ORDRE DES INGÉNIEURS DU QUÉBEC

MAI 2018 SESSION

Open-book examination **Calculator : only authorized models** **Duration : 3 hours**

16-CH-A2 Exam
Unit operations and separation processes

This examination consists of 6 questions.

Questions	Value	Score
1. Hydraulic network	20 points	
2. Separation of an ethanol / isobutyl alcohol mixture	20 points	
3. Terminal velocity of falling of coffee droplets	10 points	
4. Liquid-liquid extraction	20 points	
5. Fast questions	15 points	
6. Pumping water	15 points	
Total	**100 points**	

1. Hydraulic network *(20 points)*

You must size the hydraulic feed network of a distillation column. This feed has a flow rate of 9600 kg/h of an oxygen-argon mixture, a density of 1100 kg/m^3 and a vapor pressure of 700 mmHg.

The mixture is pumped from a liquid storage tank to the distillation column. The liquid level in the storage tank is 10 m and the column is fed at a height of 15 m. The pressure in the tank is 2 bar and the pressure in the column is 1 bar. The internal diameter of the stainless steel pipe is 2 inches.

A) What is the velocity (m/s) of the mixture in the pipe?

Calculations have shown that the friction losses in the suction and discharge areas of the hydraulic system are 100 kPa and 650 kPa, respectively.

You have at your disposal a radial flow centrifugal pump with a 120 mm rotor rotating at 2800 rpm. This pump can develop a maximum load of 100 m for the operating flow.

B) Can this pump be suitable for the operation? Justify by appropriate calculations.
C) If the NPSHR at this flow rate is 0.5 m, will this pump be cavitating? Justify by appropriate calculations.

2. Separation of an ethanol / isobutyl alcohol mixture *(20 points)*

Separation of a binary mixture ethanol (1) – isobutyl alcohol (2) is carried out by continuous distillation using a column with a partiel reboiler and a total condenser. In the whole unit, the pressure is 1 atm. The feed is liquid at its boiling point, feed is to the optimal tray, and the reflux is at saturation temperature.

The feed flowrate is 1 kmol/min and contains **35,5% mass-fraction** ethanol. The distillate has to contain 90% of the ethanol fed to the column on a molar basis. The flowrate of the residue has to be 0,54 kmol/min. For a reflux ratio of 1.6, determine analytically :

A) the composition of the distillate and residue.
B) the compositions of liquid and vapor leaving and entering stage no. 1 (consider the top of the column as stage no. 1).
C) the temperatures on stages no. 1 and no. 2.
D) the flowrates of liquid and vapor in the stripping section.

