UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

ORIGINAL

SCHOOL OF ENGINEERING

PRACTICAL TEST: OCTOBER 2019

COURSE AND CODE: CHEMICAL ENGINEERING PRACTICALS 2 ENCH3CP

DURATION: 3 HOURS

TOTAL MARKS: 80

INTERNAL EXAMINER(S): DR K MOODLEY
PROF P NAIDOO

INTERNAL MODERATOR(S):

EXTERNAL MODERATOR:

INSTRUCTIONS:

1. Ensure that your student number is written on the **Answer Book.**
2. Answer questions on the provided answer book. You may request additional paper if necessary.
3. Only scientific calculators may be used. Programmable calculators are not allowed. Statistic calculations must be shown in sufficient details to illustrate your understanding of the procedure.
4. This is a CLOSED book test. All necessary equations and tables are provided in the data sheet on pages 9-12.
5. There are **SEVEN** questions. Answer only **FOUR** questions per instructions. **Answer in ink.**
6. Tick the questions that must be marked.

Q1 (VLE) or (IPMT)	Q2 (Pump & Fan)	Q3 (Fluidization) or (RTD)	Q4 (CT)

SECTION A

QUESTION 1: VAPOUR LIQUID EQUILIBRIUM (VLE)

The modified VLE still of Ndlovu (2005) is shown below. The still was modified from that of Joseph et al. as used in your VLE practical to be able to perform measurements for systems displaying high relative volatilities, i.e., exhibiting large differences in concentration between the vapour condensate and liquid in the return lines.

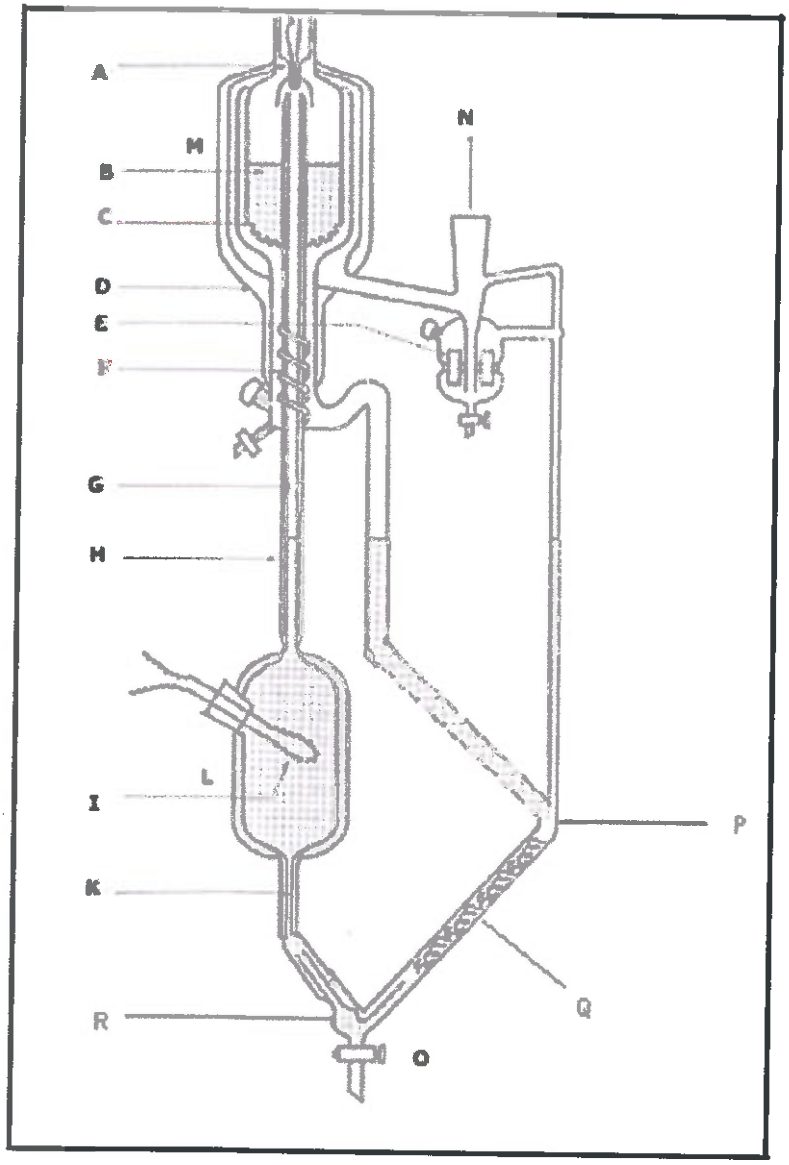


FIGURE 1.1 VLE Still of Ndlovu (2005)

