

1.

Pretende-se extrair o ácido acético contido em 800g de uma solução aquosa com 55% (percentagem mássica de ácido acético) ($T = 20^\circ\text{C}$), adicionando-se 400g de éter isopropílico, sem variação de temperatura.

- Determinar as composições e massas das fases em equilíbrio, depois da adição do éter;
- Para a remoção do ácido ainda existente na fase refinada obtida da operação anterior, adiciona-se éter isopropílico na proporção de 1:1. Determine as composições e as massas das novas fases em equilíbrio.

The aim is to extract the acetic acid contained in 800g of an aqueous solution with 55% (mass percentage of acetic acid) ($T = 20^\circ\text{C}$), by adding 400g of isopropyl ether without varying the temperature.

- Determine the compositions and masses of the phases in equilibrium, after the addition of ether;
- To remove the acid still present in the raffinate phase obtained from the previous operation, isopropyl ether is again added in a 1:1 ratio. Determine the compositions and masses of the new phases at equilibrium.

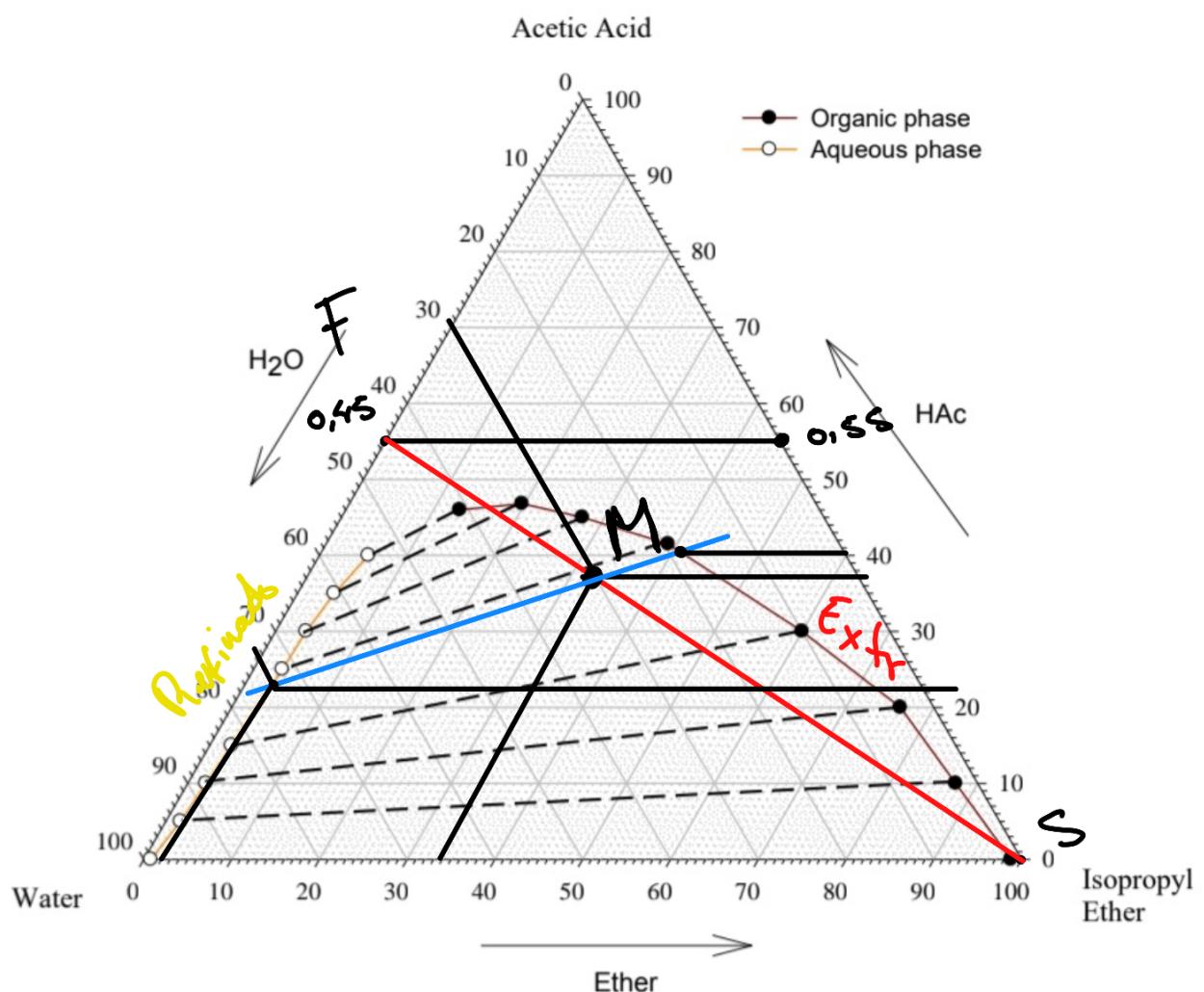
Experimental data:

For the isopropyl ether – water – acetic acid ternary system, the conjugated phases have the following compositions at 20°C :

| Organic phase | | | Aqueous phase | | |
|-----------------|-------------|-------|-----------------|-------------|-------|
| Isopropyl ether | Acetic acid | water | Isopropyl ether | Acetic acid | water |
| 98.80 | 0.00 | 1.20 | 0.80 | 0.00 | 99.20 |
| 87.50 | 10.00 | 2.50 | 1.70 | 5.00 | 93.30 |
| 76.20 | 20.00 | 3.80 | 2.10 | 10.00 | 87.90 |
| 60.00 | 30.00 | 10.00 | 2.50 | 15.00 | 82.50 |
| 39.00 | 41.50 | 19.50 | 3.30 | 25.00 | 71.70 |
| 27.50 | 45.00 | 27.50 | 3.50 | 30.00 | 66.50 |
| 19.70 | 46.80 | 33.50 | 4.20 | 35.00 | 60.80 |
| 13.00 | 46.00 | 41.00 | 5.60 | 40.00 | 54.40 |

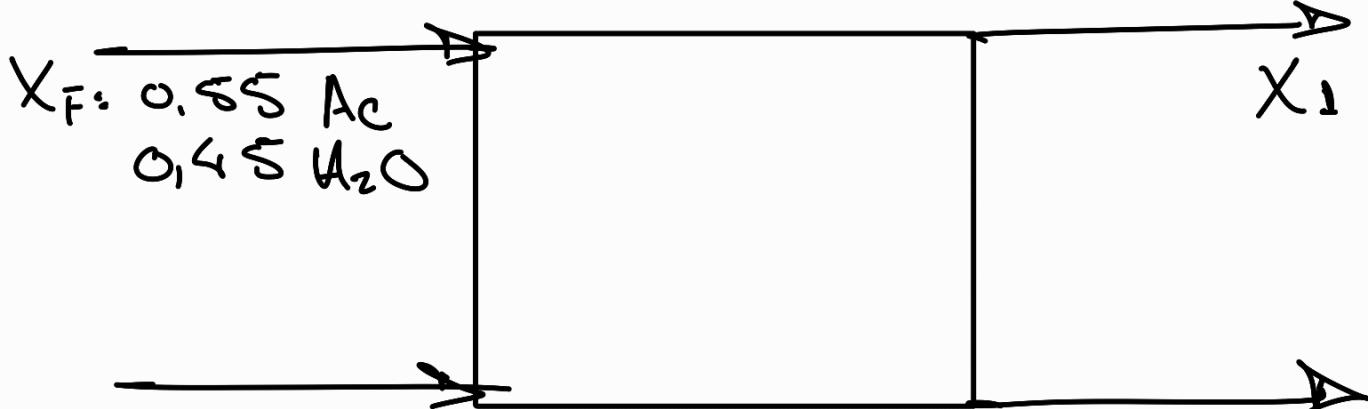
As composições usadas para fazer os cálculos

Ternary System - 20°C



$$F: 800 \text{ g}$$

R_1



$$S = 100 \text{ g}$$

E_1

G_1

$$g_S = 0$$

a) $x_{i,\text{eq}} = ?$

$$F + S = M : 400 + 800 = 1200 \text{ g}$$

Regra da Alavanca

$$\frac{S}{F} = \frac{x_F - x_M}{x_M - y_S} = \frac{\overline{FM}}{\overline{MS}}$$

$$\frac{400}{800} = \frac{0,55 - x_M}{x_M - 0} \Rightarrow x_M = 0,37$$

$$x_{M, H_2O} = 0,30 , \quad x_{M, \text{Eter}} = 0,33$$

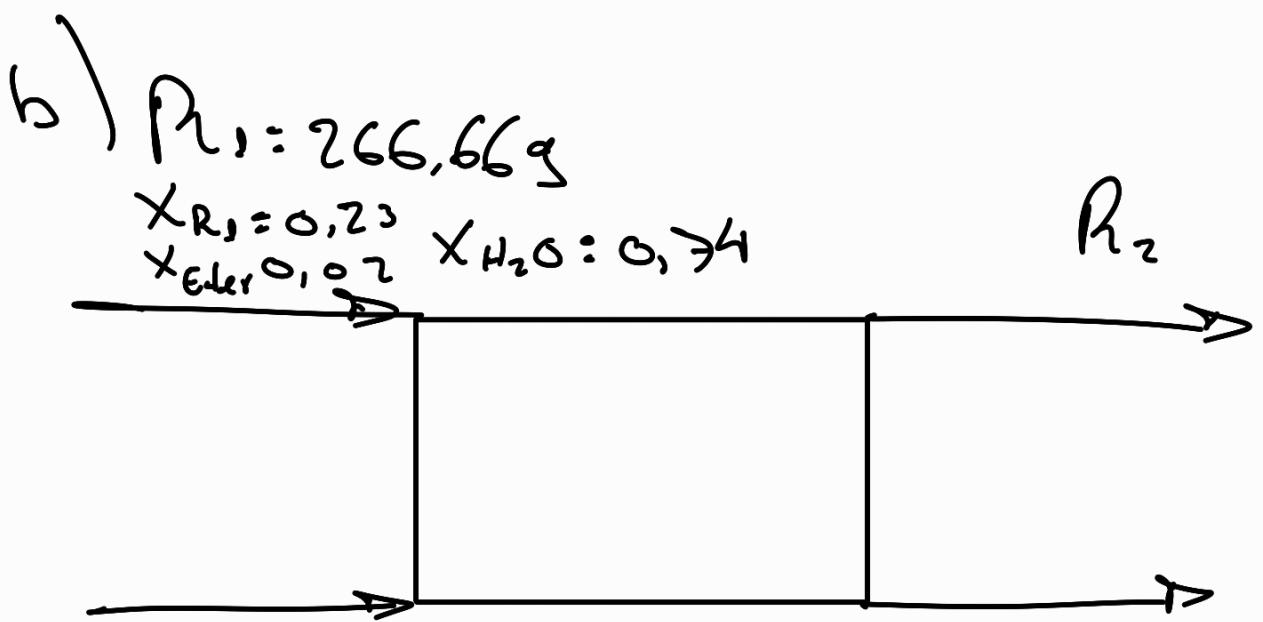
$$M = R_1 + \bar{E}_1$$

$$\frac{\overline{R_1 E_1}}{\overline{R_1 M}} = \frac{y_1 \cdot x_1}{x_M - x_1} = \frac{M}{\bar{E}_1}$$

