Université d'Ottawa
Faculté de génie
Département de
génie chimique et biologique

uOttawa
L'Université canadienne
Canada's university

University of Ottawa
Faculty of Engineering
Department of
Chemical and Biological Engineering

CHG 2317
MIDTERM

Last Name: ________________
First Name: ________________
Student Number: ________________

Duration: 75 minutes

- The exam is **open book** but **closed notes**. It is scored out of a total of 34 marks and the value of each question is recorded in parentheses next to the question.
- One double-sided letter sized study aid is permitted.
- Work may be written on the back of the page if necessary but you should not need to write that much.

Marks:

Question	1 (/10)	2 (/8)	3 (/8)	4 (/8)	Total (/34)
Mark					

1. Answer the following questions. **(Each question is worth 2 points)**

   a. **True or False:** Henry's Law is applicable to dilute ideal solutions.

   b. **True or False:** It is possible to know the absolute value of enthalpy or internal energy in a process material.

   c. **Multiple Choice:** Superheated steam has a specific enthalpy of 3095 kJ/kg at a pressure of 40 bar absolute. What is the degree of superheat?
      a. 350 °C
      b. 250 °C
      c. 150 °C
      d. 100 °C

   T^{sat} @ 40 bar = 250.3 °C

   $T_{superheated\ steam}$ = 350 °C → Degree of super heat = 99.7 °C

   d. **Multiple Choice:** The vapour pressure of n-decane at 100 °C is:
      a. 3.733 mmHg
      b. 71.73 mmHg
      c. 1.856 mmHg
      d. 5527 mmHg

   $\log p^{sat} = 6.95707 - \frac{1503.568}{100 + 194.738}$ ⇒

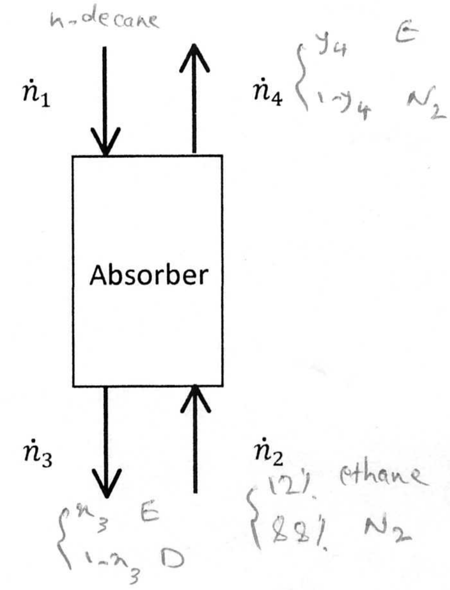
   $p^{sat} = 71.73$ mmHg

   e. **Multiple Choice:** Saturated liquid water at 15 bar gauge has a specific internal energy of:
      a. 2592.4 kJ/kg
      b. 842.9 kJ/kg
      c. 2593.8 kJ/kg
      d. 856.7 kJ/kg

   $P_{absolute} = 15 + 1 = 16$ bar

   $\hat{U} = 856.7 \frac{kJ}{kg}$

2. A counter-current absorber, operating at 14.696 psia and 55 °F is used to absorb ethane from nitrogen using *n*-decane. The gas stream ($\dot{n}_2$) enters the bottom of the absorber with a 12 mol% ethane concentration, while pure *n*-decane enters from the top ($\dot{n}_1$). Under these conditions, 96% of the ethane entering the unit is absorbed. Assume that none of the *n*-decane is vaporized into the vapour stream and that the exiting liquid stream is in equilibrium with the entering gas stream. Use a basis of 100 kmol/h for the entering gas stream ($\dot{n}_2$). **Hint:** The Cox chart can be used in this case.



a) Determine the liquid to gas feed ratio ($\dot{n}_1/\dot{n}_2$) for this system. **(7 points)**

n_2 and n_3 are in equilibrium

$n_2 = 100 \frac{kmol}{h}$

N_2 balance: $0.88 \times n_2 = n_4 \times (1-y_4)$ ⟹

E balance: $0.12 \times n_2 \times 0.04 = n_4 \times y_4$

$\begin{cases} n_4 = 88.48 \ kmol/h \\ y_4 = 0.005 \end{cases}$

Raoult's law: $P_T \times 0.12 = x_3 \times P^*_{@ 55°F}$, P^* from Cox chart $= 500 \ psi$ $= 25857.5 \ mmHg$

$x_3 = 0.0035$

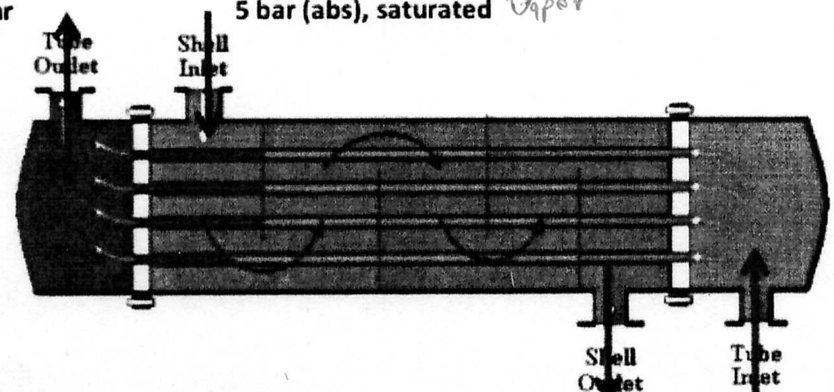
E balance: $n_2 \times 0.12 = n_4 \times y_4 + n_3 \times x_3$ ⟹ $n_3 = 3266.21 \frac{kmol}{h}$