A-Temperature sensor, B-s/s wire mesh packing. C-Equilibrium chamber, D-Vacuum jacket, E-magnetic stirrer, F- s/s spiral, G-Cottrell tube, H-Vacuum jacket, I-Glass tube, K-Capillary, L-Reboiler, M-Equilibrium chamber, N-Inlet to condenser , O-Drain Valve, P-Mixing tee, Q-Glass spiral. R-mixing chamber

1.1 Explain the differences in the still presented in Figure 1.1 to that used in your practical and elaborate on the reasons for the modifications.

(6)

1.2 The measured data for the 2-propanol (1) + n-dodecane (2) system at 343.15 K is presented graphically in Figure 1.2 and tabulated in Table 1.1.

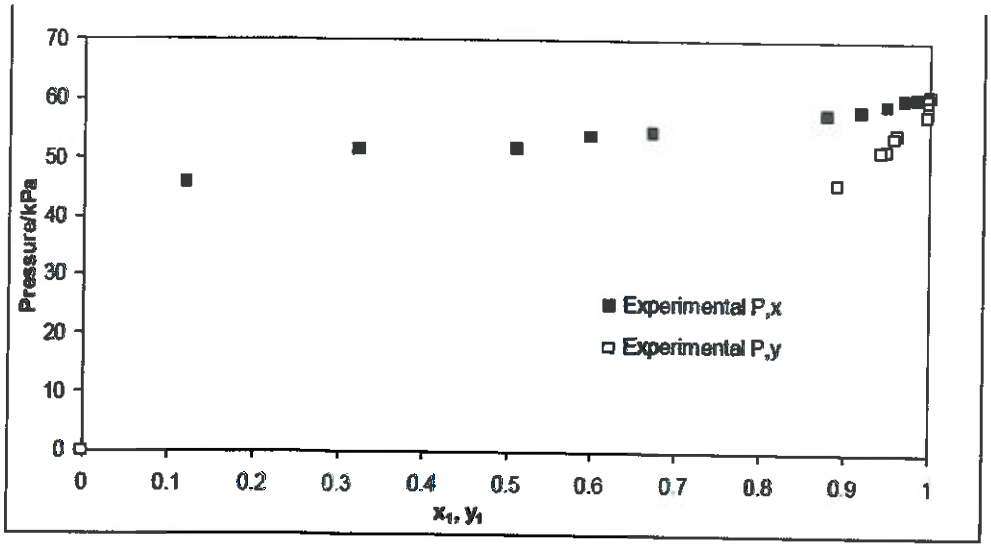


Figure 1.2. P-x-y plot for system 2-propanol (1) + n-dodecane (2) at 343.15 K.

Table 1.1. VLE data for the system 2-propanol (1) + n-dodecane (2) at 343.15 K.

P (kPa)	x_1	y_1	γ_1	γ_2
60.35	0.999	0.985	1.001	12.332
60.17	0.998	0.970	1.004	10.751
59.34	0.998	0.949	1.012	9.078
58.32	0.998	0.919	1.027	7.336
57.42	0.997	0.880	1.053	5.827
54.29	0.962	0.673	1.309	2.657
53.78	0.957	0.599	1.454	2.209
51.74	0.949	0.511	1.688	1.835
51.32	0.943	0.325	2.582	1.356
45.65	0.892	0.123	6.048	1.074

(i) Is the Margules 3-suffix model an appropriate model to correlate the data? Show with explanations.

(5)

(ii) *Bhownath et al.* regressed the data using various activity coefficient models as shown in Table 1.2. Comment on the suitability of the models for correlating the system.

(2)

(iii) Comment on the measured experimental data as presented in Figure 1.2.

(6)

Table 1.2. Activity model parameters and deviations between calculated and experimental measurements for 2-propanol (1) + n-dodecane (2) system.