$$\bar{E}_1 = 1200 \left(\frac{0,37 - 0,23}{0,41 - 0,23} \right)$$

$$= 933,33 \text{ g}$$

$$R_1: 1200 - 933,33 = 266,66 \text{ g}$$

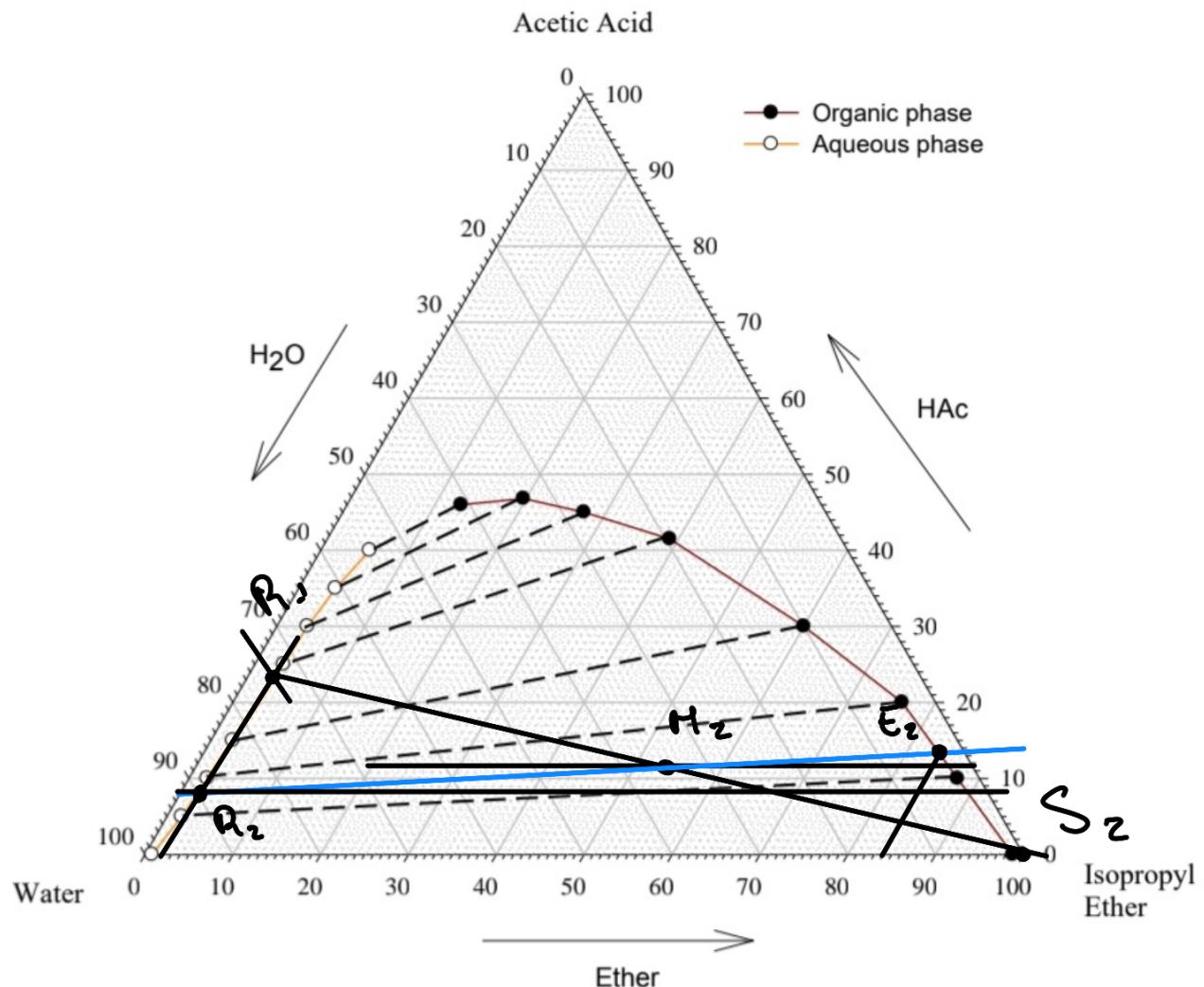


$$S_2 = 266,66 \text{ g}$$

$$S_3 = 0$$

$$R_1 + S_2 = M_2 = 266,66 + 266,66 \\ = 533,32 \text{ g}$$

Ternary System - 20°C



$$\frac{S_2}{R_2} = \frac{x_{H_2} - x_{S_2}}{y_2 - x_{H_2}}$$

$$1 = \frac{x_{H_2} - 0,23}{0 - x_{H_2}}$$

$$x_{H_2} = 0,23 - x_{H_2}$$

$$X_{M_2} = \frac{0,23}{2} = 0,115$$

$$M_2 = R_2 + E_2$$

$$\frac{M_2}{E_2} = \frac{y_2 - x_2}{x_{M_2} - x_2} =$$

$$\frac{533,32}{E_2} : \frac{0,13 - 0,08}{0,115 - 0,08}$$

$$E_2 = 533,32 \left(\frac{0,115 - 0,08}{0,13 - 0,08} \right)$$

$$= 373,32 \text{ g}$$

$$R_2 = 533,32 - 373,32$$

$$= 160 \text{ g}$$

$$x_2 = 0,08, x_{2,H_2O} = 0,9, x_{2,E^+} = 0,02$$

$$\gamma_2 = 0.13, \gamma_{2'} E_1 = 0.84, \gamma_{2, H_2O} = 0.03$$

2.

Pretende-se recuperar acetona de uma solução aquosa a 30 °C usando acetato de etilo, $\text{CH}_3\text{COOCH}_2\text{CH}_3$, como solvente.

A corrente de alimentação, contendo 25 % de acetona e 75 % de água, entra na base da coluna de extracção a um caudal de 250 kg/h. O solvente, puro, entra no topo a um caudal de 97 kg/h. Deseja-se um produto refinado com 10 % de acetona. Calcule:

- A concentração e o caudal da corrente de extracto;
- O número de andares de equilíbrio necessários para esta separação.

The aim is to recover acetone from an aqueous solution at 30 °C using ethyl acetate, $\text{CH}_3\text{COOCH}_2\text{CH}_3$, as solvent.

