ORDRE DES INGÉNIEURS DU QUÉBEC

MAI 2019 SESSION

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

16-CH-A2 Exam
Unit operations and separation processes

This examination consists of 5 questions.

Questions	Value	Score
1. Solvent-recovery plan	20 points	
2. Binary distillation	20 points	
3. Pumping water	25 points	
4. Air conditioning	20 points	
5. Sedimentation of particles	15 points	
Total	**100 points**	

1. Solvent-recovery plant *(20 points)*

A solvent-recovery plant consists of a plate-column absorber and a plate-column stripper. 90% of the benzene (B) in the gas stream is recovered in the absorption column. Concentration of benzene in the inlet gas is 0,06 mol B/mol B-free gas. The oil entering the top of the absorber contains 0,01 mol B/mol pure oil. In the leaving liquid, X = 0,19 mol B/mol pure oil. Operating temperature is 25^{o}C.

Superheated steam is used to strip benzene out of the benzene-rich oil at 110^{o}C. Concentration of benzene in the oil = 0,19 and 0,01 (mole ratios) at inlet and outlet, respectively. Oil-to-steam (benzene-free) flow rate ratio = 2.0. Vapors are condensed, separated, and removed.

MW oil = 200 g/mol MW benzene = 78 g/mol MW gas = 32 g/mol

Calculate :

A) The molar flow rate ratio of B-free oil to B-free gas in the absorber (L'/V'). ***(6 points)***
B) The number of theoretical stages in the absorber. **Use the following graph (page 3) and insert this page in your answer book. *(7 points)***
C) The minimum steam flowrate in the stripper per mol of B-free oil. **Use the following graph (page 4) and insert this page in your answer book. *(7 points)***

INSERT THIS PAGE IN YOUR ANSWER BOOK.