Activity coefficient model	343.15K
Wilson	
λ_{12}-λ_{21} (J/mol)	9650.867
λ_{12}-λ_{22} (J/mol)	1848.416
Average δP (kPa)	0.023
Average δy_1	0.011
NRTL	
g_{12}-g_{11} (J/mol)	2145.874
g_{12}-g_{22} (J/mol)	2131.191
α	-0.067
Average δP (kPa)	0.031
Average δy_1	0.020
UNIQUAC	
u_{12}-u_{11} (J/mol)	455.279
u_{12}-u_{22} (J/mol)	1566.403
Average δP (kPa)	0.294
Average δy_1	0.102

DATA

	$T_{\text{normal boiling pt, 1 atm}}$ (°C)	Molar mass (g/mol)
2-propanol	85	60.096
n-dodecane	216	170.340

TOTAL /20/

ANSWER QUESTION 1 (VLE OR IPMT)

QUESTION 1: INTERPHASE MASS TRANSFER (IPMT)

1.1 State the expression relating the rate of mass transfer, then explain how the mass transfer coefficient, k_w, was determined for this practical?

(3)

1.2 The use of common dimensionless numbers (Re, Sc, Pr, etc.) in understanding engineering processes and systems helps to relate these measurements to a specific physical system, i.e., Reynold's number to forced convection or flow. Explain the significance and use of the Sherwood and Schmidt numbers in this experiment, as well as the meaning of B in the following expression:

$$Sh = aRe^B Sc^C$$

(3)

1.3 The fragrance industry is booming with use of new scents, and extension of its applications in different products. Jasmone ($C_{11}H_{16}O$) is a valuable specialty chemical obtained via extraction of the plant material (jasmine flowers) in water. Benzene is then used to concentrate this essence extract. Jasmone is 170 times more soluble in benzene than in water hence is a popular solvent.

Your task as the engineer is to consider **solvent extraction (liquid-liquid) and hydro-distillation (steam)** for the extraction of jasmone.

(i) In using the current laboratory set-up, explain the key aspects in the preparation of the experiment. (5)

(ii) In performing a calibration to determine the concentration of the extract in each of the phases, explain the calibration technique when using the refractometer?

(4)

(iii) Explain some (at least four) criteria you would consider in assessing these two competing technologies of extraction and hydro distillation.

(5)

TOTAL /20/

QUESTION 2: PUMP & FAN

a) Can linear regression be used in the subsequent calculations or data analysis of the P&F practical? (1)

b) With **only** the help of a diagram, explain how you can determine the operating conditions of a fan? (5)

c) How can uncertainty in the pump measurements be taken into account? (2)

d) In the pump and fan practical, state the pump speeds that were used to carry out the experiment? (1)

e) What is the purpose of the fan experiment? (2)

f) Which instrument was used to determine the speed of the pump and the volumetric flowrate of water? (2)

g) If the speed of the centrifugal pump is increase with 10%, what will be the increase in the capacity and head of the pump in percent? Show sample calculations. (3)

h) Suppose that the centrifugal pump used in the Pump and Fan practical has a capacity of 60 l/min, a 1.5 kW motor, and operates at 50% of the stated maximum speed. What is the resulting change to the pump capacity and power needed if the pump was to operate at its maximum speed? (4)

TOTAL /20/

ANSWER QUESTION 3 (FLUIDISATION OR RTD)

