UNIVERSITY COLLEGE LONDON

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EXAMINATION FOR INTERNAL STUDENTS

For the following qualifications :-

B.Eng.   M.Eng.   M.Sc.

Chemical Eng E849: Mass Transfer Operations

COURSE CODE	:	**CENGE849**
UNIT VALUE	:	**0.50**
DATE	:	**14-MAY-02**
TIME	:	**14.30**
TIME ALLOWED	:	**3 hours**

02-C0183-3-100

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Chemical Engineering

E849

*Answer **FIVE** questions only.*
*Each question carries a total of **25 marks** distributed as shown [ ]*

Additional stationery provided: graph paper

1. An air stream containing ammonia (NH_3) is to be purified by continuous counter-current contact with clean water in a packed tower. The inlet gas contains 7% by volume of ammonia of which 99% is to be removed. The ammonia-free mass flowrate of air is 5000 kg/h m^2.

The equilibrium solubility of ammonia in water on a molar ratio basis is given by:

$Y_A^* = 0.9\ X_A$

where Y_A^* is the mole ratio of ammonia in the gas phase and X_A is the mole ratio of ammonia in the liquid phase.

Calculate the following:

a) the minimum liquid solvent flow rate [8]

b) the required height of the packed column when the liquid solvent flow rate is 2 times the minimum and assuming that the mass transfer coefficient is $K_{OG}a = 300$ kmol/h m^3 [17]

(average molecular weight of air = 29; molecular weight of ammonia = 17)

2. 10000 kg/hr of a mixture containing 40% (mole) methanol (CH_3OH) and 60% (mole) water (H_2O) is fed to a fractionating column to produce a distillate containing 90% (mole) methanol and a residue containing 90% (mole) water. The column is operating at 760 mmHg and is equipped with a total condenser and a partial reboiler. Assume that the feed, the distillate and the residue are all saturated liquids.

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

a) enthalpies of feed, distillate and residue [2]
b) minimum reflux ratio Rmin [3]
c) number of theoretical stages for a reflux ratio R = 1.5 Rmin [15]
d) condenser and reboiler thermal duties for a reflux ratio R = 1.5 Rmin [5]

Data
Enthalpy-concentration diagram and a y-x diagram for the methanol-water system provided.

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3. A multicomponent light hydrocarbons mixture is to be fed as saturated liquid (q=1) into a tray tower operating at 2 atm in conjunction with a total condenser and a partial reboiler. The composition of the feed is given in Table 1. The distillate will have a content of n-pentane equal to a molar fraction of 0.05 and negligible n-hexane; the bottom product (residue) will have a content of n-butane equal to a molar fraction of 0.05 and negligible propane.

Table 1

All compositions are given in molar fractions	
	Feed (x_F)
1) propane	0.17
2) n-butane	0.32
3) n-pentane	0.35
4) n-hexane	0.16

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: $\ln(P^\circ)=A-(B/(T+C))$

where: [P°=mmHg] [T=K]

Fenske's Equation:

$$N_M + 1 = \frac{\ln\left[\left(\frac{x_{LK}}{x_{HK}}\right)_D \left(\frac{x_{HK}}{x_{LK}}\right)_B\right]}{\ln(\alpha_{LK})}$$

where:

N_M = minimum number of theoretical stages in column

q = heat to vaporize 1 mole of feed ÷ molar latent heat of feed

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

x = liquid mol fraction

F, D, B = feed, distillate and residue respectively

LK, HK = light key and heavy key respectively

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4. An existing sieve tray is to be used to process a vapour flowrate of 4500 kg/h (density 2.85 kg/m^3) and a liquid flowrate of 2800 kg/h (density 810 kg/m^3). The column dimensions are as follows:

Tray type:	sieve tray - single pass	
Column diameter	D	0.80 m
Tray spacing	l_t	0.45 m
Weir height	h_w	38 mm
Weir length	l_w	0.56 m
Hole diameter	d_h	6 mm
Downcomer clearance	h_{ap}	38 mm
Column cross-sectional area	A_c	0.50 m^2
Downcomer area	A_d	0.05 m^2
Net area	$A_n = A_c - A_d$	0.45 m^2
Active area	$A_a = A_c - 2A_d$	0.40 m^2
Total hole area	$A_h = 0.10A_a$	0.04 m^2
Tray metal thickness	t	2.4 mm

Calculate the following:

a) percentage flooding (% flooding) [7]