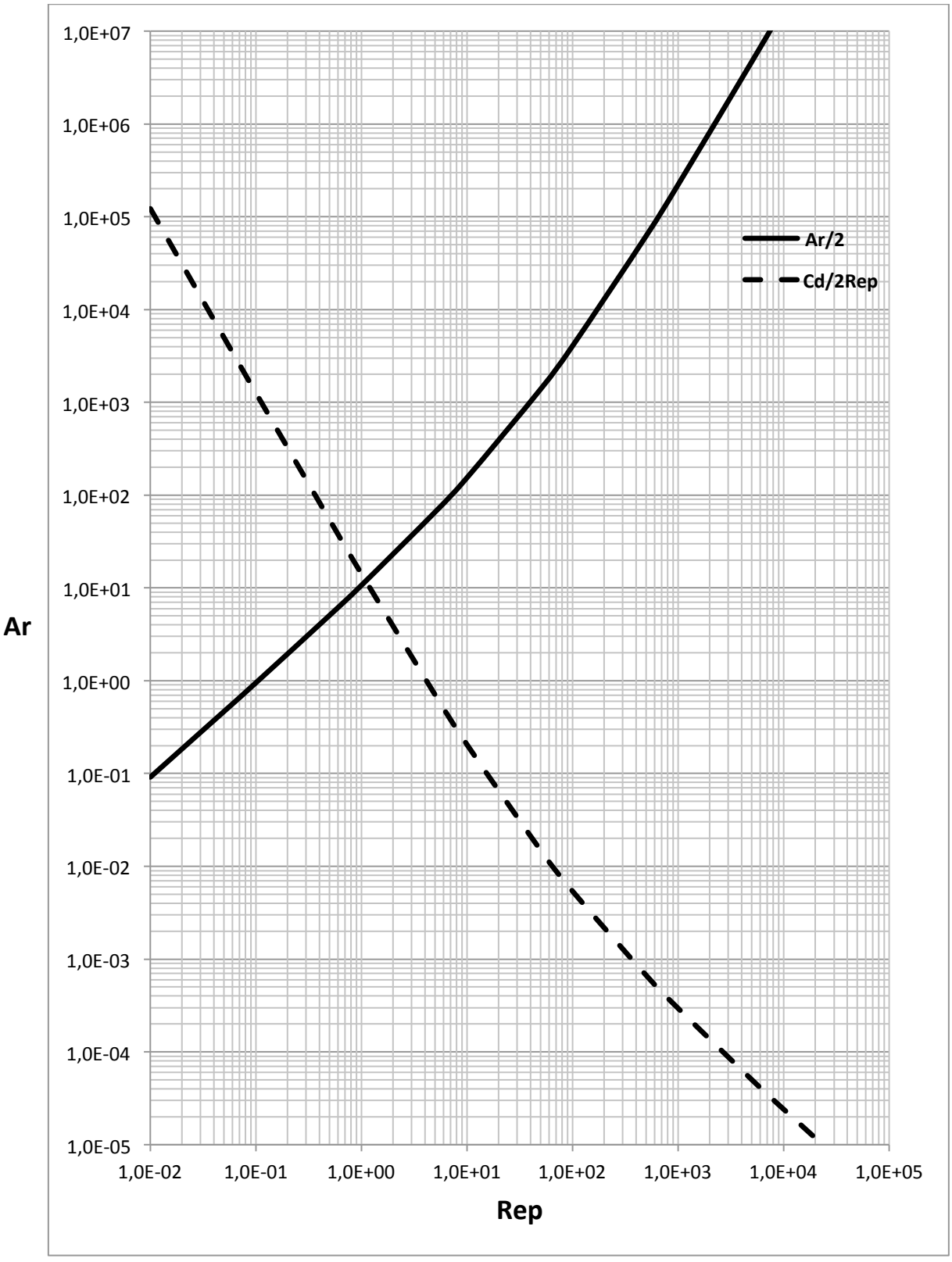
MW ethanol (C_2H_5OH) = 46 g/mol
MW isobutyl alcohol ($C_4H_{10}O$) = 74 g/mol

Equilibrium data : Ethanol (1) – Isobutyl alcohol (2)

x_1 (% mol)	y_1 (% mol)	T(^oC)
0,039	0,109	105,90
0,077	0,205	104,10
0,123	0,304	102,00
0,197	0,428	99,25
0,285	0,552	96,10
0,331	0,602	94,40
0,416	0,685	92,00
0,467	0,731	90,30
0,543	0,782	88,75
0,669	0,862	85,50
0,753	0,908	83,70
0,766	0,914	83,20
0,827	0,938	82,20
0,966	0,990	79,40

3. Terminal velocity of falling of coffee droplets *(10 points)*

Calculate the terminal velocity of fallling of spherical droplets of a coffee extract. The droplets have a diameter of 400 microns and are free-falling into the air. The density of the coffee extract is 1.03 and the air is at a temperature of 149 ^{o}C. The viscosity of the air at 149 ^{o}C = 2.3 x 10^{-5} Pa-s.