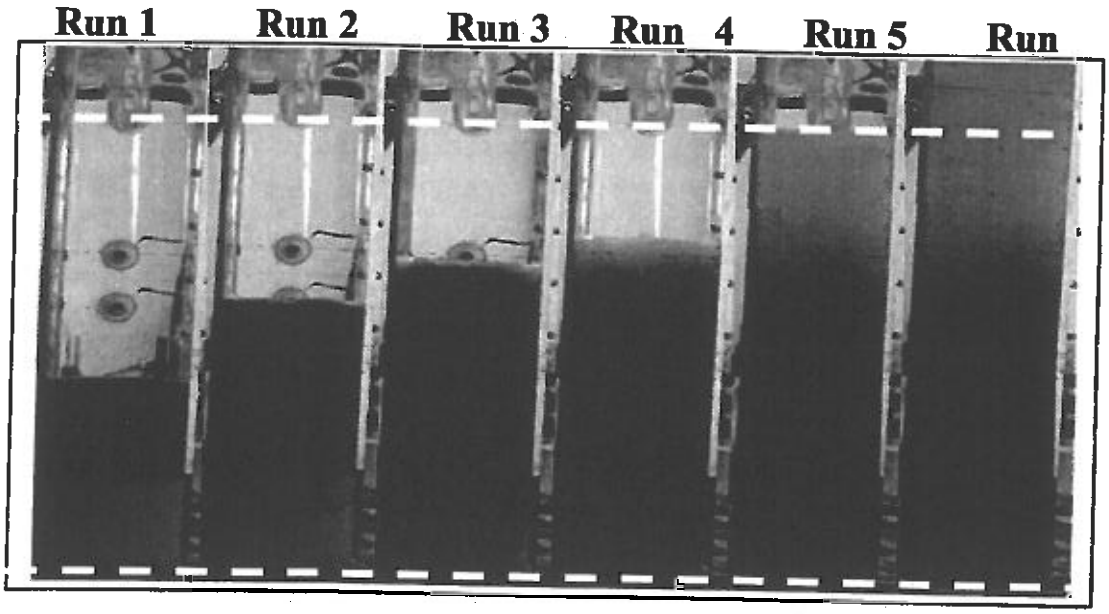
QUESTION 3: FLUIDIZATION

The experimental behaviour of a wet fluidized bed was determined by Chun et al. (2011)[1] and is shown in Figure 4.1 below.

The superficial velocities for each run are:

Run 1 = 18.2 mm/s, Run 2 = 28.1 mm/s, Run 3 = 32 mm/s, Run 4 = 38.2 mm/s,
Run 5 = 43.1 mm/s, Run 6 = 48 mm/s.

The apparatus diameter is 210 mm and the test section height is 1.8 m, indicated by the white dashed lines. The volume of granular material in the bed is 0.009606 m^3.



a) What behaviour is being exhibited in Run 4-6 and what conditions could cause such a behaviour to occur?

(4)

b) Determine correlative expressions that will allow for the calculation of superficial velocity from bed height for the two distinct fluidization regimes.
Hint: Since the behaviour of each regime can be correlated by a linear equation, a graphical solution is not necessary.

(12)

c) Determine the superficial velocity at which the behaviour above would begin to occur (transition point) in this bed.

(4)

TOTAL /20/

ANSWER QUESTION 3 (FLUIDISATION OR RTD)

QUESTION 3: RESIDENCE TIME DISTRIBUTION

A tracer test was conducted with the following results:

Table 5.1: Tracer Test Results.