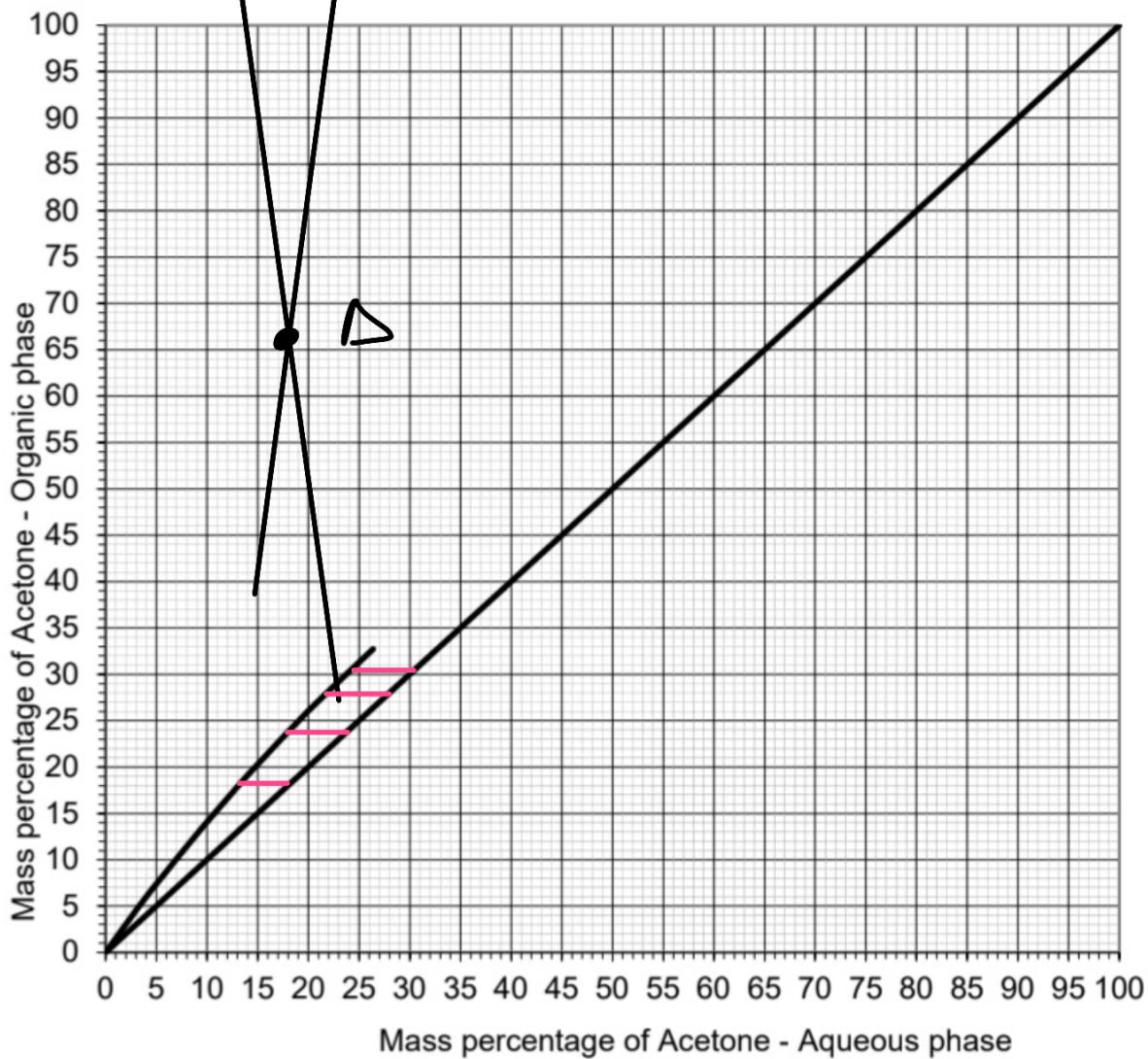
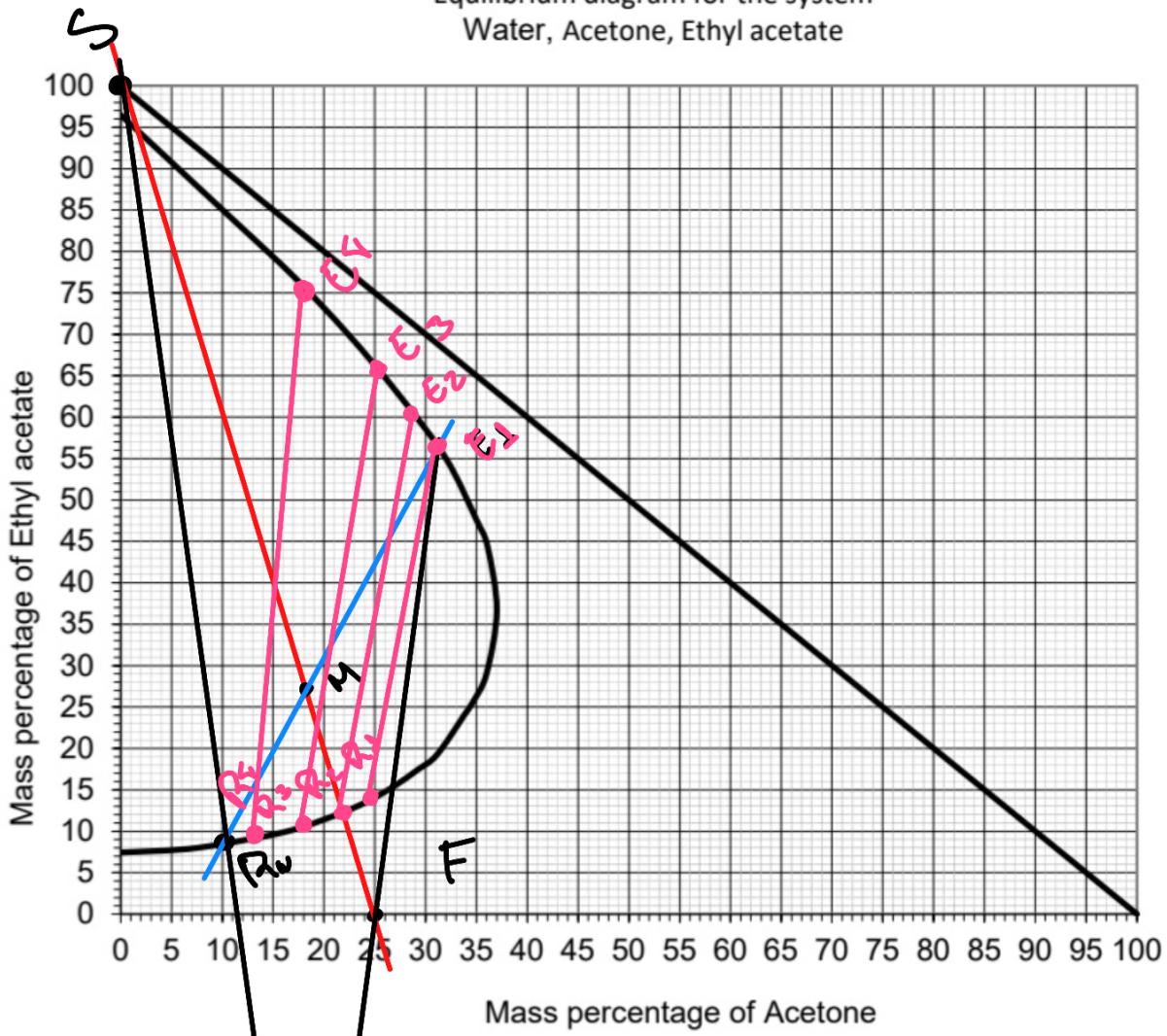
The feed stream, containing 25% acetone and 75% water, enters the base of the extraction column at a flow rate of 250 kg/h. The pure solvent enters at the top of the column at a flow rate of 97 kg/h. A raffinate product with 10% acetone is desired. Calculate:

- The concentration and flow rate of the extract stream;
- The number of equilibrium stages required for this separation.

Experimental data:

| Equilibrium data | | | Organic phase | | | Aqueous phase | | |
|------------------|---------|-------|---------------|---------|-------|---------------|---------|-------|
| Ethyl acetate | Acetone | Water | Ethyl acetate | Acetone | Water | Ethyl acetate | Acetone | Water |
| 7.4 | 0.0 | 92.6 | 91.0 | 4.8 | 4.2 | 8.3 | 3.2 | 88.5 |
| 8.0 | 7.6 | 84.4 | 85.8 | 8.7 | 5.5 | 8.0 | 6.0 | 86.0 |
| 9.9 | 16.1 | 74.0 | 80.5 | 13.4 | 6.1 | 8.3 | 9.5 | 82.2 |
| 11.9 | 21.1 | 67.0 | 76.2 | 17.6 | 6.2 | 9.2 | 12.8 | 78.0 |
| 13.6 | 24.3 | 62.1 | 73.0 | 20.0 | 7.0 | 9.8 | 14.8 | 75.4 |
| 15.5 | 27.0 | 57.5 | 69.4 | 23.2 | 7.4 | 10.2 | 17.5 | 72.3 |
| 17.4 | 29.2 | 53.4 | 65.1 | 25.8 | 9.1 | 12.2 | 19.8 | 68.0 |
| 19.2 | 31.1 | 49.7 | 62.2 | 27.4 | 10.4 | 11.8 | 21.2 | 67.0 |
| 24.0 | 33.8 | 42.2 | 54.0 | 32.7 | 13.3 | 15.0 | 26.4 | 58.6 |
| 25.5 | 34.6 | 39.9 | | | | | | |
| 29.0 | 36.0 | 35.0 | | | | | | |
| 36.7 | 37.0 | 26.3 | | | | | | |
| 44.4 | 36.1 | 19.5 | | | | | | |
| 47.6 | 35.0 | 17.4 | | | | | | |
| 55.0 | 32.0 | 13.0 | | | | | | |
| 62.5 | 27.5 | 10.0 | | | | | | |
| 70.0 | 22.4 | 7.6 | | | | | | |
| 77.0 | 17.0 | 6.0 | | | | | | |
| 83.7 | 11.2 | 5.1 | | | | | | |
| 96.5 | 0.0 | 3.5 | | | | | | |

Equilibrium diagram for the system
Water, Acetone, Ethyl acetate



$$X_F = 0,25$$

$$S = 97 \text{ kg h}^{-1}$$

$$X_{F, H_2O} = 0,75$$

$$y_s = 0$$

$$F = 250 \frac{\text{kg}}{\text{h}}$$

$$X_N = 0,1$$

a) $y_n = ?$ $E_N = ?$

$$\begin{aligned} F + S &= T = 250 + 97 \\ &= 347 \text{ kg.h}^{-1} \end{aligned}$$

$$\frac{S}{F} = \frac{\overline{MF}}{\overline{SM}} = \frac{X_F - X_M}{X_M - y_s}$$

$$\frac{S}{F} X_M - \frac{S}{F} y_s = X_F - X_M$$

$$X_M = \frac{X_F + \frac{S}{F} y_s}{\frac{S}{F} + 1}$$

$$X_M = 0,25 + \frac{97}{250}(0)$$

$\underbrace{\qquad\qquad\qquad}_{\frac{97}{250} + 1}$

$$= 0,18$$

↓

$$Y_N = 0,31$$

↓

$$\frac{\bar{E}_N}{M} = \frac{\overline{R_N M}}{\overline{R_N E_N}} = \frac{X_M - X_N}{Y_N - X_N}$$

$$\bar{E}_N = 347 \cdot \frac{(0,18 - 0,1)}{(0,31 - 0,1)}$$

$$\bar{E}_N = 132,19 \text{ kg.h}^{-1}$$

$$R_N = M - \bar{E}_N = 347 - 132,19$$

$$= 214,809525 \text{ kg.h}^{-1}$$

b) $N^o = ? \Rightarrow$ Graficamente
 São 4-5 andares

3.

Nicotina é extraída de uma solução aquosa usando querosene como solvente. A água e o querosene são imiscíveis.

