

ORDRE DES INGÉNIEURS DU QUÉBEC

MAY 2015 SESSION

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

14-AL-A2
MASS TRANSFER OPERATIONS

This examination consists of 6 questions.

Questions	Value	Score
1. Distillation	20 points	
2. Humidity	15 points	
3. Liquid-liquid extraction	15 points	
4. Condensation	15 points	
5. Cooling tower	15 points	
6. Absorption	20 points	
Total	100 points	

Useful data can be found at the end of the exam.

1. Distillation (20 points)

Separation of a binary mixture ethanol (1) – isobutyl alcohol (2) is carried out by continuous distillation using a column with a partial 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 **35,3% mass-fraction** ethanol. The distillate has to contain 90% of the ethanol fed to the column. 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)	$T(^{\circ}C)$
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

2. Humidity (15 points)

A process is used for conditioning air before sending it into a laboratory. The flowrate is $2 \text{ m}^3 \text{ (NTP)/min}$. Characterize the air that will be desiccated by adsorption using calcium sulphate (CaSO_4).

Before treatment, the dry temperature of the air is 38°C , while the wet-bulb temperature is 25°C . For the air before treatment evaluate :

- A) the absolute humidity;
- B) the percentage of humidity;
- C) the dew point temperature;
- D) the humid volume;
- E) the enthalpy.

Calculate also the amount of water that will be captured (adsorbed) by the CaSO_4 over a period of one hour.

Use the psychrometric chart available on page 6 and insert this page in your answer book.

3. Liquid-liquid extraction (15 points)

To recuperate acetic acid from 500 kg of its aqueous solution, liquid-liquid extraction with pure isopropyl ether as the solvent is used. The initial concentration of acid acetic in the feed mixture is 40% mass. After extraction, the aqueous solution should not contain more than 7% of acetic acid.

Your co-worker had started the calculations and placed already the point P. The results are summarized in a figure shown on the next page. Finish the calculations by determining :

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

Use the following graph (page 4) and insert this page in your answer book.

INSERT THIS PAGE IN YOUR ANSWER BOOK.

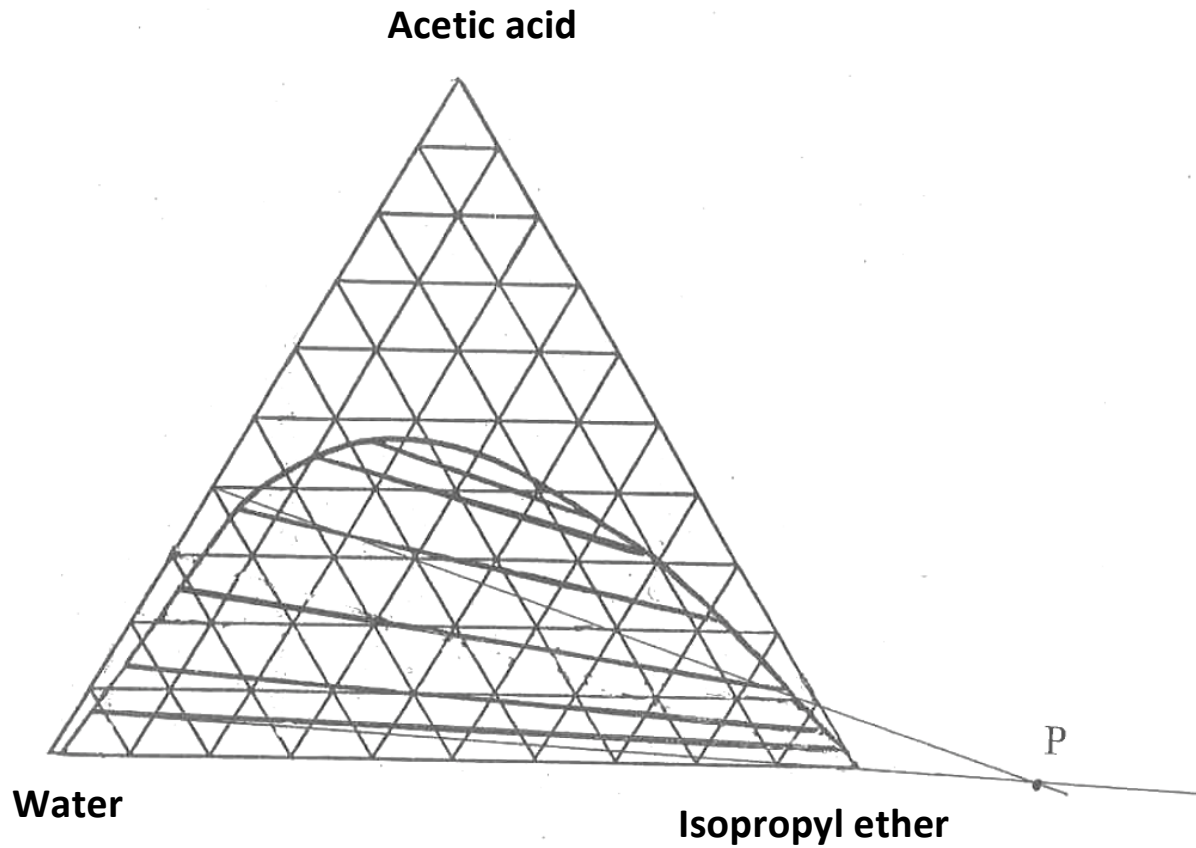


Figure: Diagram for the ternary system Water/Isopropyl ether/Acetic acid (For question 3)