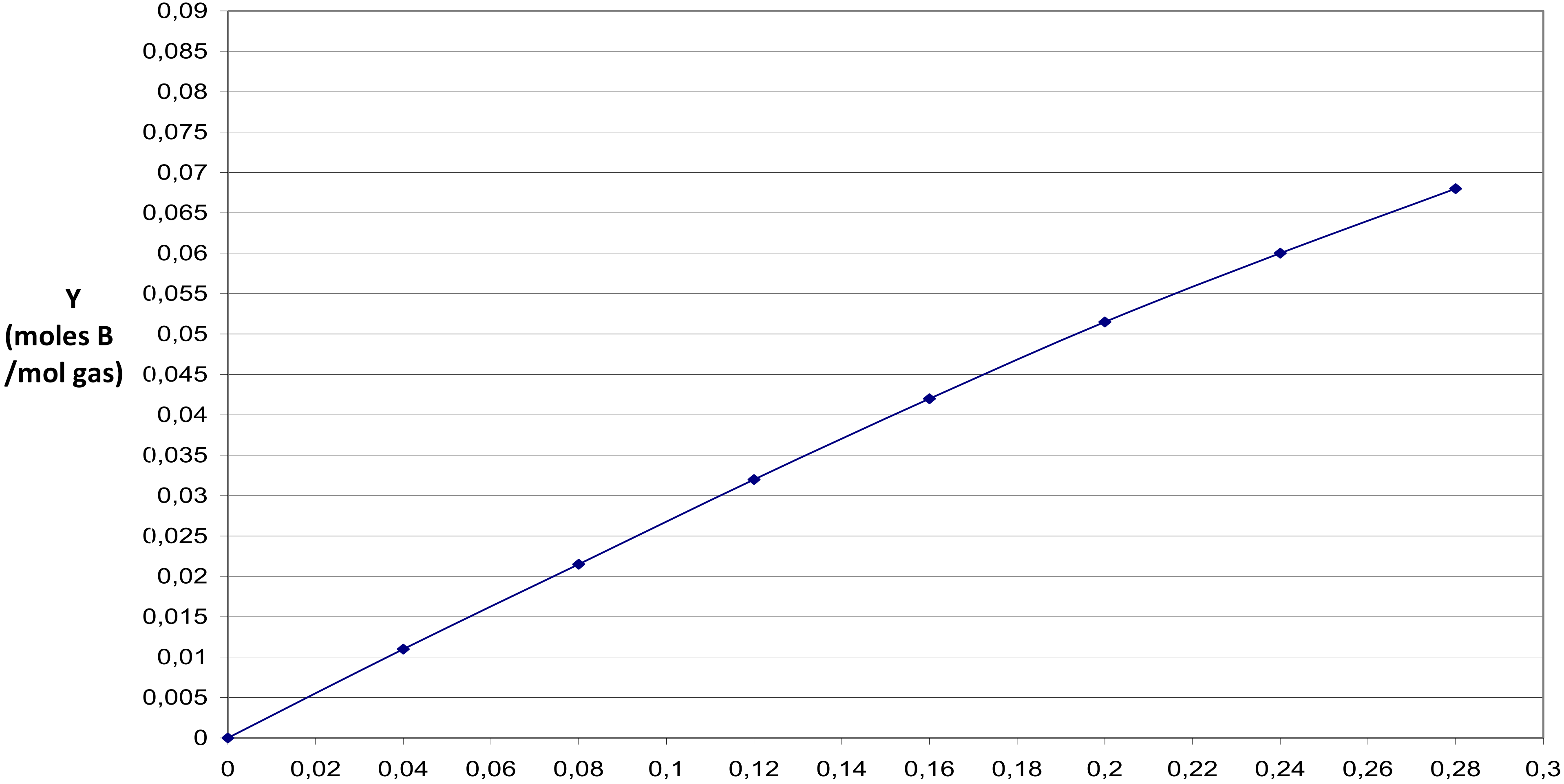

Figure: Equilibrium curve of absorption of benzene in oil (For question 1)