t (s)	0	5	10	15	20	25	30	35
C (mg/dm^3)	0	0	0	6	12	6	0	0

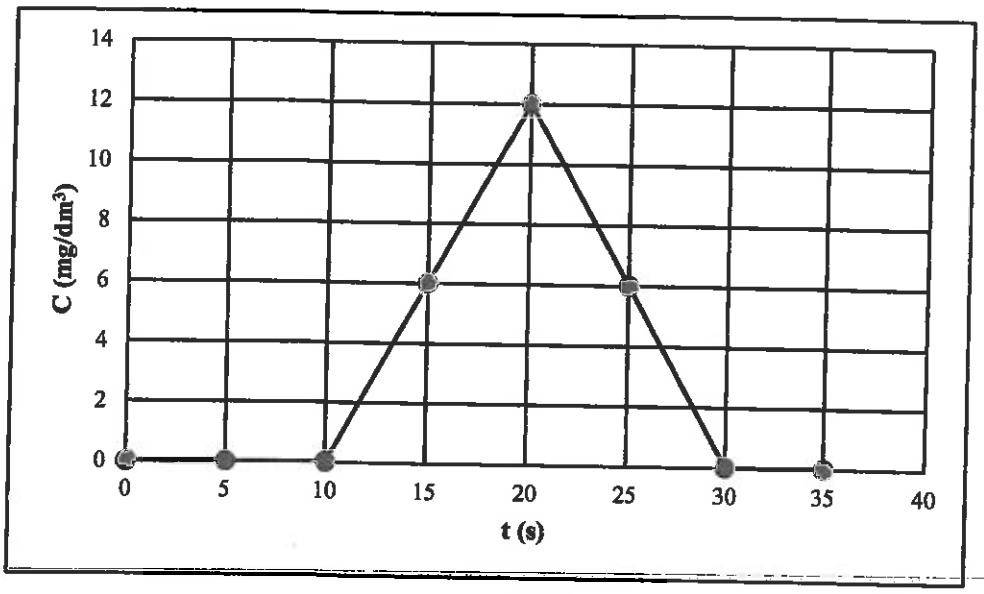


Figure 5.1: Plot of Concentration Versus Time

a) Determine the residence time distribution at each measured time interval and the fraction of material that spends 15-20 seconds in the reactor. (4)

b) Sketch the cumulative distribution function including all measured time steps. (4)

c) Confirm the mean residence time by calculation. (6)

d) Determine the standard deviation. (6)

TOTAL /20/

QUESTION 4: COOLING TOWER

a) Using technically specific terms (and equations where necessary) pertaining to cooling tower operation, define the following:

i) Range
ii) Approach
iii) Effectiveness
iv) Cooling capacity
v) Evaporation loss
vi) Fill

(6)

b) To analyse the operational performance of a cooling tower, what measurements/observations should be taken and why?

(4)

c) What is the significance of the wet bulb temperature and how does it affect the performance of a cooling tower?

(5)

d) How can the performance of a cooling tower be improved if it is not functioning effectively?

(5)

TOTAL /20/

DATA SHEETS

1) General statistical formulae

Standard deviation: $s = \sqrt{\frac{\sum_{i=1}^{N}(Y_i - \bar{Y})^2}{N-1}}$

Confidence interval on the mean: $\bar{Y} \pm t_{(\alpha/2, N-1)} \cdot \frac{s}{\sqrt{N}}$

Test statistic: $t_0 = \frac{\bar{x}_1 - \bar{x}_2}{S_p\sqrt{\frac{1}{n_1} - \frac{1}{n_2}}}$ where $S_p = \frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1 - n_2 - 2}$

Table of t- statistic values

	α/2		
N-1	0.05	0.025	0.005
2	4.303	6.205	14.089
3	3.182	4.177	7.453
4	2.776	3.495	5.598
5	2.571	3.163	4.773
6	2.447	2.969	4.317
7	2.365	2.841	4.029
8	2.306	2.752	3.833
9	2.262	2.685	3.690
10	2.228	2.634	3.581
15	2.131	2.490	3.286
30	2.042	2.360	3.030

$\bar{X} = average\ X\ value = \frac{\sum X_i}{N}$

$\bar{Y} = average\ Y\ value = \frac{\sum Y_i}{N}$

$S_{XX} = \sum_i (X_i - \bar{X})^2 = \sum_i (X_i^2) - \frac{(\sum X_i)^2}{N}$

$S_{YY} = \sum_i (Y_i - \bar{Y})^2 = \sum_i (Y_i^2) - \frac{(\sum Y_i)^2}{N}$

$S_{XY} = \sum_i (X_i - \bar{X})(Y_i - \bar{Y}) = \sum_i (X_i Y_i) - \frac{(\sum X_i)(\sum Y_i)}{N}$

Slope: $b = \frac{S_{XY}}{S_{XX}}$

Intercept: $a = \bar{Y} - b\bar{X}$

Coefficient of correlation : $r_{XY} = S_{XY}/\sqrt{S_{XX} \times S_{YY}}$

Standard deviation of the regression coefficient $S_b = \sqrt{\frac{S_{YY} - b^2 S_{XX}}{N-2}}$

Confidence interval on the slope is $b \pm t_{(\alpha/2, N-2)} \frac{S_b}{\sqrt{S_{XX}}}$

2) Cooling Tower

C_p of water at 25°C = 4.181 kJ/kg.K

Efficiency of a cooling tower: $\frac{\text{Range}}{\text{Approach} + \text{Range}}$

