UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

PRACTICAL TEST: OCTOBER 2018

COURSE AND CODE: CHEMICAL ENGINEERING PRACTICALS 2 ENCH3CP

DURATION: 2 HOURS

TOTAL MARKS: 80

INTERNAL EXAMINER(S): MR MG NTUNKA

INTERNAL MODERATOR(S): DR J POCOCK

EXTERNAL MODERATOR: DR K TUMBA

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. **ALL** questions should be attempted. **Answer in ink.**
4. 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.
5. This is a CLOSED book test. All necessary equations and tables are provided in the data sheets on pages 7-10.

QUESTION 1: FLUIDIZED BEDS

For the fluidized bed practical, the rotameter which has been installed needs to be calibrated. The measured data are included in Table 1.1.

Table 1.1 Calibration of the fluidized bed rotameter and summary of statistics

Flow rate, Y [l/min]	Rotameter reading, X [%]	Statistics
15	10	$N = 7$
35	20	$\bar{X} = 49.2$
60	35	$\bar{Y} = 86.7$
100	55	$S_{XX} = 5670.8$
140	80	$S_{YY} = 18483.3$
170	95	$S_{XY} = 10233.3$

a) Compute the calibration equation and the correlation coefficient R^2.

(4)

b) Calculate the uncertainty for the estimated slope at an interval confidence of 95%.

(4)

c) The Sauter mean diameter of a sample of particles with a distribution of particle diameter is calculated using the expression for d_s below. What average property of the sample does the Sauter mean diameter represent?

$$d_s = 1/\sum \frac{f_i}{d_i}$$

(2)

d) In the wet fluidization, ilmenite and calcite are separated using a dry high intensity magnetic separator and are screened over a range of sieves to determine the size distribution. What did you observe from the plotted histogram of the particle size distribution?

(2)

TOTAL /12/

QUESTION 2: PUMP & FAN

a) Can linear regression be used in the subsequent calculations or data analysis of the P&F practical? If no, explain how best you can take into account uncertainty in the pump measurements.

(3)

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

(5)

c) From the following data, **calculate** the pump head of the multistage centrifugal pump in Figure 2.1.

Suction pipe internal diameter

d_{is}=12cm

Discharge pipe internal diameter

d_{id}=5cm

Discharge elevation h_d= 3m

Suction elevation h_s = negligible

Discharge pipe length = 7.2m

Flow rate on discharge side = 3.4l/s

Suction side pressure = 120kPa

Discharge side pressure = 300kPa

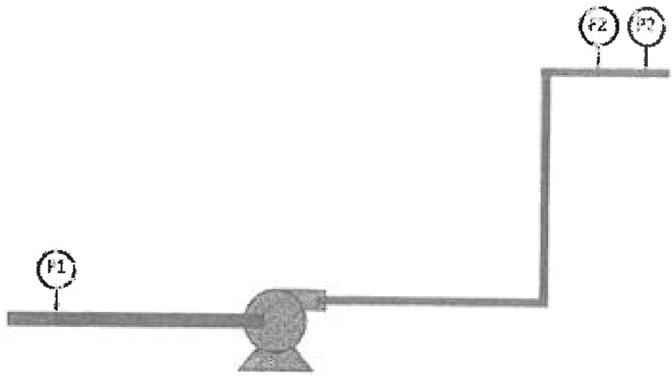


Figure 2.1: Multistage centrifugal pump and associated measurements

(11)

d) Is it true or false that "generally, the larger the pump, the higher the efficiency? What range was the efficiency of pump under investigation in the P&F practical?

(3)

TOTAL /22/

QUESTION 3: COOLING TOWER

A graduate engineer is interested in studying the performance of an induced-draught cooling tower, which is influenced by TWO key process variables (or control factors). The engineer decides to design an experiment in order to investigate the effect of these variables on the performance of that cooling tower.

a) Give two reasons why the One-Factor-At-a-Time (OFAT) strategy is not an appropriate approach to engineering experimentation.

(2)

b) If the process variables are represented by A and B, and the response variable by Y, propose a factorial design at two levels with three replicates for the cooling tower experiment.

(3)

c) Propose a mathematical model for the study with interactions between parameters A and B.