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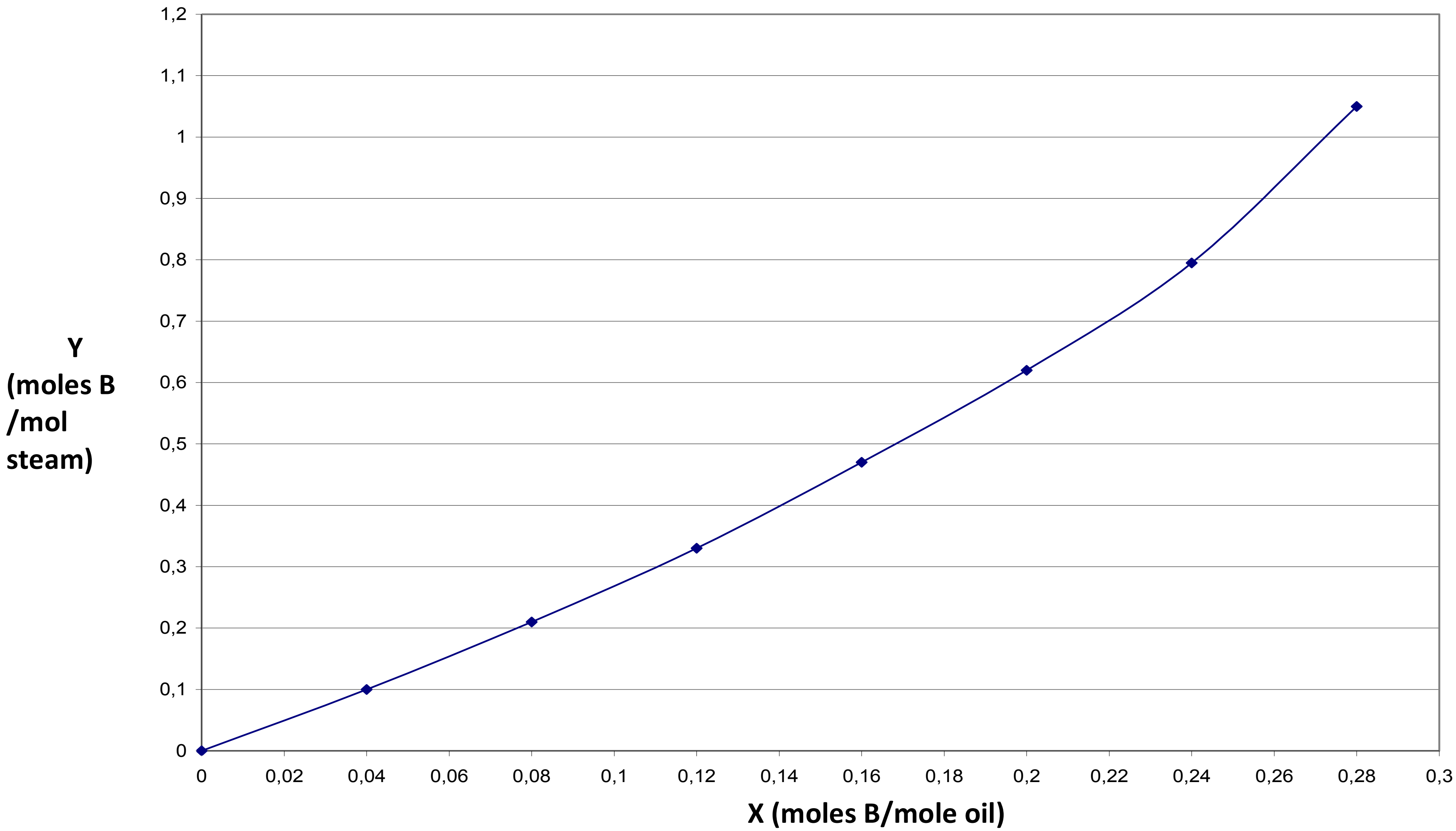


