UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

EXAMINATIONS: JUNE 2019

COURSE AND CODE: CHEMICAL ENGINEERING PRINCIPLES 1 ENCH1EA

DURATION: 3 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINER(S): DR J POCOCK
MRS N MASEKO

INTERNAL MODERATOR(S): PROF I GOVENDER

EXTERNAL MODERATOR: DR SL KIAMBI

INSTRUCTIONS:

1. **ALL** questions should be attempted.
2. **Two answer books are provided. Label them Book A and Book B respectively. Answer Section A in Book A and Section B in Book B.**
3. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
4. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
5. This examination question paper, together with all associated diagrams **MUST BE HANDED IN TOGETHER WITH YOUR SCRIPT.**

Student Number:

SECTION A

QUESTION 1

A process is being developed to manufacture an industrial chemical continuously on a large scale.

There are two raw materials (for ease, these are given as A and B and are available at room temperature) which react exothermically in the presence of a solid catalyst.

The main reaction forms two products C and D as well as a by-product E. All of the B is consumed in the reactor, whilst excess A exits with the products. Table 1, gives the general properties of the products and reactants.

Component	Density (liquid state) (kg/m^3)	Normal Melting Point (°C)	Normal Boiling Point (°C)	Miscibility in liquid state
A	500	-210	-120	Not known
B	920	-15	72	With C and E
C	880	-10	88	With B and E
D	1000	0	100	Immiscible with B,C and E
E	900	3	115	With C and B

Table 1 – Material Properties

a) The reaction takes place at 200°C and is exothermic. What state (vapour, liquid or solid) do A and B have to be in when they enter the reactor?

(1)

b) As the reaction is exothermic, does heat have to be added or removed from the reactor to maintain the constant 200°C reactor temperature?

(1)

c) D is immiscible with C and E. What steps could you take and what unit can be used to separate a product stream of mainly pure D from a mixed stream of C and E?

(3)

d) C and E are miscible. Using data from the table, explain what unit operation can be used to separate them and why?

(3)

e) Using your answers to the above questions and including any necessary heat exchangers and transport devices, generate a Process Flow Diagram on the plain paper provided for production of C, D and E. Remember to include removal (and recycling) of excess A in your PFD, include your student number on the diagram, label the units and provide a table of units linked to the labels.

(25)

TOTAL /33/

QUESTION 2

The following data has been provided from an old data source in a combination of cgs and American Engineering Units. In order to effectively use the information, your team need to convert it all to SI units which are the standard in South Africa. Using the conversion table provided on page 5. Carry out the conversions to SI units.

a) The specific heat capacity of a 9 mol% NaCl solution is given as 0.81 cal/(g.°C) what is its specific heat capacity in J/(kg.K)?

(3)

b) The latent heat of saturated air at 110 °F is given as 958 BTU/lb_m what is the latent heat in kJ/kg and what temperature is the saturated air at in °C?

(4)

c) A piston based pump can pump 37 US Gal/min with a piston speed of 38 ft/min. What is the flowrate possible in m^3/s and what is the piston speed in m/s?

(4)

d) The thermal conductivity of benzene is 0.092 BTU/(hr)(ft^2)(°F/ft) what is it in W/(m.K)?

(5)

e) The pressure of the main reactor vessel is 120 lb_f/in^2 what is it in bar?

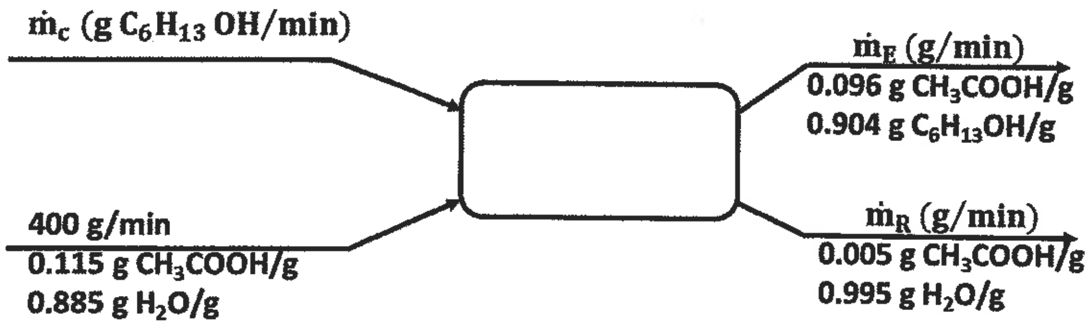
(1)