(1)

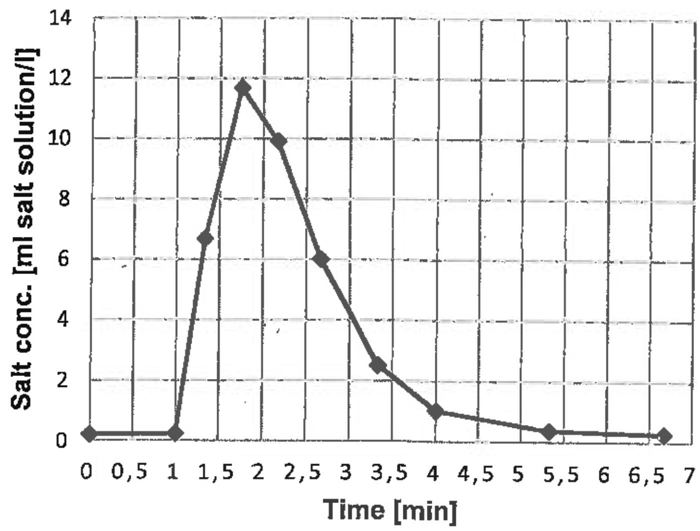
d) In today's economic framework situation of energy conservation and sustainability, utilizing cooling water efficiently is a vital engineering consideration. Is there a range of one process variable that would give a maximum response variable (good performance) regardless of the other process variable on the operation of the induced draught cooling tower? Describe the conditions under which you will optimally run the cooling tower.

(5)

TOTAL /11/

QUESTION 4: RESIDENCE TIME DISTRIBUTION

The following trace was obtained from the RTD practical by injecting $10ml$ of a concentrated salt solution into the experimental plug flow reactor (without tubes) at a flow rate of $0.45l/min$. The table contains values for the selected data points.



Time $[min]$	Conc. $[ml/l]$
0.00	0.21
1.00	0.23
1.33	6.68
1.75	11.69
2.17	9.92
2.67	6.00
3.33	2.51
4.00	1.02
5.33	0.37
6.67	0.27

Figure 4.1: concentration profile of the effluent from the plug flow reactor after a pulse injection of salt at time $t = 0$.

a) Perform a consistency test on the data in the table.

(10)

b) What sources of uncertainty in data and calculation procedure may impact on the salt recovery consistency test.

(2)

c) What is the unit of the area under the response curve?

(1)

TOTAL /13/

QUESTION 5: VAPOUR LIQUID EQUILIBRIUM

The two-suffix Margules equation $G^E = Ax_1x_2$ is the simplest expression for the excess Gibbs free energy that is obeyed by chemically similar materials. A is the model parameter.

a) Derive the two expressions for the activity coefficients that result from the Margules equation model.

(5)

b) Show on a graph the typical plots of $\ln\gamma_1$, $\ln\gamma_2$ and G^E/RT against the composition.

(4)

c) Explain with the aid of a flowchart show how you can use the Gibbs-Duhem equation to check whether the VLE data for the system Ethanol-Cyclohexane at atmospheric pressure are thermodynamically consistent.

(5)

TOTAL /14/

QUESTION 6: INTER-PHASE MASS TRANSFER

a) In the IPMT practical, what (conceptually) is C_s? Give an approximate value of C_s.

(2)

b) What can interfacial resistance to mass transfer be attributed to?

(4)

c) What is the driving force for mass transfer in the IPMT practical? Describe in your own words and provide an equation.

(2)

TOTAL /8/

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

N-1	α/2 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: $\frac{\Delta P}{L} gc = 150\frac{(1-\varepsilon)^2}{\varepsilon^3}\frac{\mu u_c}{(\Phi sdp)^2} + 1.75\frac{1-\varepsilon}{\varepsilon^3}\frac{\rho uc^2}{\Phi sdp}$

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

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

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

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

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

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

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 $k_w At = -V_W ln\left[\frac{C_s - C}{C_s}\right]$

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

Antoine Equation: $\log_{10}(P_{vp})[bar] = A - \frac{B}{T[K] + C - 273.15}$

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

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

Antoine Constant for Ethanol

A	5.33675
B	1648.22
C	230.918

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: $\frac{G^E}{RT} = Ax_1x_2$

Margules 3 suffix model: $\frac{G^E}{RT} = (A_{21}x_1 + A_{12}x_2)x_1x_2$

Van Laar model: $\frac{G^E}{RT} = \frac{A_{12}A_{21}x_1x_2}{x_1A_{12} + x_2A_{21}}$

7) Residence Time Distribution

Numerical Integration : $\int_0^\infty C(t)dt = \sum \frac{1}{2}(t_{i+1} - t_i)(y_{i+1} + y_i)$

Mean residence Time : $MRT = \frac{\sum_{i=1}^{\infty}(C_i \times t_i \times \Delta t_i)}{\sum_{i=1}^{\infty}(C_i \times \Delta t_i)}$

Variance : $\sigma^2 = \overline{t}^2 - (MRT)^2$

with $\overline{t}^2 = \frac{\sum_{i=1}^{\infty}(C_i \times t^2_i \times \Delta t_i)}{\sum_{i=1}^{\infty}(C_i \times \Delta t_i)}$