D balance: $n_1 = n_3 \times (1-x_3)$ ⟹ $n_1 = 3254.69 \frac{kmol}{h}$

⟹ $\frac{n_1}{n_2} = 32.55$

b) The assumption that the exiting liquid is in equilibrium with the entering gas is not entirely valid. What would need to be the height of the column for this to be valid? **(1 point)** should be infinitely tall

3. Saturated steams is used to heat a stream of toluene (C_7H_8) in a heat exchanger shown below. The vapour entering the heat exchange is saturated at an absolute pressure of 5 bar. All of vapour eventually condenses in the heat exchanger and leaves as saturated liquid at 36 °C. The toluene enters the heat exchange at 27 °C and 7 bar (abs) and is heated at constant pressure to 107 °C; and stays in the liquid phase at all times. The mass flow rate of toluene is 75 kg/s. The specific enthalpy of toluene at the given pressure is 184.86 kJ/kg at 27 °C and 333.05 kJ/kg at 107 °C; relative to a common reference.



a) To heat the toluene from 27 to 107 °C, how much energy (kW) must be transferred? **(3 points)**

$Q = 75 \times (333.05 - 184.86) = 11114.25$ (kW)

b) Assuming that all the energy transferred from the steam goes to the toluene, at what rate (m^3/s) must steam be supplied to the exchanger? Use the steam tables. **(5 points)**

$Q = m \times (H_{in} - H_{out})$

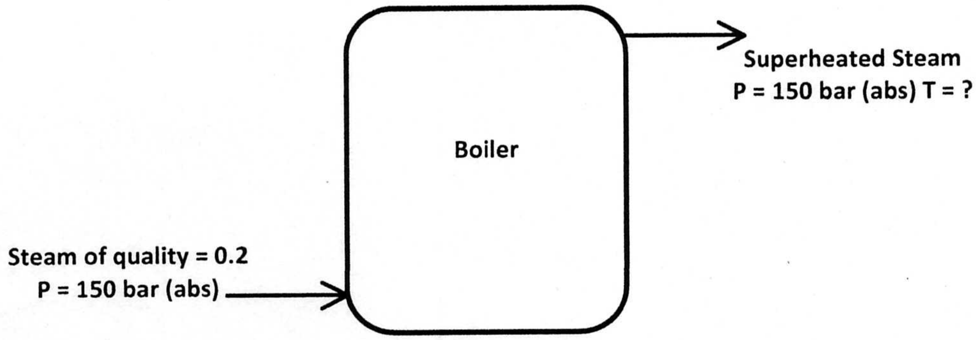
$H_{in} = 2747.5 \frac{kJ}{kg}$ $\Rightarrow$ $m = \frac{11114.25}{(2747.5 - 150.7)} = 4.28 \frac{kg}{s}$

$H_{out} = 150.7 \frac{kJ}{kg}$

$V_{in} = 0.375 \frac{m^3}{kg}$ $\Rightarrow$

$V = 4.28 \times 0.375 = 1.61 \frac{m^3}{s}$

4. The *quality* of water vapour is increased in a boiler i.e., the ratio of vapour to liquid is increased. Steam entering a boiler has a *quality* of 0.2 (i.e., 20 wt% vapour, 80 wt% liquid) and is at a pressure of 150 bar and the *vapour phase* flow rate is 500 kg/h. In the boiler, heat is added to the steam at 600 kJ/(kg of H_2O). The steam exits the boiler as superheated steam at 150 bar.



a) What is the temperature (°C) of the superheated steam leaving the boiler? **(6 points)**

$n_L = \left(\frac{1-x}{x}\right) n_V \Rightarrow n_L = 2000 \frac{kg}{h} \Rightarrow H_L = 1611 \frac{kJ}{kg}$, $H_V = 2615 \frac{kJ}{kg}$

$n_V = 500 \frac{kg}{h}$

$\Rightarrow H_{\text{Superheated steam}} = Q + x \times H_V + (1-x) \times H_L = 600 + 0.2 \times 2615 + 0.8 \times 1611$

$\Rightarrow H_{\text{Superheated steam}} = 2411.8 \rightarrow$ linear interpolation: $T = 300°C$, $H = 1338.2 \frac{kJ}{kg}$; $T = 350°C$, $H = 2695 \frac{kJ}{kg}$

$\Rightarrow T = 339.6°C \Rightarrow n_{\text{Superheated Steam}} = n_L + n_V = 2000 + 500$

$n_{\text{Superheated Steam}} = 2500 \frac{kg}{h}$

b) What is the flowrate of the superheated steam leaving the boiler (kg/h)? **(2 points)**

$n_{\text{superheated Steam}} = 2500 \frac{kg}{h}$