

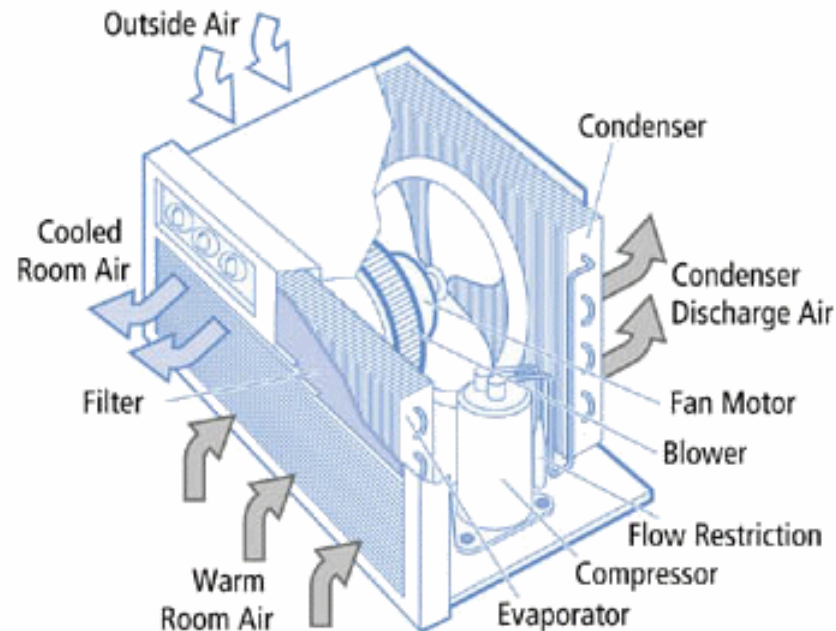
Balance de materia y energía

QUIM-MS-2008

Caso

Balance de materia en un equipo de acondicionamiento

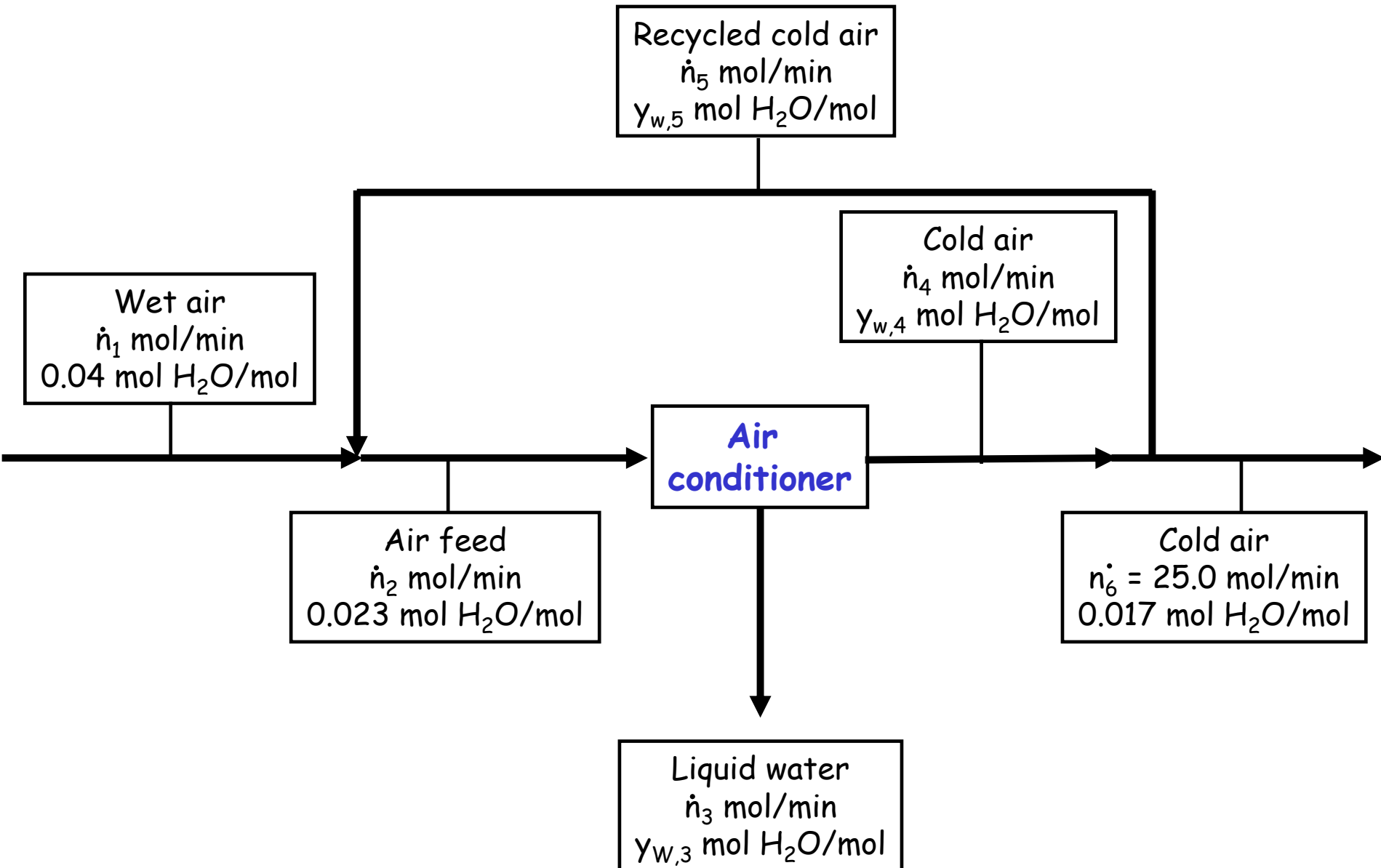
Components of a Room Air Conditioner



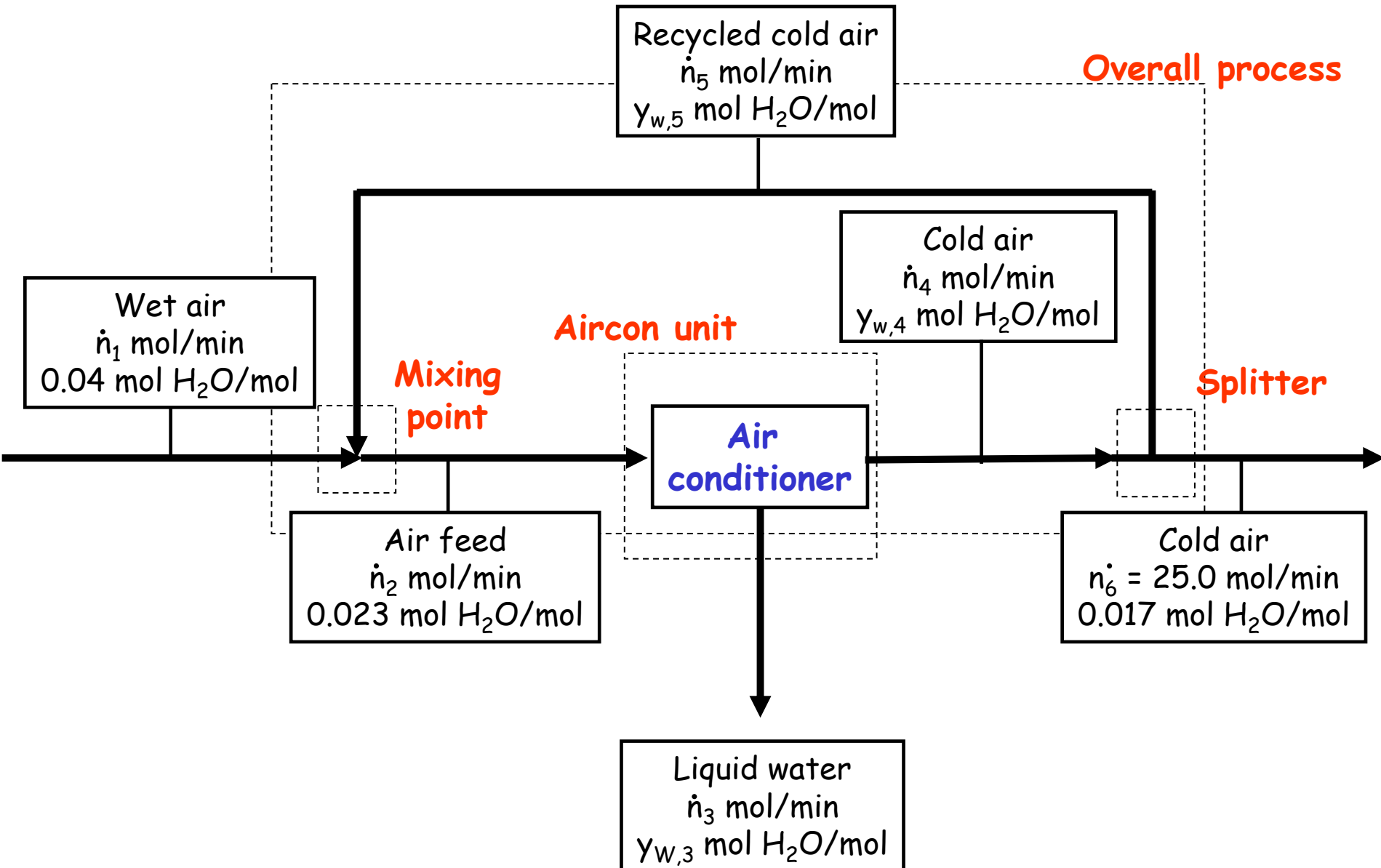
Problem statement

Fresh air containing 4.00 mole% water vapour is to be cooled and dehumidified to a water content of 1.70 mole% water. A stream of fresh air is combined with a recycle stream of previously dehumidified air and passed through the cooler. The blended stream entering the unit contains 2.30 mole% water. In the air conditioner some of the water in the feed is condensed and removed as liquid. A fraction of the dehumidified air leaving the cooler is recycled and the remainder is delivered to a room. Taking 25.0 mol/min of dehumidified air delivered to the room, calculate the fresh feed rate, rate of water condensation, and the rate of recycled dehumidified air.