Ar vs Re_p graph for sedimentation of spherical particles

4. Liquid-liquid extraction *(20 points)*

An extractor is to be designed such that acetone will be extracted from a feed mixture of 0.3 mass-fraction acetone and 0.7 mass-fraction ethyl acetate. Water will be used to extract the acetone, and the water is assumed to be pure. The raffinate will have a composition of 7% acetone and 93% ethyl acetate, while the extract will have a composition of 12% acetone, 8% ethyl acetate, and 80% water. A ternary phase diagram is given for this system, along with corresponding tie lines. The feed to the column has a flowrate of 20 000 kg/h and the solvent-to-feed ratio is assumed to be 1.75. **Use the following graph (page 7) and insert this page in your answer book.**

A) Determine the number of theoretical stages needed.
B) Determine the solvent, extract and raffinate flowrates (kg/h).

INSERT THIS PAGE IN YOUR ANSWER BOOK.

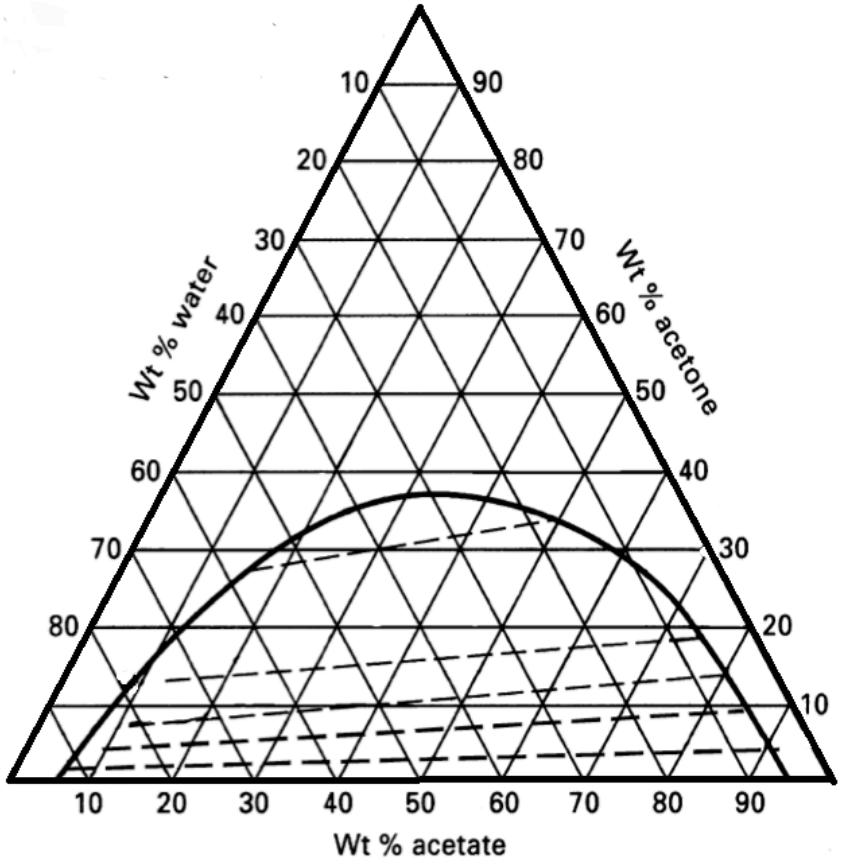
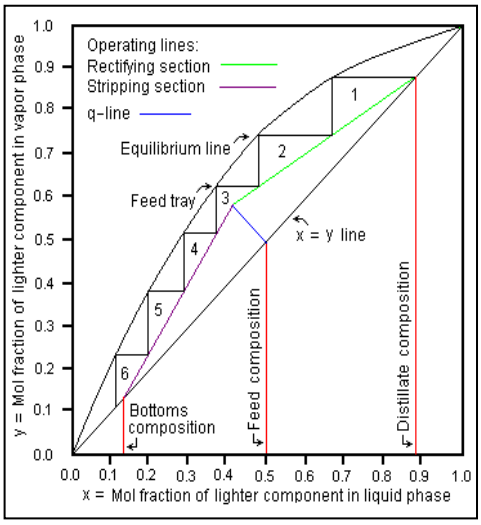


Figure: Diagram for the ternary system Water/Ethyl Acetate/Acetone (For question 4)

5. Fast questions *(15 points)*

A. The following plot was obtained for a distillation column. If a total condenser and a partial reboiler are used and the column efficiency is 50%, what is the number of stages in the column ?



