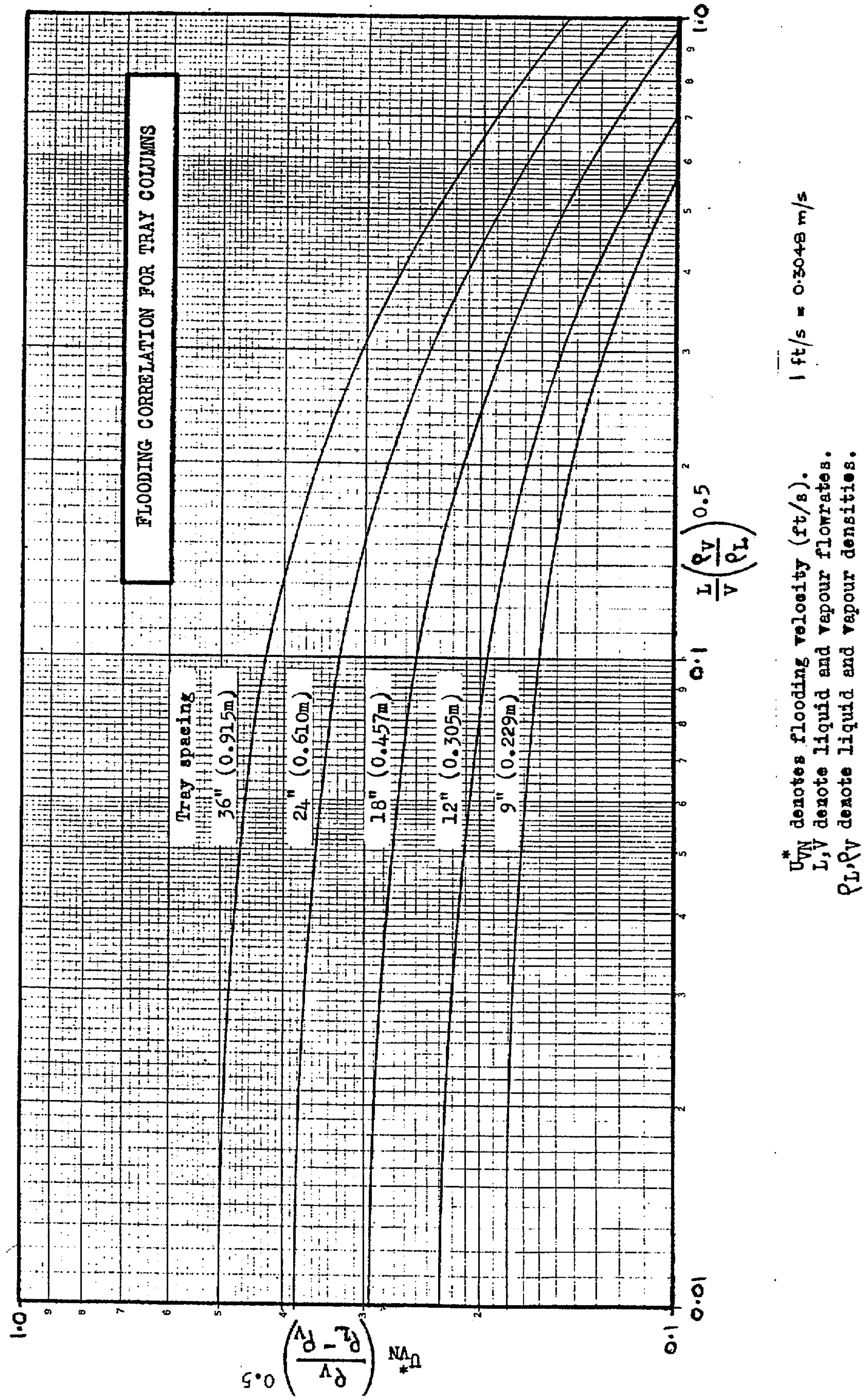
$h_w = 50$ $\quad h_{ap} = 40$ $\quad l_w = 0.77D$ $\quad A_d = 0.12A$ $\quad A_h = 0.08A_A$

$h_o = 70u^2(\rho_V / \rho_L)$ $\quad h_{ow} = 750(q/l_w)^{0.667}$

$h_{da} = 1.66\times10^8 (q/(h_{ap}l_w))^2$

where A = column cross-sectional area (m^2)
A_A = tray active area(m^2)
A_d = downcomer area (m^2)
A_h = total hole area (m^2)
D = tray diameter (m)
h_{ap} = height of bottom edge of downcomer apron above tray surface(mm)
h_{da} = head loss under downcomer apron (mm clear liquid)
h_o = head loss across dry holes (mm)
h_{ow} = crest over outlet weir (mm clear liquid)
h_w = height of outlet weir (mm)
l_w = length of outlet weir (m)
q = liquid flowrate (m^3/s)
u = vapour velocity through holes (m/s)
ρ_L = density of clear liquid (kg/m^3)
ρ_V = density of vapour (kg/m^3)

TURN OVER



FLOODING CORRELATION FOR TRAY COLUMNS
Tray spacing
36" (0.915m)
24" (0.610m)
18" (0.457m)
12" (0.305m)
9" (0.229m)
$\frac{L}{V}\left(\frac{\rho_V}{\rho_L}\right)^{0.5}$
0.01
0.1
1.0
$U^*_{VN}\left(\frac{\rho_V}{\rho_L - \rho_V}\right)^{0.5}$
U^*_{VN} denotes flooding velocity (ft/s).
L,V denote liquid and vapour flowrates.
ρ_L, ρ_V denote liquid and vapour densities.
1 ft/s = 0.3048 m/s

END OF PAPER