Given:

$$\text{percentage flooding} = 100\frac{u_n}{u_f}$$

where:

u_n is the actual gas velocity based on net area A_n

$$u_f = K_1\sqrt{\frac{\rho_l - \rho_v}{\rho_v}}$$

(ρ_v and ρ_l are the densities of vapour and liquid respectively)

note that K_1 must be read from the chart provided after calculating the F_{LV} factor:

$$F_{LV} = \frac{L_W}{V_W}\sqrt{\frac{\rho_v}{\rho_l}}$$

(L_W and V_W are the mass flow rates of vapour and liquid respectively, kg/s)

CONTINUED

b) total tray pressure drop (h_t) [mm] [7]

Given:
$h_t = h_d + (h_w + h_{ow}) + h_r$ [mm]

where:
h_d = dry plate drop = $51 (u_h/C_{vo})^2 (\rho_v/\rho_l)$ [mm]
u_h is the actual gas velocity through holes, based on total hole area A_h
note that C_{vo} must be read from the chart provided
h_{ow} = crest of liquid over the weir = $750(L_w/(\rho_l l_w))^{0.667}$ [mm] (L_w as kg/s)
$h_r = 12500/\rho_l$ [mm]

c) height of liquid in the downcomer (h_b) [mm] [6]

Given:
$h_b = (h_w + h_{ow}) + h_t + h_{dc}$ [mm]

where:
$h_{dc} = 166(L_w/(\rho_l A_{ap}))^2$ [mm] (L_w as kg/s)
and $A_{ap} = h_{ap} * l_w$ [m^2]

d) downcomer residence time [5]

Given:
$t_r = \frac{A_d h_b \rho_l}{L_w}$ [sec] (L_w as kg/s, h_b as metre)

Data
Chart for calculating flooding velocity
Chart for calculating discharge coefficient C_{vo}

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

b) Write equations describing for 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 assumption that you may make. [5]

f) Twelve hours are required under constant drying conditions to reduce the moisture content of a wet solid from 24% to 6% with a critical moisture content of 12% and an equilibrium moisture content of 3%. How long would it take to dry a similar material from 36% to 9%? [12]

(All compositions are given on a dry basis)

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6. A power plant uses 360000 kg/h cooling water taken from a river nearby. After usage within the power plant, the cooling water has increased its temperature up to 40°C.
Environmental regulations impose that before the cooling water is discharged to the river it must be cooled down to 20°C. To this purpose, a forced draught countercurrent cooling tower is to be used.
Assuming that the wet bulb temperature of inlet air fed to the tower is 10°C and that the temperature of outlet air (nearly saturated) is 30°C, compute the following:

a) Air flow rate flowing through the tower; [10]

b) Number of gas transfer units (NTU), with the aid of a graphical construction on the graph paper supplied, which must be attached to your answer book. [15]

Data:

Heat capacity of liquid water: 4.19 kJ/kg °C

Saturated Air Temperature °C	10	15	20	25	30	35	40	45
Enthalpy of Saturated Air-Water vapour mixture (kJ/kg)	29.5	42.4	57.9	77	100.6	130.3	167.8	215.6

Standard graph paper to be supplied (A4 size)