- Se tiver uma solução aquosa com 1% (percentagem mássica) de nicotina determine a percentagem de extracção usando 150 kg de solvente por cada 100 kg de alimentação;
- Qual a percentagem de extracção se forem usados 3 andares de equilíbrio e 50 kg de solvente em cada.

Nicotine is extracted from an aqueous solution using kerosene as a solvent. Water and kerosene are immiscible.

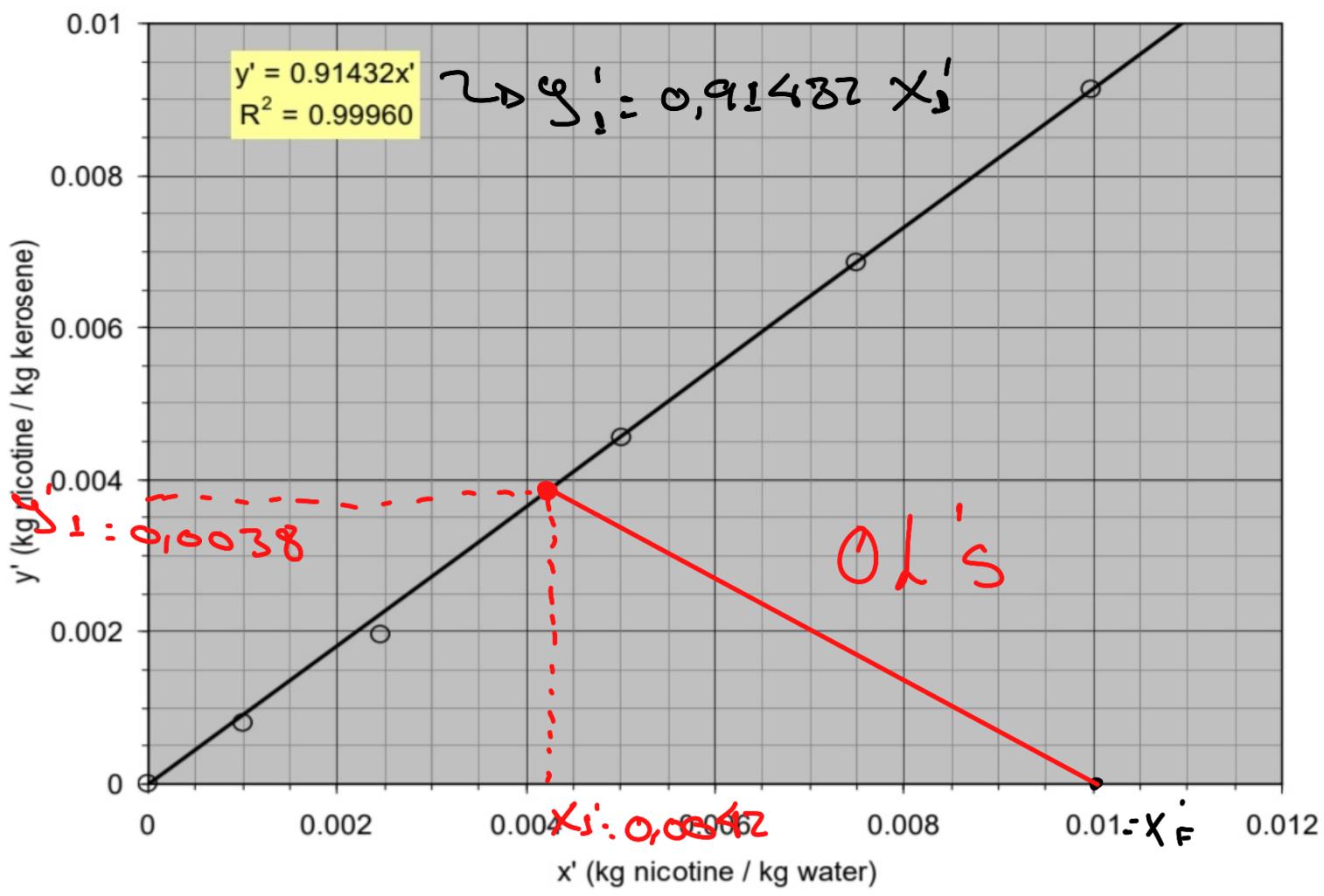
- If you have an aqueous solution with 1% (mass percentage) of nicotine, determine the extraction percentage using 150 kg of solvent per 100 kg of feed;
- What is the extraction percentage if 3 equilibrium stages and 50 kg of fresh solvent are used in each stage.

Experimental data:

Equilibrium curve for the system nicotine – water - kerosene

| x' (kg nicotine/kg water) | y' (kg nicotine/kg water) |
|-----------------------------|-----------------------------|
| 0.0 | 0.0 |
| 0.00101 | 0.000807 |
| 0.00246 | 0.001961 |
| 0.00502 | 0.004560 |
| 0.00751 | 0.006860 |
| 0.00998 | 0.009130 |
| 0.02040 | 0.01870 |

Equilibrium diagram for the system:
Water, Kerosene, Nicotine



$$F = 100 \text{ Kg} (1\% C) \quad S = 150 \text{ Kg} (100\% B)$$

$$x'_F = 0,01$$

$$y'_S = 0$$

$$A = 100 (1 - 0,01) = 99 \text{ kg}$$

$$B_1 = 150 \text{ kg}$$

$$- \frac{A}{B} = \frac{y'_S - y'_I}{x'_F - x'_I} \quad \text{OL's A}$$

$$x'_F = \frac{0,01}{1 - 0,01} \quad \begin{array}{l} \text{Prazão media} \\ \text{para tirar a} \\ \text{incot. e traço-} \\ \text{lhar só com t, O} \end{array}$$

$$= 0,0101$$

$$- \frac{A}{B} = - \frac{99}{150} = - 0,66$$

$$- 0,66 = \frac{0 - y'_I}{x'_F - x'_I}$$

Pelo equilíbrio

$$-0,66 = \frac{0 - (0,91437)(x'_i)}{0,0101 - x'_i}$$

$$\Rightarrow x'_i = 0,00423 \quad \cancel{\downarrow}$$

$$y'_i = (0,91437) / (0,00423) \\ = 0,6038676 \quad \cancel{\downarrow}$$

b) 3 andares

Para 1^o andar $B = 50 \text{ kg}$

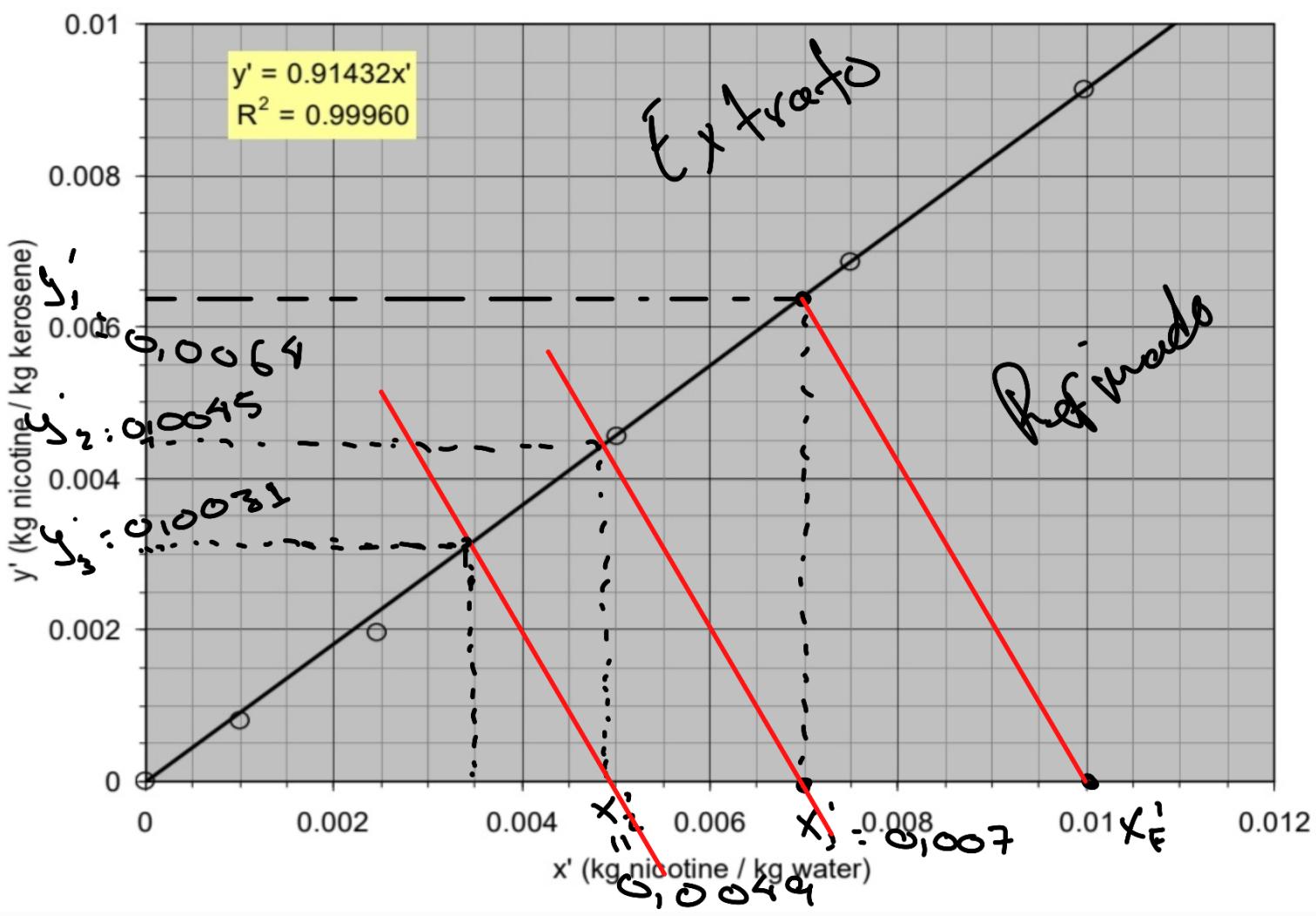
$$- \frac{A}{B} = - \frac{99}{50} = - 1,98 \quad \cancel{\downarrow}$$

$$x'_F = 0,0101$$

$$x'_1 = \frac{(1,98)(0,0105)}{1,98 + 0,91432} \\ = 0,007$$

$$y'_1 = (0,91432)(0,007) = 0,0064$$

Equilibrium diagram for the system:
Water, Kerosene, Nicotine



$$y'_3 = 0,0031 \quad \cancel{A}$$

$$x'_3 = 0,0035 \quad \cancel{S}$$

4.