Figure: Equilibrium curve of stripping of benzene in oil (For question 1)

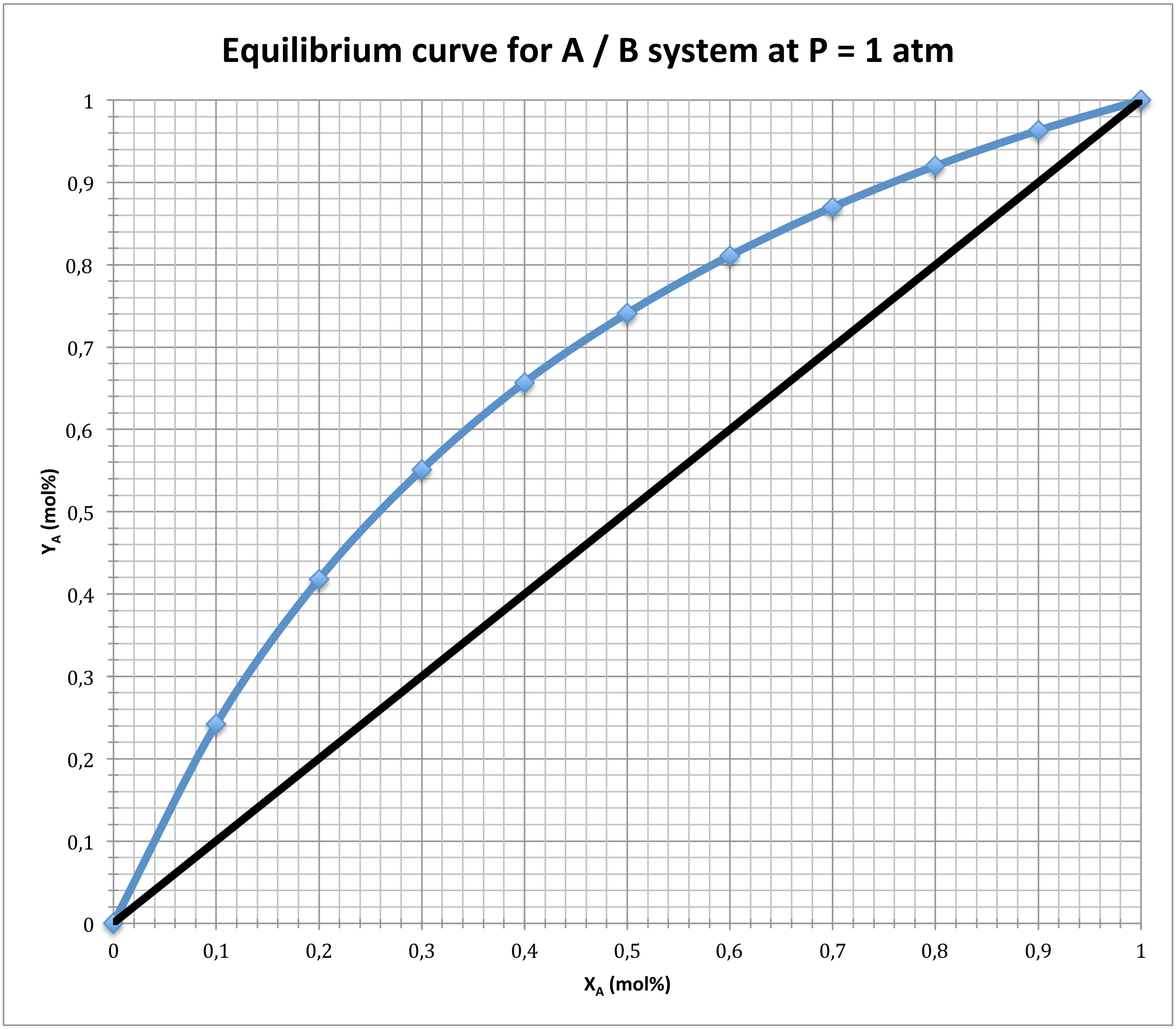
2. Binary distillation *(20 points)*

The binary mixture A/B containing 50 mol% A has to be separated by distillation. We need 97 mol% A overhead and a minimum of 97 mol% B in the bottoms. For an atmospheric system with a total condenser and a partial reboiler and a temperature such that the **feed is half vaporized as it enters the column**, calculate :

A) the minimum reflux ratio ; ***(6 points)***
B) the theoretical stages needed at total reflux ; ***(4 points)***
C) the theoretical stage needed using a reflux ratio of two times the minimum ; ***(7 points)***
D) the feed plate number. ***(3 points)***

Use the McCabe-Thiele method and insert next page in your answer book.

Insert this page in your answer book.



3. Pumping water *(25 points)*

You must size the hydraulic feed network of a cooling tower. This feed has a flowrate of 7200 m^3/day of water at 20^oC. The vapor pressure of the water at 20 ^oC is 2336.8 Pa and its viscosity is 0.001 Pa.s. The hydraulic network is shown below :