4. Condensation (15 points)

A gas mixture from a cracking unit of a petrochemical installation is flowing through a piping system under a pressure of 2000 kPa. The composition of the mixture is :

Gas	Wt %
Methane	11,64
Ethane	31,17
Ethylene	29,08
Propane	10,66
Propylene	17,45

Determine : (*equilibrium coefficients chart is available on page 7*)

- A) the temperature at which the mixture will start condensing in the piping ;
- B) the composition of the first drop when the condensation occurs.

5. Cooling tower (15 points)

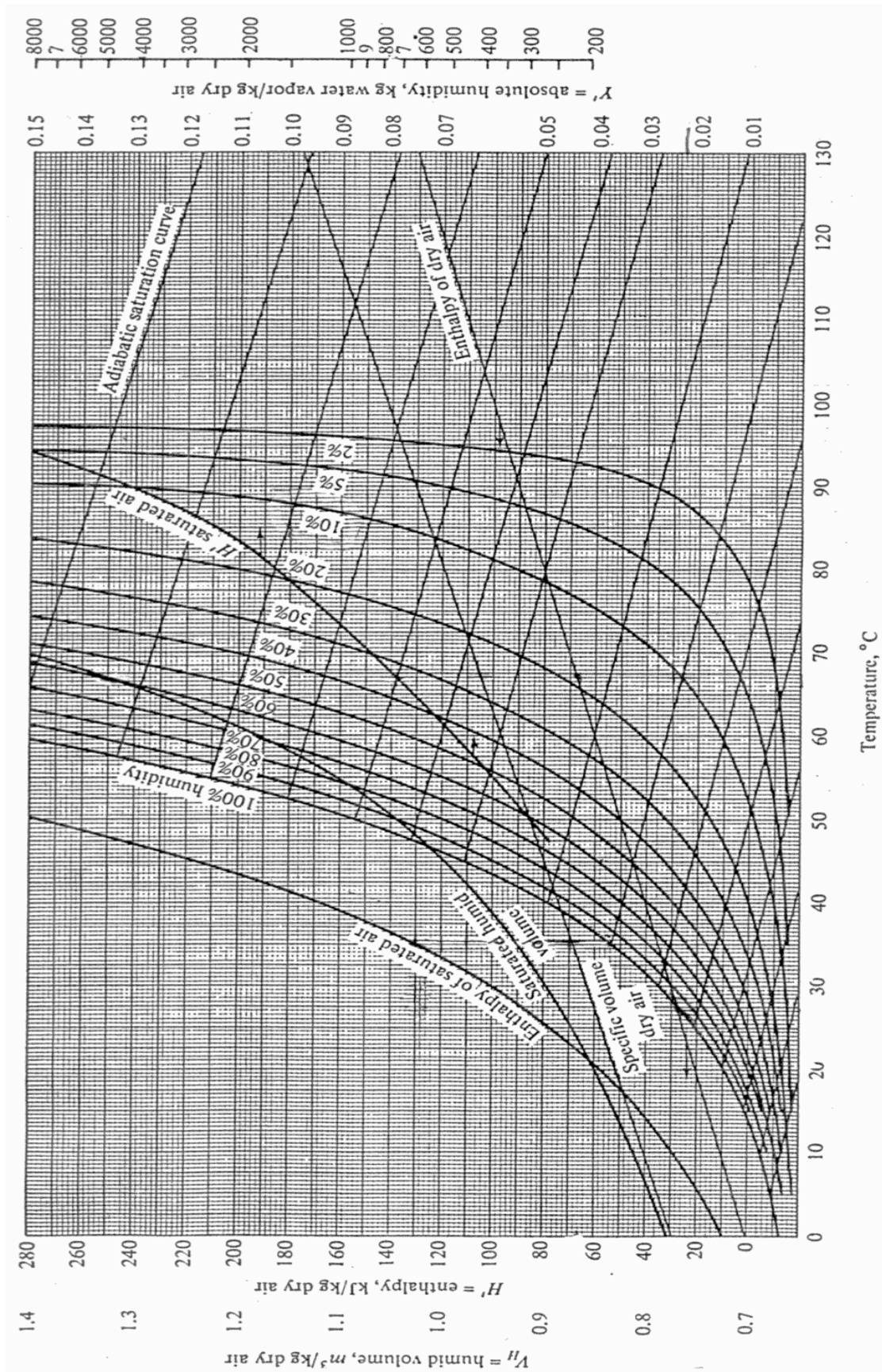
Water at 50°C and flowing at 6000 L/min has to be cooled in a cooling tower of 4m x 4m cross-section. During the cooling, 8000 kW of heat had to be removed by the air flowing at 4800 m³/min. The air inlet dry temperature is 30°C and the wet-bulb temperature is 20°C. Calculate the temperature of the cooled water at the outlet.