Se 1000 kg/h de uma solução aquosa contendo 1% de nicotina for contactada com querosene a 20 °C para reduzir o teor em nicotina para 0.1% determine:

a) O caudal mínimo de solvente;

b) O número de andares necessários, se o caudal de solvente for de 1150 kg/h.

$$F = 1000 \text{ Kg} \cdot \text{h}^{-1}$$

$$x_F = 0,01$$

$$x'_N = 0,001$$

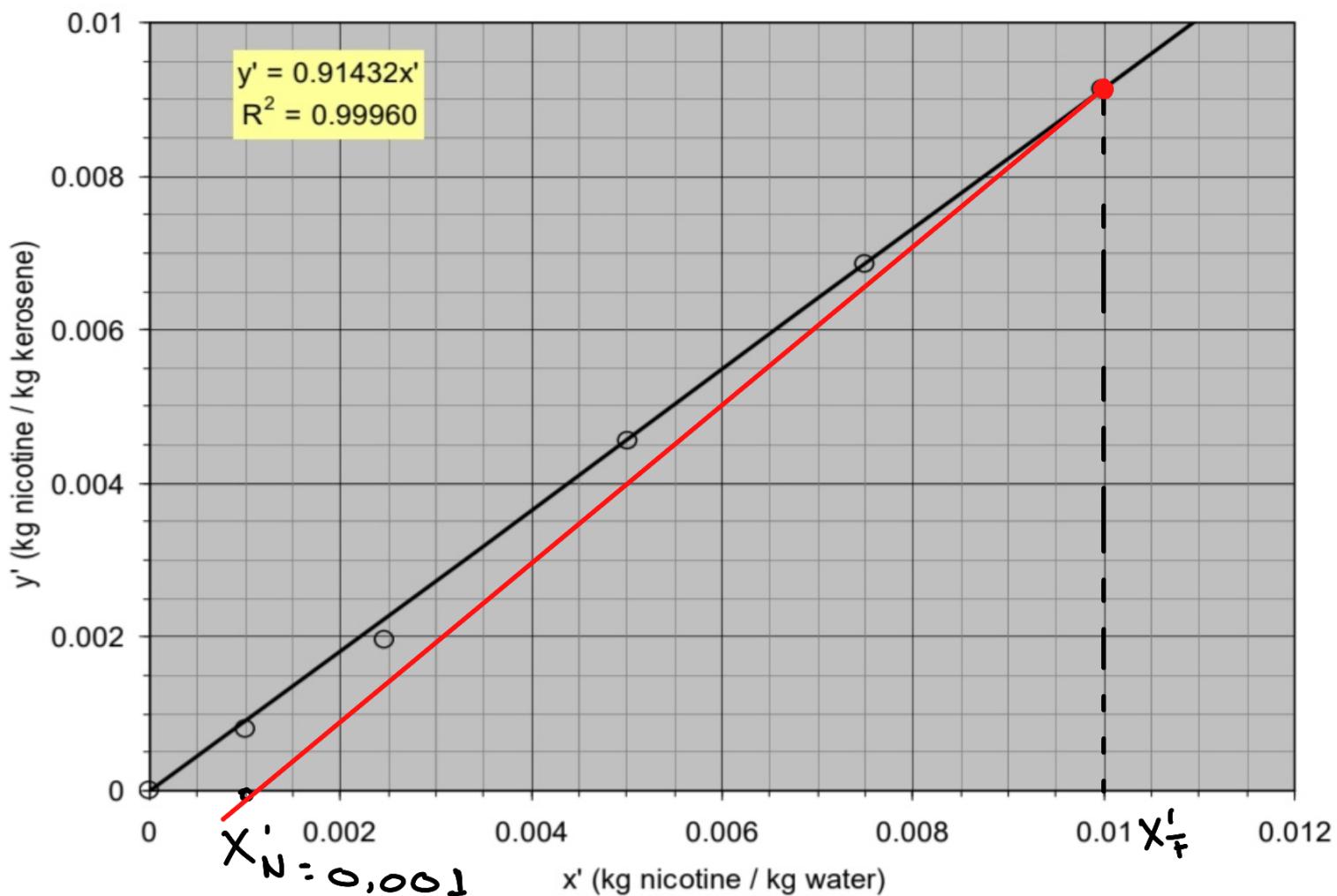
a) $S_{\min} = ?$

$$\underline{\text{O h.s}} : - \frac{A}{B} = \frac{y'_s - y'_s}{x'_f - x'_N}$$

$$1^{\circ} \quad A = (1000)(1 - 0,01) = 990 \text{ Kg} \cdot \text{h}^{-1}$$

$$2^{\circ} \quad x'_F = 0,01 \quad y'_s = 0$$
$$x'_N = 0,001$$

Equilibrium diagram for the system:
Water, Kerosene, Nicotine

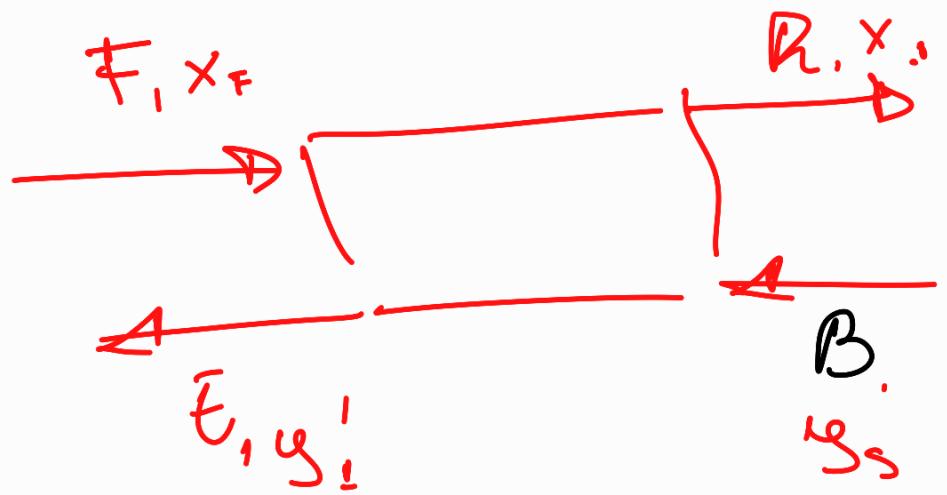


$$3^{\circ} S_{\min} \Rightarrow N \rightarrow \infty$$

$$-\frac{A}{B_{\min}} = \frac{0 - (0,91432)(0,01)}{0,01 - 0,001}$$

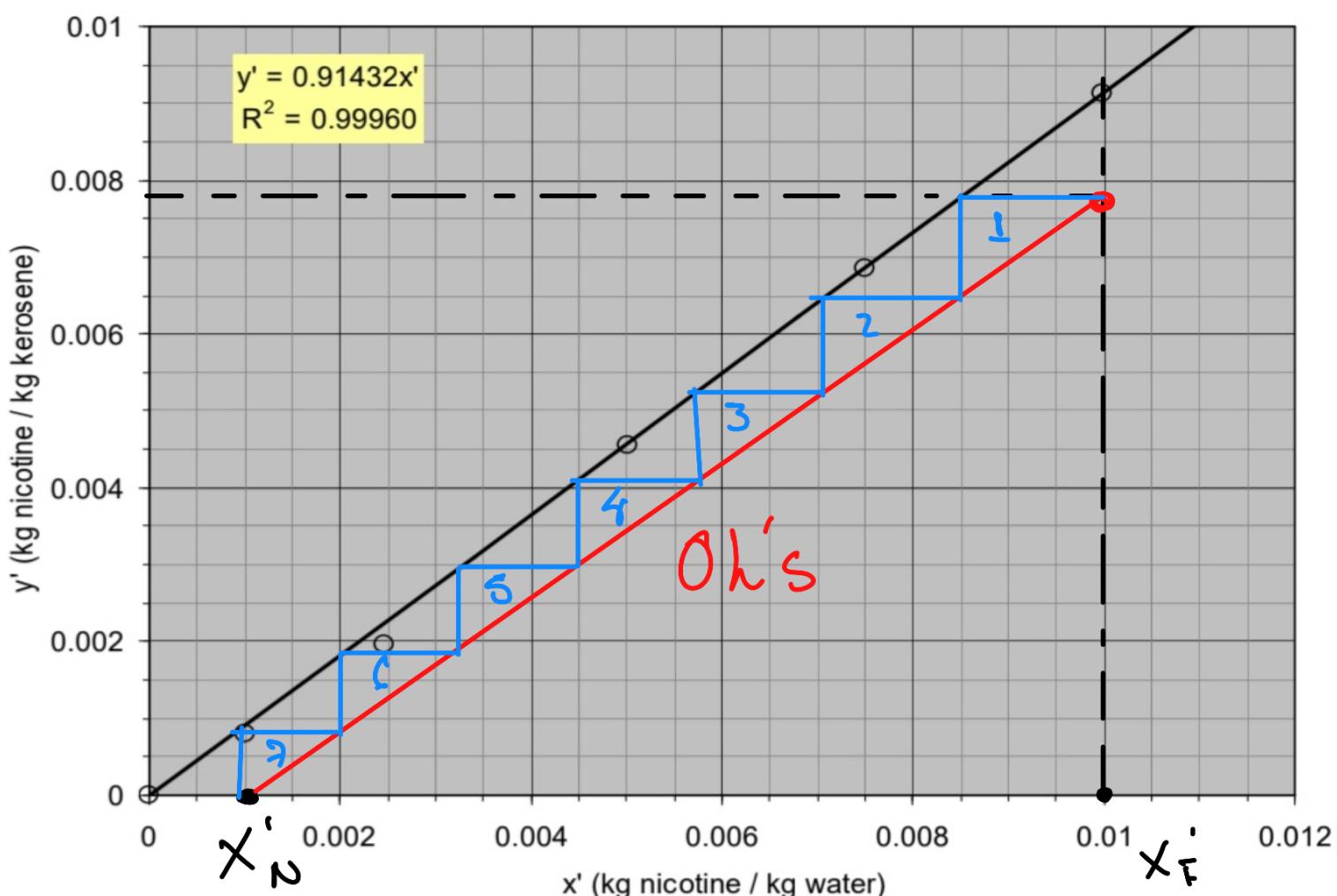
$$B_{\min} = \frac{(990)(0,01 - 0,001)}{(0,91432)(0,01)} \text{ contre corrigé}$$