TOTAL /17/

SECTION B

QUESTION 3

Liquid extraction is an operation used to separate the components of a liquid mixture of two or more species. In the simplest case, the mixture contains two components: a solute (A) and a liquid solvent (B). The mixture is contacted in an agitated vessel with a second liquid solvent (C) that has two key properties: A dissolves in it, and B is immiscible or nearly immiscible with it. (For example, B may be water, C a hydrocarbon oil, and A a species that has significant solubility in both water and oil.) Some of the A transfers from B to C, and then the B-rich phase (the raffinate) and the C-rich phase (the extract) separate from each other in a settling tank. If the raffinate is then contacted with fresh C in another stage, more A will be transferred from it. This process can be repeated until essentially all of the A has been extracted from the B. Shown below is a flowchart of a process in which acetic acid (aa) is extracted from a mixture of acetic acid and water (w) into 1-hexanol (h), a liquid immiscible with water.



a) What is the number of independent material balances that can be written for this process? (2)

b) Do a degree of freedom analysis for this process. (3)

c) Calculate $\dot{m}_R$, $\dot{m}_E$ and $\dot{m}_C$. (11)

d) Calculate the difference between the acetic acid in the 400 g/min stream and the one in the $\dot{m}_R$ stream, show that this difference is equal to the acetic acid in the $\dot{m}_E$ stream. (4)

e) What is the difference between a steady and an unsteady state? Give an example of a process that falls in each of these operating states. (4)

TOTAL /24/

QUESTION 4

Three hundred kg/min of steam at 50 °C enters a boiler and exits at 200 °C and 15 bar. The approach velocity of the steam is negligible and the steam exits the boiler through a 0.08 m internal diameter (ID) pipe. The specific volume of the exit stream is 0.23 m^3/kg. The specific enthalpy of the steam is 2860 kJ/kg at the entrance and 2974 kJ/kg when exiting.

a) What is the exit velocity of the steam?

(7)

b) Write down the energy balance equation for this process and explain why some terms are eliminated.

(4)

c) Calculate the heat gained in kilowatts.

(7)

d) What is the difference between an adiabatic and an isothermal process?

(2)

TOTAL /20/

QUESTION 5

Calculate the heat required to raise 200 kg of nitrous oxide from 20 °C to 150 °C in a constant volume vessel. The constant volume heat capacity of N_2O in this temperature range is given by the equation

$$C_v(\text{kJ/kg.}^\circ\text{C}) = 0.885 + 9.42\text{x}10^{-4}\text{T}$$

where T is in °C .

TOTAL /6/

UNIT CONVERSION TABLE

Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb_m = 35.27392 oz 1 lb_m = 16 oz = 5×10^{-4} ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10^6 microns (μm) = 10^{10} angstroms (Å) = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mile 1 ft = 12 in. = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m^3 = 1000 L = 10^6 cm^3 = 10^6 mL = 35.3145 ft^3 = 220.83 imperial gallons = 264.17 gal = 1056.68 qt 1 ft^3 = 1728 $in.^3$ = 7.4805 gal = 0.028317 m^3 = 28.317 L = 28,317 cm^3
Force	1 N = 1 kg·m/s^2 = 10^5 dynes = 10^5 g·cm/s^2 = 0.22481 lb_f 1 lb_f = 32.174 lb_m·ft/s^2 = 4.4482 N = 4.4482×10^5 dynes
Pressure	1 atm = 1.01325×10^5 N/m^2 (Pa) = 101.325 kPa = 1.01325 bar = 1.01325×10^6 dynes/cm^2 = 760 mm Hg at 0°C (torr) = 10.333 m H_2O at 4°C = 14.696 $lb_f/in.^2$ (psi) = 33.9 ft H_2O at 4°C = 29.921 in. Hg at 0°C
Energy	1 J = 1 N·m = 10^7 ergs = 10^7 dyne·cm = 2.778×10^{-7} kW·h = 0.23901 cal = 0.7376 ft-lb_f = 9.486×10^{-4} Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft·lb_f/s = 9.486×10^{-4} Btu/s = 1.341×10^{-3} hp

Example: The factor to convert grams to lb_m is $\frac{2.20462 lb_m}{1000\ g}$

To convert temperatures:

A change of temperature of 1 °C is equivalent to a change in temperature of 1 K and equivalent to change in temperature of 1.8 °F

To convert absolute temperatures T(°F)=1. 8 T(°C)+32