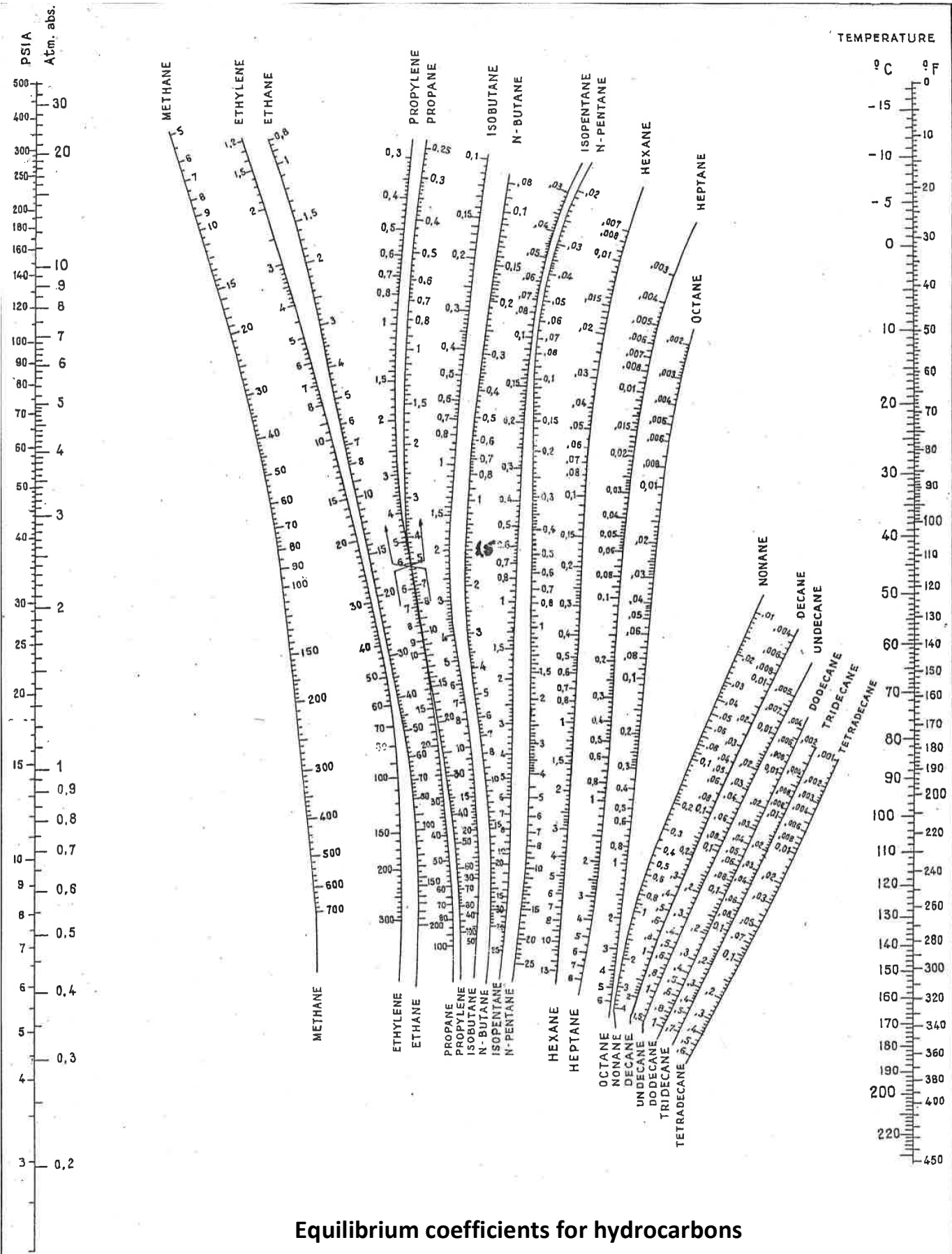
Use the psychrometric chart available on page 6 and insert this page in your answer book.

6. Absorption (20 points)

A gas effluent containing 10% vol. CO₂ has to be treated by water to remove 95% of CO₂. The effluent flowrate is 694 L/s. Absorption takes place at 25°C and at atmospheric pressure. Calculate the amount of water necessary to absorb the CO₂ assuming that a 50% excess of water with respect to the minimum quantity will be used. The equilibrium data is represented by the equation : $Y = 48X$.

INSERT THIS PAGE IN YOUR ANSWER BOOK.





Equilibrium coefficients for hydrocarbons