$$B_{\min} = 974,5 \text{ kg.h}^{-1} \text{ contre } X_F$$



b)

Equilibrium diagram for the system:
Water, Kerosene, Nicotine



$$\frac{990}{1150} \approx \frac{y_s' - y_1'}{x_F' - x_n'}$$

?

$$y_i = \frac{990}{1150} (0.01 - 0.001)$$

$$= 0.0077$$

$$N^2_{\text{prato}} = 7$$

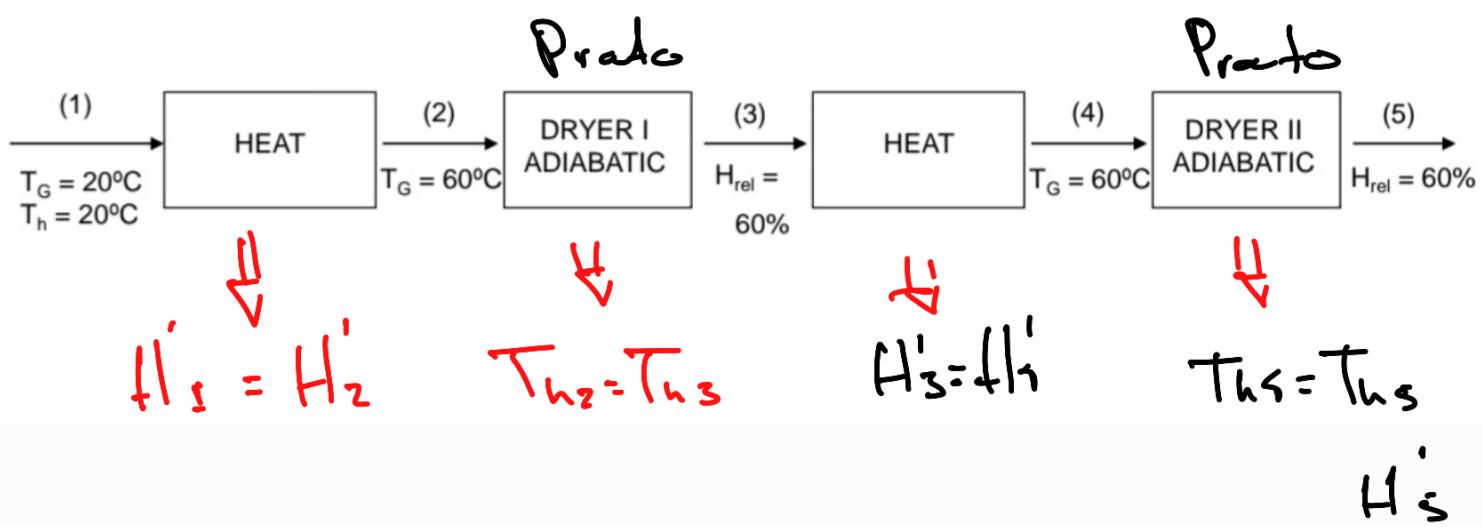
Seca Gern

In a drying process, a **dryer with two sets of trays is used to dry a wet solid.**

Air **saturated** to 20°C is previously heated to 60°C before passing through the first set of trays. The air leaves this 1st stage with a relative humidity of 60% and is heated again to 60°C before entering the second set of trays. At the exit of this 2nd stage, the air has again a relative humidity of 60%.

Assuming that **the drying process takes place adiabatically** and that the final temperature of the solid on each shelf equals the wet thermometer temperature of the air that contacts it, calculate:

- The final temperature of the solid in each set of trays.
- The total amount of water taken from the solid per kg of dry air.

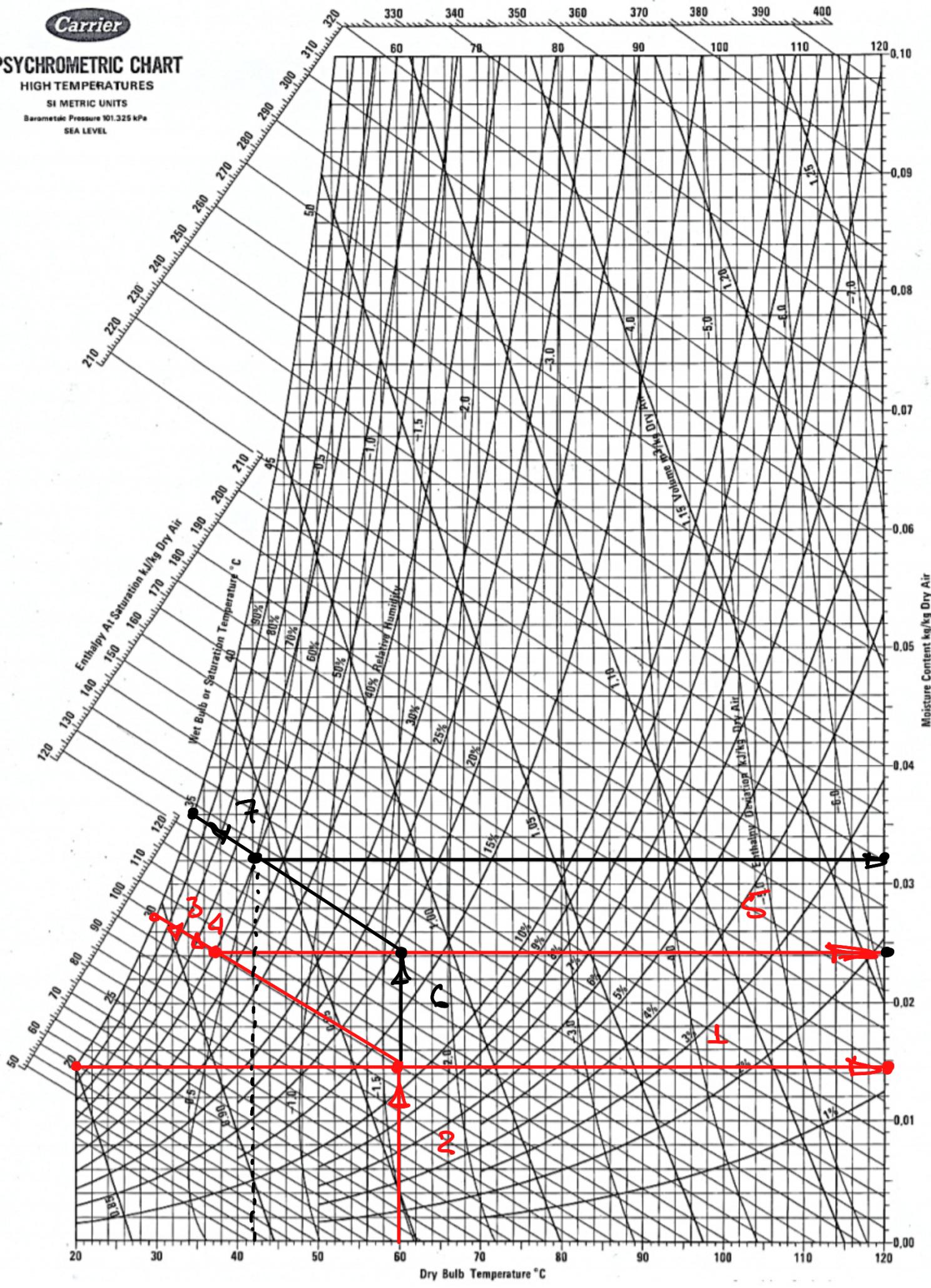


a) $T_{h2} \neq T_{h5}$

Carrier

PSYCHROMETRIC CHART

HIGH TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL



$$H_1' = 0,0145 \frac{kg\ H_2O}{kg\ Ar\ sec} = H_2'$$

$$T_{h_2} = 30^\circ C$$

$$H_3' = 0,024 \frac{kg\ H_2O}{kg\ Ar\ sec} = H_4'$$

$$T_{h_4} = 34,5^\circ C$$

b) $m_{\frac{H_2O}{Ar}} = 0,032 - 0,0145$

$$= 0,0175 \frac{kg\ H_2O}{kg\ Ar\ sec}$$

Problem

It is intended to dry a granular solid from 70% to 5% in water (weight percentages).

In the drying process a **fluidized bed dryer** is used, with the aim of obtaining 45 kg/h of dry material. Atmospheric air is used for this effect, which is heated to 80°C before being introduced into the dryer.