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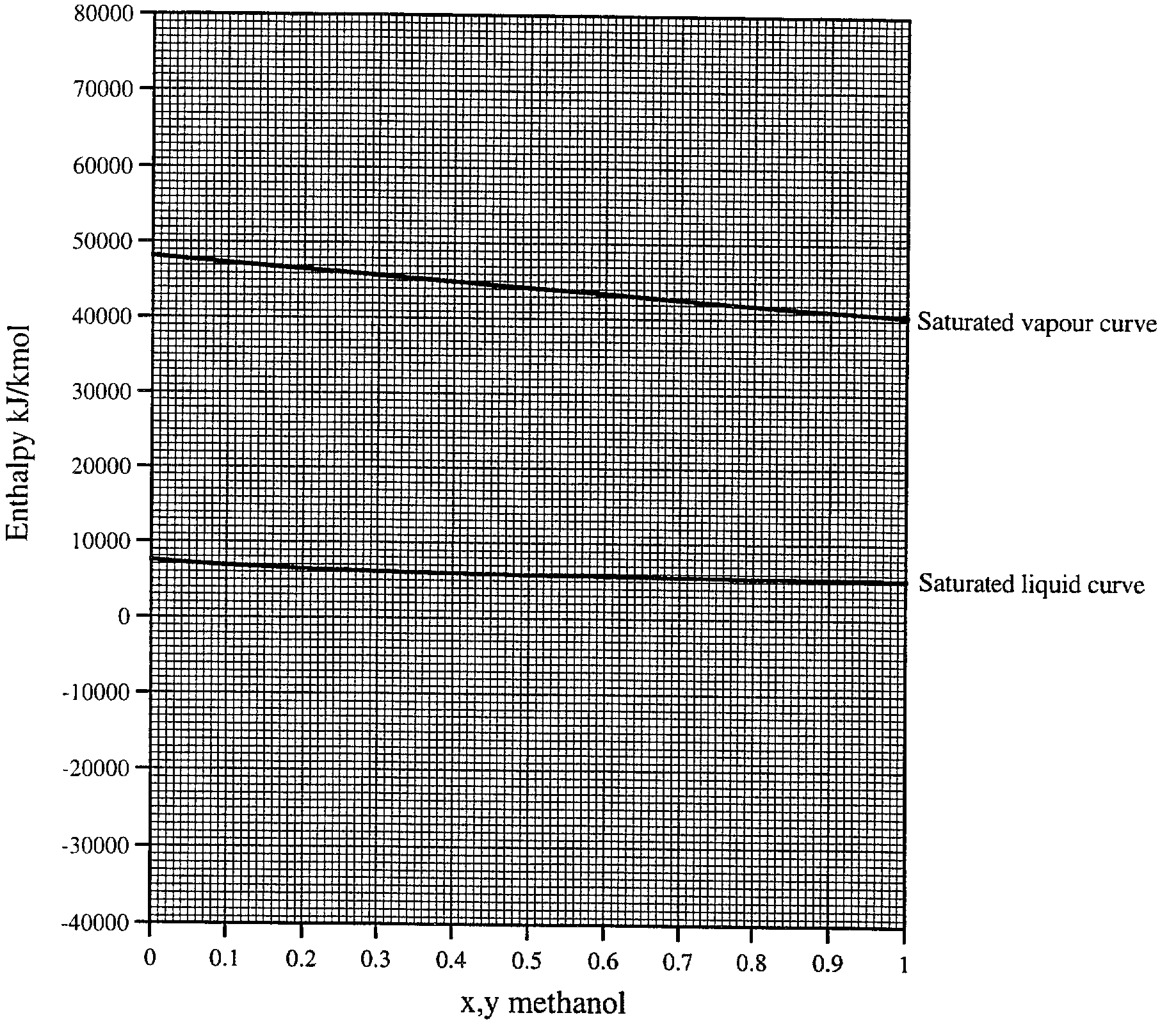
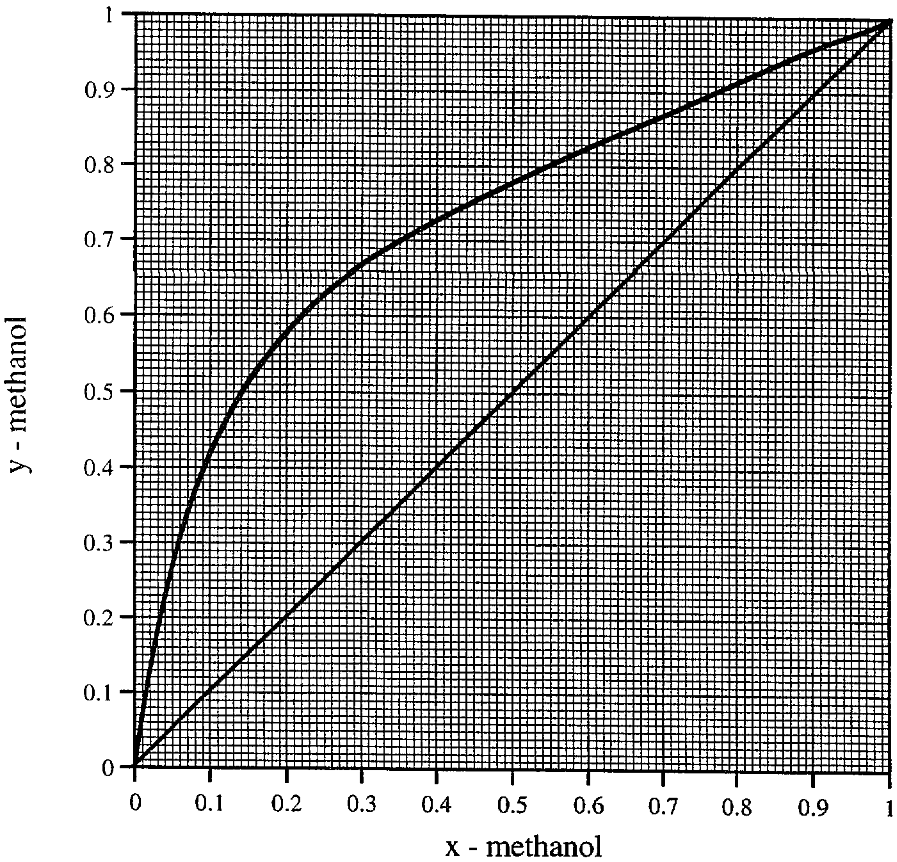
E-849 Exam paper 2002: Question number 2