I. 5.8
II. 8
III. 10
IV. 12

B. Which of the following statements is true ?

I. A partial reboiler consumes more energy than a total reboiler.
II. The hydraulic network head of a distillation column is usually insulated.
III. The flow of steam V in a distillation column is different from the flow of steam $\bar{V}$ when the feed is a liquid/vapor mixture.
IV. Decreasing the operating pressure in a distillation column makes it more difficult to achieve separation.

C. For absorption columns with the same feed rates and performing the same separation (same purity at the output), the diameter of the packing used is varied as per the following table :

$D_{packing}$ (mm)	L_{column} (m)	H_{OL} (m) (height of a transfer unit)
25	1.4715	0.7600
35	1.55	0.8005
50	1.8269	0.9436

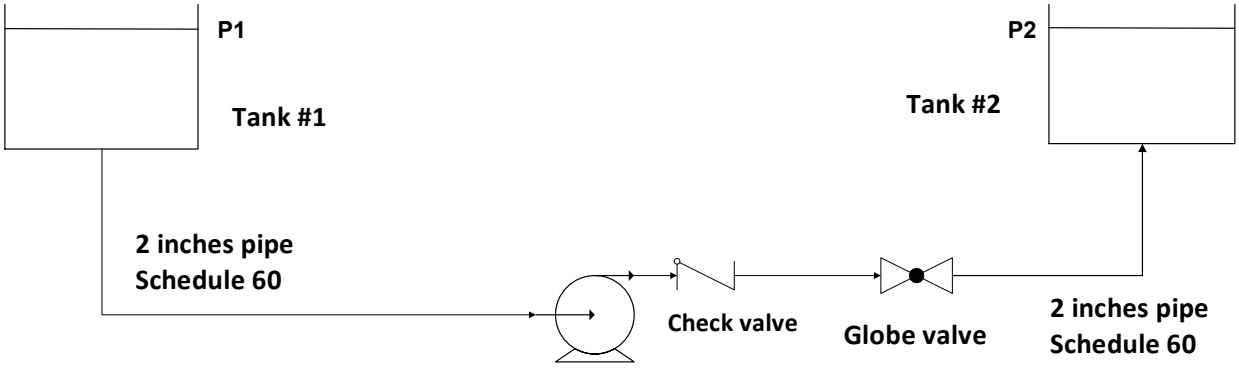
I. What is the value of N_{OL} (number of transfer units) for $D_{packing}$ = 25 mm ?
II. Why does H_{OL} increase when $D_{packing}$ increases ?

D. Explain two impacts of increasing the reflux ratio when operating a distillation column.

E. What is the role of the reflux in a distillation system?

6. Pumping water *(15 points)*

Water at 20 ^{o}C is pumped, using a radial centrifugal pump (blades directed backwards) from tank # 1 to tank # 2. Both tanks are open to the atmosphere. Suppose the rotor speed is fixed.



Answer the following questions and justify each answer**.**

Questions	Decrease	Increase	Don't change
A. What happens to the NPSH if the liquid level in tank # 2 is lower and the flow is kept constant?			
B. What happens to the NPSH if the globe valve is closed slightly?			
C. What happens to the NPSH if the liquid level in tank # 1 is lower and the flow is kept constant?			
D. What happens to the NPSHR if the suction line is shorter and the flow is kept constant?			
E. What happens to the pressure drop ($\Delta P = P2-P1$) if the globe valve is fully opened and the flow rate is doubled?			
F. What happens to the load developed by the pump if the globe valve is closed slightly?			
G. What happens to the flow if the globe valve is closed slightly?			