$\rho = 998 \frac{kg}{m^3}$

Effect of A: $A = \frac{1}{2}[ab + a - b - (1)]$

Effect of B: $B = \frac{1}{2}[ab + b - a - (1)]$

Interaction effect AB: $AB = \frac{1}{2}[ab + (1) - a - b]$

3) Fluidised Beds

Ergun equation: $\frac{\Delta P}{L} gc = 150 \frac{(1-\varepsilon)^2}{\varepsilon^3} \frac{\mu u_c}{(\Phi sdp)^2} + 1.75 \frac{1-\varepsilon}{\varepsilon^3} \frac{\rho u c^2}{\Phi sdp}$

Kunii & Levenspiel equation: $\frac{1.75}{\varepsilon^3 \phi_s} . \mathrm{Re}^2 + 150 \frac{(1-\varepsilon)}{\varepsilon^3 \phi^2} . \mathrm{Re} = \mathrm{Ga}$

Galileo Number: $\mathrm{Ga} = \frac{d_p^3 \rho (\rho_s - \rho) g}{\mu^2}$

Reynolds number: $\mathrm{Re} = \frac{u_{mf} d_p \rho}{\mu}$

Minimum bubbling velocity: $u_{mb} = \exp(0.716F) 2.07 \frac{d_p * \rho^{0.006}}{\mu^{0.347}}$

Quadratic formula: $ax^2 + bx + c = 0; \quad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Richardson Zaki equation $\frac{u_c}{u_i} = \varepsilon^n$

$Ga = 18 Re_t' \ (Ga < 3.6)$

$Ga = 18 Re_t' + 2.7 \ (Re_t')^{1.687} \ (3.6 < Ga < 10^5)$

$Ga = \frac{1}{3} (Re_t')^2 \ (Ga < 10^5)$

Sphericity =0.78

Particles diameter : $d_p = d_s \times \Phi$

4) Interphase Mass Transfer

Mass Transfer Flux: $\frac{dN}{dt} = k_w(C_s - C(t))dt$ or $k_w A t = -V_W ln\left[\frac{C_s - C}{C_s}\right]$

5) Pump and Fan

Energy Balance: $\frac{v_1^2 - v_2^2}{2} + \frac{P_1 - P_2}{\rho} + g(z_1 - z_2) + \frac{W_s}{\rho} = \frac{4L}{d_i} \cdot f \cdot \frac{u^2}{2}$

Manometer equation: $\frac{\Delta P}{\rho} = R'(SG - 1) - h$

Power: $Power = H_{pump} \cdot \rho \cdot g \cdot Q$

$g = 9.81\, m/s^2$

Churchill equation: $f = \left[\left(\frac{8}{Re}\right)^{12} + (A + B)^{-1.5}\right]^{\frac{1}{12}}$

With $A = \left[-2.457 ln\left(\left(\frac{7}{Re}\right)^{0.9} + 0.27\frac{\varepsilon}{d}\right)\right]^{16}$

And $B = \left(\frac{37530}{Re}\right)^{16}$

Assume $\varepsilon = 1 \times 10^{-6}$

$\rho = 1000\frac{kg}{m^3}$

And $\mu = 1.0 \times 10^{-3}$

6) Vapour Liquid Equilibria

Universal Gas Constant, R [L bar K^{-1} mol^{-1}] = 0.0831447

R [J mol^{-1} K^{-1}] = 8.31447

Modified Raoult's Law: $y_i P = x_i \gamma_i P_i^{sat}$

Gibbs Excess Energy: $\frac{G^E}{RT} = x_1 ln\gamma_1 + x_2 ln\gamma_2$

Margules 2 suffix model: $\frac{G^E}{RT} = A x_1 x_2$

Margules 3 suffix model: $\frac{G^E}{RT} = (A_{21}x_1 + A_{12}x_2)x_1 x_2$

Van Laar model: $\frac{G^E}{RT} = \frac{A_{12}A_{21}x_1 x_2}{x_1 A_{12} + x_2 A_{21}}$

7) Residence Time Distribution

$$E(t) = \frac{C(t)}{\int_0^\infty C(t)dt}$$

$$F(t) = \int_0^t E(t)dt$$

$$t_m = \tau = \int_0^\infty tE(t)dt$$

$$\sigma^2 = \int_0^\infty (t-\tau)^2 E(t)dt$$

1. Chun et al. 2011. Layer inversion and mixing of binary solids in two-and three-phase fluidized beds. Chemical engineering science, 66(14), pp.3180-3184.