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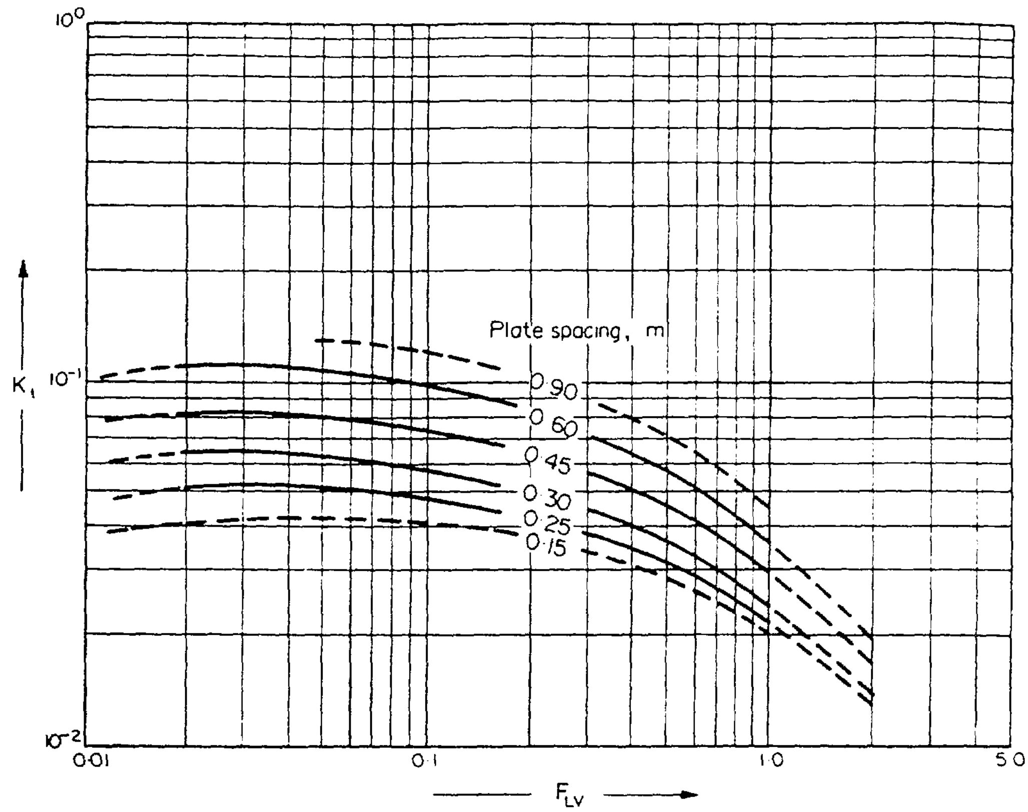
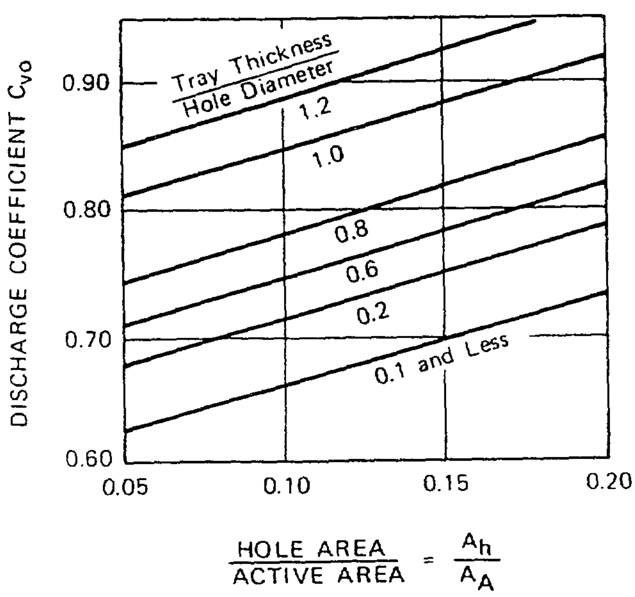


Flooding velocity, sieve plates

E 849 - 2002 EXAMS - QUESTION 4 - DIAGRAMS TO BE PROVIDED



Discharge coefficient for sieve trays.

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