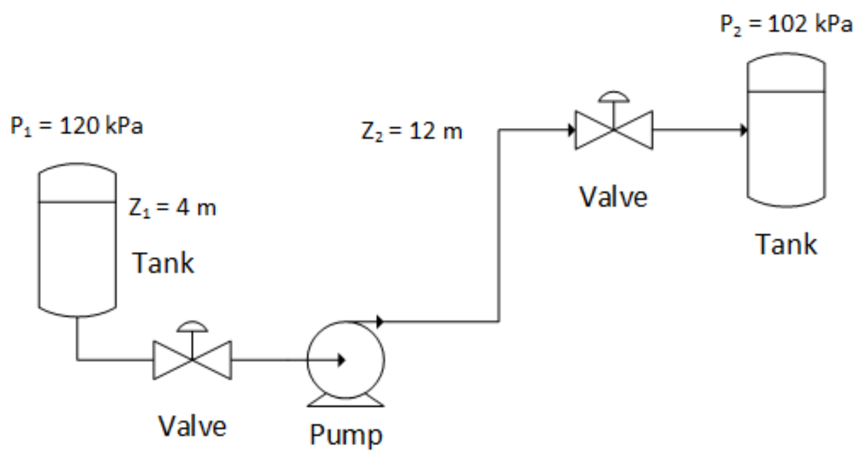


Figure – Hydraulic network

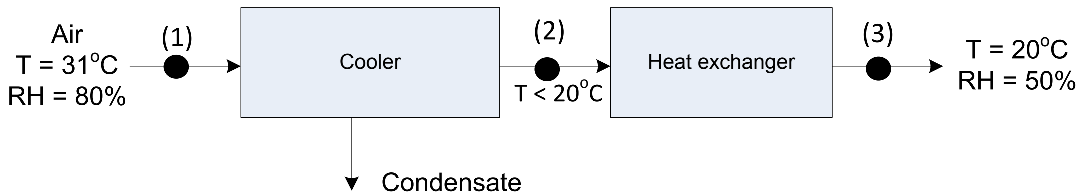
Hydraulic network information :

Suction	Discharge
L = 17 m (piping)	L = 42 m (piping)
d_{pipe} = 150 mm	d_{pipe} = 150 mm
1 elbow 90^o, K = 0,24	2 elbows 90^o, K = 0,24
Globe valve, L_{eq} = 4 m	Globe valve, L_{eq} = 4 m
	Swing check valve L_{eq} = 4 m

A) What is the velocity (m/s) of the water in the pipe? ***(2 points)***
B) What is the Reynolds number in the pipe? ***(2 points)***
C) Calculate the developed load (ΔH) that the pump should have, assuming that the friction factor in the pipes is f_m = 0.016. ***(10 points)***
D) If the NPSHR at this flowrate is 10 m, will this pump be cavitating? Justify by appropriate calculations. ***(10 points)***
E) What would be the impact of a decrease in temperature on the vapor pressure ? ***(1 point)***