The air at the exit of the dryer has a relative humidity of 90%. Knowing that the atmospheric air before being heated has a temperature of 40°C and a wet thermometer temperature of 40°C, calculate the dry air flow required in the drying process. Admit that the dryer works adiabatically.

Carrier

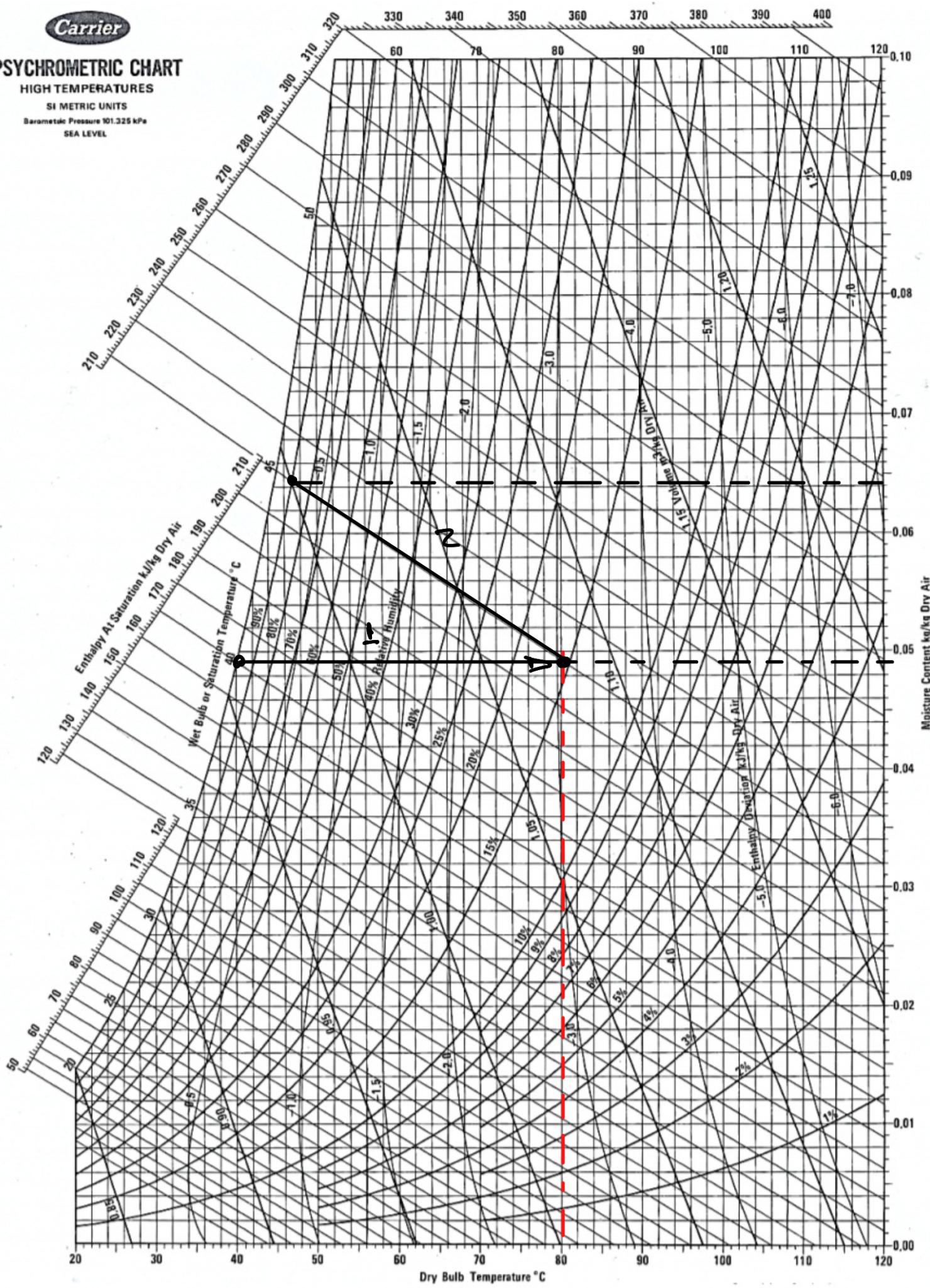
PSYCHROMETRIC CHART

HIGH TEMPERATURES

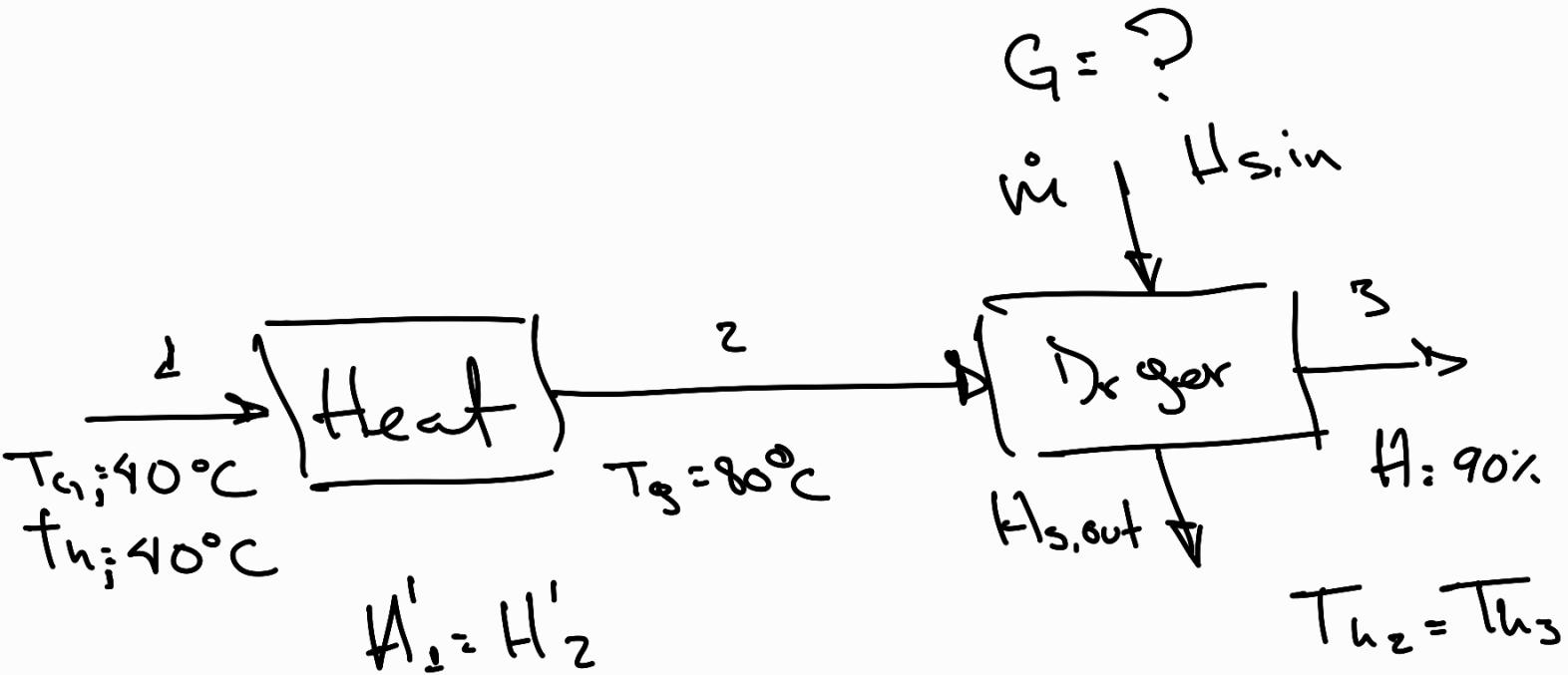
SI METRIC UNITS

Barometric Pressure 101.325 kPa

SEA LEVEL



$$70\% \rightarrow 5\% \quad \dot{m} = 45 \text{ kg h}^{-1}$$



$$H'_2 = 0,049 \frac{\text{Kg H}_2\text{O}}{\text{Kg Ar sec}}$$

$$H'_3 = 0,064$$

$$Th_2 = 45^\circ\text{C}$$

$$\begin{array}{ccc} 45 & \xrightarrow{\hspace{1cm}} & 30 \\ \times & \xrightarrow{\hspace{1cm}} & 70 \end{array}$$

$$\dot{m}_{in} = 105 \text{ kg h}^{-1} \text{ H}_2\text{O}$$

$$X_{ext} = 105 - 2,328 = 102,63 \frac{\text{kg H}_2\text{O}}{\text{h}}$$

$$X_{out} = 2,3681$$

$$0,015 \text{ Kg H}_2\text{O} \rightarrow 1 \text{ Kg Ar}$$

$$102,63 \text{ Kg H}_2\text{O} \rightarrow G$$

$$G = \frac{102,63}{0,015} = 6842 \text{ Kg Ar.h}^{-1}$$

Problem

A **tray dryer** is used to dry raw cotton with 0.7 g/cm^3 of density when dried. It is intended to obtain a product with $0.1 \text{ g water/g dry cotton}$, starting from an initial humidity of $1 \text{ g water/g dry cotton}$.

The trays have dimensions of $60 \times 60 \text{ cm}$. The material to be dried is arranged in the trays with a thickness of 1 cm . The trays are arranged in such a way that drying takes place only from the upper surface, the lower surface being insulated.

The drying air enters at 75°C , and its humid thermometer temperature is 50°C . The air flow through the surface of the dryer is 2500 kg/h/m^2 .

Previous experiments under the same conditions have shown that critical humidity (H_c) is $0.4 \text{ g water/g dry solid}$, and that the drying velocity during the "Falling rate period" is proportional to the moisture of the mixture. Calculate the time it takes to get the desired moisture.