4. Air conditioning *(20 points)*

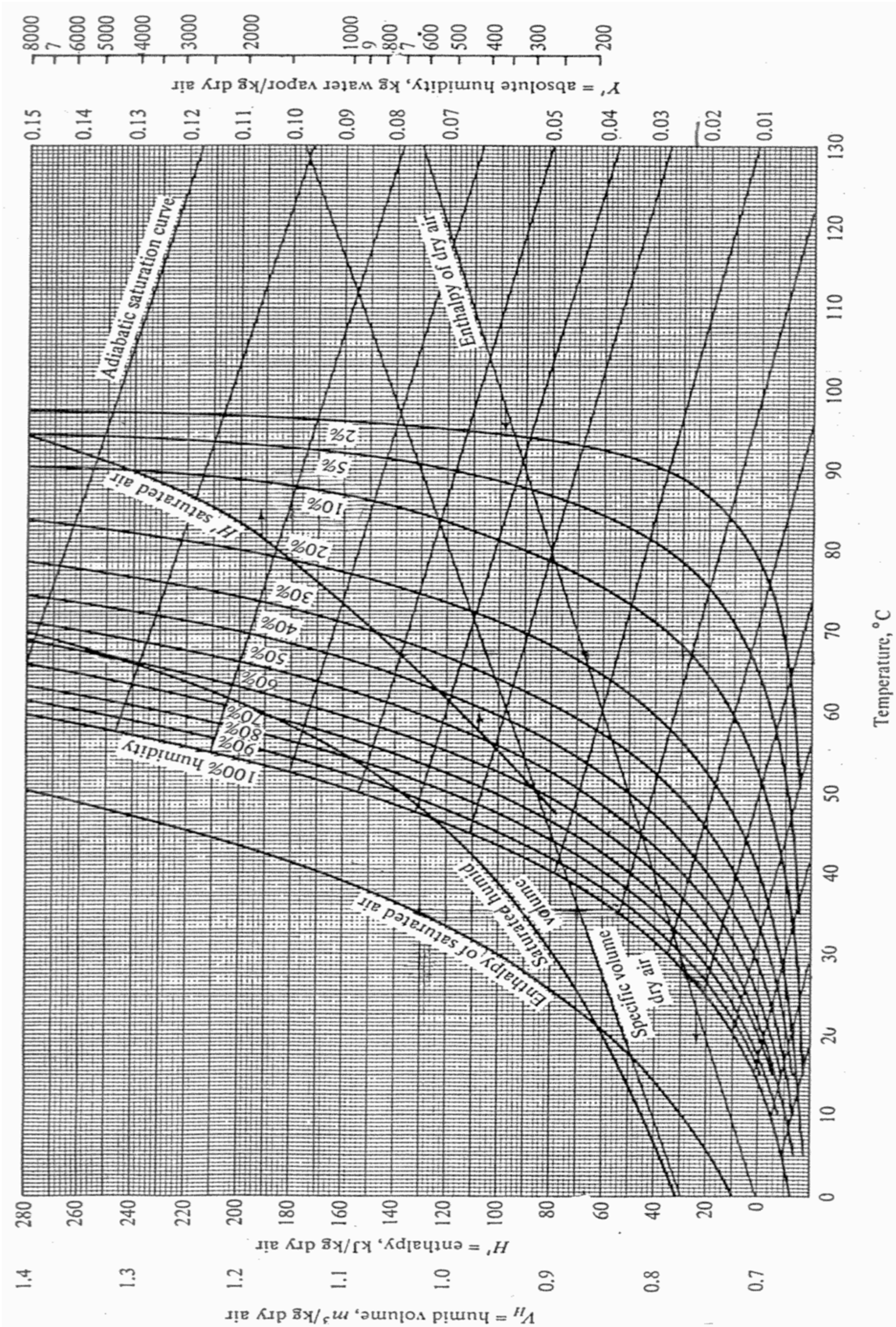
The following process illustrates a unit for conditioning air before sending it into a laboratory. For the passage of air between points (1) and (2) and between (2) and (3), complete the following table related to changes in certain parameters of the air. You can assume that the total system pressure is always 1 atm. Note: RH = relative humidity. *(Psychrometric chart is available on page 9)*



Parameters	Parameter variation : Increase, Decrease or Remain constant	Justification of your answer
A. Absolute humidity between (1) and (2) ***(3 points)***		
B. Absolute humidity between (2) and (3) ***(3 points)***		
C. Relative humidity between (2) and (3) ***(3 points)***		
D. Partial pressure of water in air between (2) and (3) ***(3 points)***		
E. Density of dry air (without considering water) between (2) and (3) ***(3 points)***		

F. Evaluate dew-point temperature, wet-bulb temperature and absolute humidity of the incoming air (point 1). ***(3 points)***

G. Evaluate enthalpy of air at the entrance and exit of the process (points 1 and 3). ***(2 points)***


Y' = absolute humidity, kg water vapor/kg dry air
Adiabatic saturation curve
Enthalpy of dry air
H', saturated air
2%
5%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100% humidity
Enthalpy of saturated air
Saturated humid volume
Specific volume dry air
Temperature, °C
H' = enthalpy, kJ/kg dry air
V_H = humid volume, m^3/kg dry air