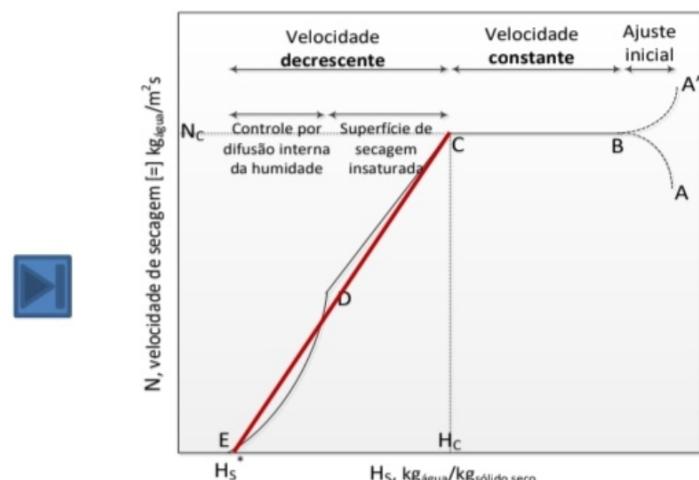
Data:

Equilibrium humidity (H_s^*): 0.031

Water vaporization enthalpy (λ_{vap}): $2.383 \times 10^3 \text{ kJ/kg}$

$h_G = 14.3 G^{0.8}$ (airflow parallel to flat surfaces)

being $h_G [=] \text{ W m}^{-2} \text{ K}^{-1}$; $G [=] \text{ kg m}^{-2} \text{ s}^{-1}$



PS

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$$\rho_{\text{cotton}} = 0,7 \text{ g cm}^{-3} \text{ Seco}$$

$$H_{S,\text{out}} = 0,1 \text{ g/g dry cotton}$$

$$H_{S,\text{in}} = 1 \text{ g/g dry cotton}$$

$$\begin{aligned} A &= 3600 \text{ cm}^2 \\ S &= 1 \text{ cm} \end{aligned} \quad \left\{ \begin{array}{l} V = 3600 \text{ cm}^3 \\ \downarrow \end{array} \right.$$

See caguen Paralela

$$T_g,\text{in} = 78^\circ\text{C} \quad T_h,\text{in} = 50^\circ\text{C}$$

$$G = 2500 \text{ Kg h}^{-1} \cdot \text{m}^{-2} \quad \downarrow$$

$$A_c = 0,4 \text{ g/g dry cotton}$$

$$t_{\text{total}} = ?$$

$$Q = h_g (T_g - T_{\text{sup}}) = N_c \lambda_{\text{vap}}$$

$$h_g = 14.3 G^{0.8}$$

$$G: 2800 \frac{\text{Kg}}{\text{h}} \cdot \frac{1}{h}$$

$$h \text{ m}^2 \quad 3600 \text{ s}$$

$$= 0,694 \text{ kg. s}^{-1} \text{ m}^{-2}$$

$$h_G = (14,3) (0,694)^{0,8} = 10,68 \text{ W.m}^2 \text{ K}^{-1}$$

$$Q = 10,68 (75 - 50) = 267 \text{ W.m}^2$$

$$N_c = \frac{267 \text{ W.m}^{-2}}{2,383 \times 10^6 \text{ J/Kg}} = 1,121 \times 10^{-4} \text{ Kg.s.m}^{-2}$$

$$M_s = 3600 \text{ cm}^3 \cdot 0,7 \frac{\text{g}}{\text{cm}^3} = 2520 \text{ g}$$

$$t_{\text{cette vole}} = - \frac{M_s}{A} \cdot \frac{(H_c - H_{s1})}{N_c}$$

$$t_{\text{deux vole}} = - \frac{M_s (H_c - H_s^*)}{N_c A} \ln \left(\frac{H_{s2} - H_s^*}{H_c - H_s^*} \right)$$

$$t_{\text{cycle vel}} = \frac{-2.52}{0.36} \left(0.4 - \frac{1}{1.121 \times 10^{-4}} \right)$$

$$= 37462 \text{ s}$$

$$t_{\text{dec}} = \frac{-(2.52)(0.4 - 0.031)}{(1.121 \times 10^{-4})(0.36)} \ln \left(\frac{0.1 - 0.031}{0.4 - 0.031} \right)$$

$$= 38634 \text{ s}$$

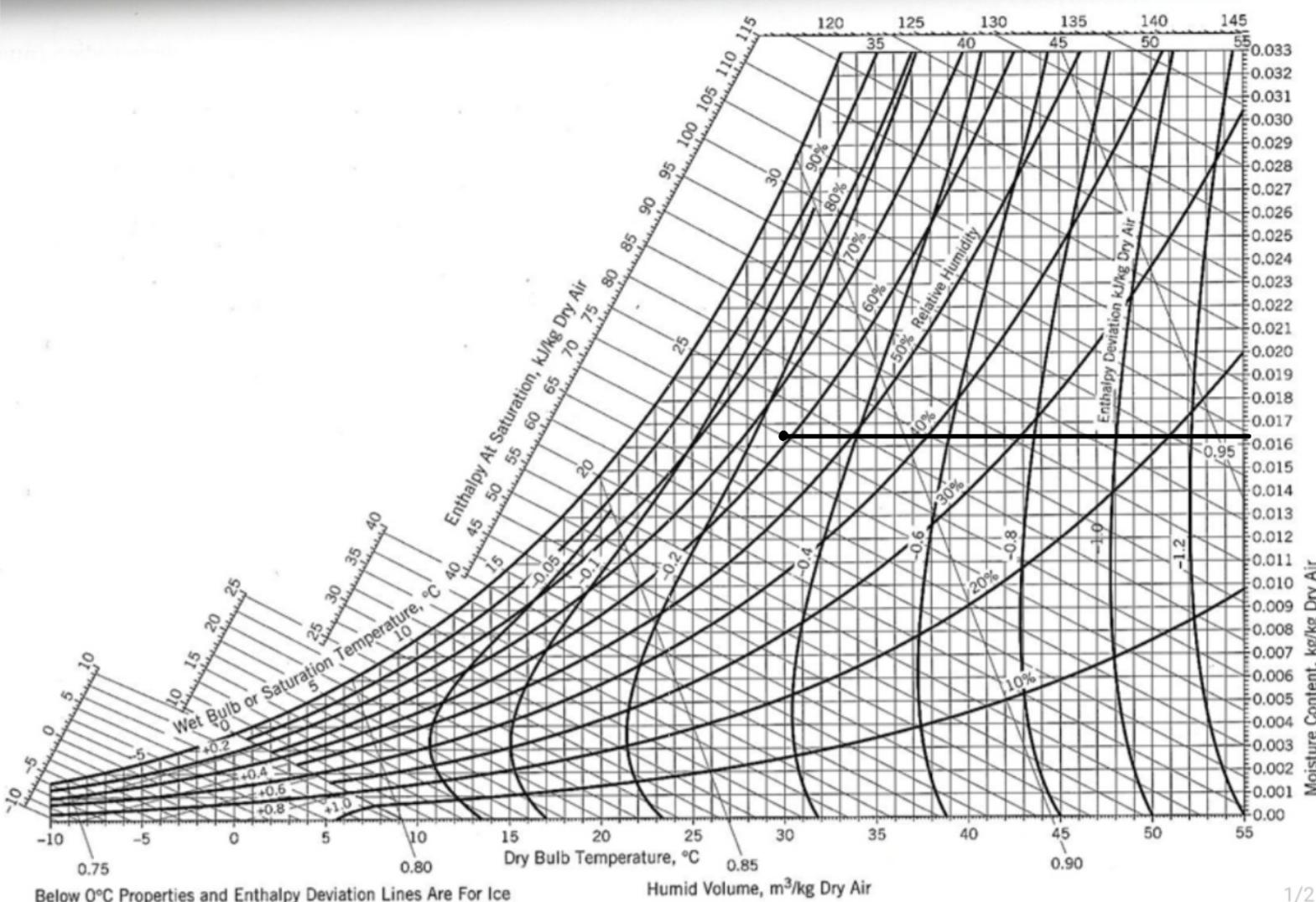
$$t_{\text{total}} = 21,13 \text{ h}$$

Problem

It is necessary a cooled water flowrate of 15 kg/s to be used in the condenser of a distillation column. The water leaves the condenser at 45°C and we want to cool it to 29°C by contact with humid air at 30°C with a wet bulb temperature of 24°C. The dry air flowrate is 10.97 kg/s.

If $K_y a = 0.9 \text{ kg/m}^3$ and the cross section area is 5.5 m^2 , which is the height of the cooling tower.

$$C_p \text{ water} = 4.187 \text{ kJ/kg}\cdot^\circ\text{C}$$



$$L = 15 \text{ Kg} \cdot \text{s}^{-1} \quad T_{g,in} = 30^\circ\text{C}$$

$$T_{L,in} = 45^\circ\text{C} \quad T_h = 25^\circ\text{C}$$

$$T_{L,out} = 29^\circ\text{C} \quad G = 10,97 \text{ Kg} \cdot \text{s}^{-1}$$

$$K_g a = 0,9 \text{ Kg} \cdot \text{m}^{-3} \quad A = 5,5 \text{ m}^2$$

$$C_p = 4,187 \text{ KJ} \cdot \text{Kg} \cdot {}^\circ\text{C}^{-1}$$

$$\bar{E}_{G1} = 72,5 + (-0,3) = 72,2 \frac{\text{KJ}}{\text{Kg Ar seco}}$$

$$H' = 0,0164 \frac{\text{Kg H}_2\text{O}}{\text{Kg Ar seco}}$$

$$Z = \frac{G}{(K_g a) S} \cdot \left\{ \begin{array}{l} \bar{E}_{G2} \\ \bar{E}_{G1} \end{array} \right. \frac{d\bar{E}_G}{\bar{E}_G^* - \bar{E}_G}$$

$$\frac{\bar{E}_{G2} - \bar{E}_{G1}}{T_{L2} - T_{L1}} = \frac{L \cdot C_p}{G} \quad \text{...}$$