5. Sedimentation of particles *(15 points)*

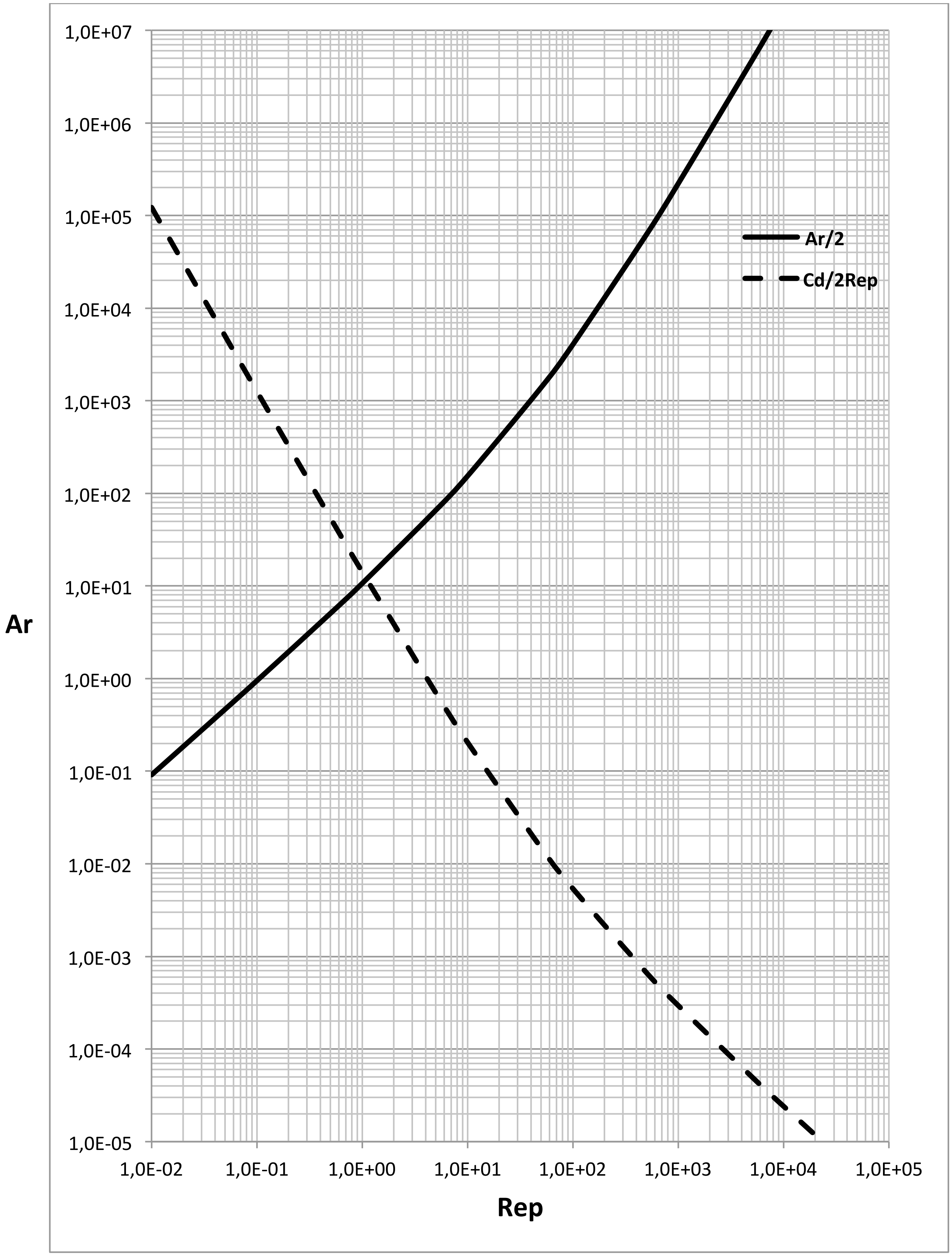
Spherical particles sediment at atmospheric pressure in air at 30 ^oC ($\mu = 1.8x10^{-5}$ kg/m.s). The falling speed of the cloud is 28 cm/s and $C_D = 5xRe_P$.

A) Calculate the density of the air (kg/m^3). ***(5 points)***
B) Calculate the equivalent diameter (µm) of a particle. ***(10 points)***

<u>Additional data:</u>

Porosity of the cloud = 0.85
Index n of Richardson and Zaki correlation: n = 3

Archimedes (Ar) vs Re_p graph for sedimentation of spherical particles is available on next page.



Ar vs Re_p graph for sedimentation of spherical particles