Flow sheet for air conditioner



Defining systems



Evaluation of material balances - I

Overall system:

$$\dot{n}_1 = 25.6 \text{ mol/min}$$

$$\dot{n}_3 = 0.6 \text{ mol/min}$$

$$\dot{n}_6 = 25.0 \text{ mol/min}$$

$$y_{w,1} = 0.040$$

$$y_{w,3} = 1.000$$

$$y_{w,6} = 0.017$$

$$Y_{DA,1} = 0.960$$

$$Y_{DA,3} = 0.960$$

$$Y_{DA,6} = 0.983$$

All other systems have one/two degrees of freedom. The equations governing all the other systems, can be expressed in terms of one/two unknown variables. The most convenient way of solving the material balance in this case is to formulate the water mole balance and the overall balance for each of the other systems:

Mixing point:

$$\dot{n}_1 + \dot{n}_5 = \dot{n}_2$$

$$0.04 \cdot \dot{n}_1 + y_{w,5} \cdot \dot{n}_5 = 0.023 \cdot \dot{n}_2$$

Aircon unit:

$$\dot{n}_2 = \dot{n}_3 + \dot{n}_4$$

$$0.023 \cdot \dot{n}_2 = \dot{n}_3 + y_{w,4} \cdot \dot{n}_4$$

Splitter:

$$\dot{n}_4 = \dot{n}_5 + \dot{n}_6$$

This is now a system with 5 equations/8 variables, which can be solved using the results obtained on the overall system

Evaluation of material balances - II

Mixing point: $\dot{n}_1 + \dot{n}_5 = \dot{n}_2$
 $0.04 \cdot \dot{n}_1 + y_{w,5} \cdot \dot{n}_5 = 0.023 \cdot \dot{n}_2$

The mole fraction of water in stream 5 equals the mol fraction in stream 6 (physical law from point around splitter). Furthermore, from the material balance around the whole system we know the molar flow rate of stream 1:

$$25.6 + \dot{n}_5 = \dot{n}_2$$
$$0.04 \cdot 25.6 + 0.017 \cdot \dot{n}_5 = 0.023 \cdot \dot{n}_2$$

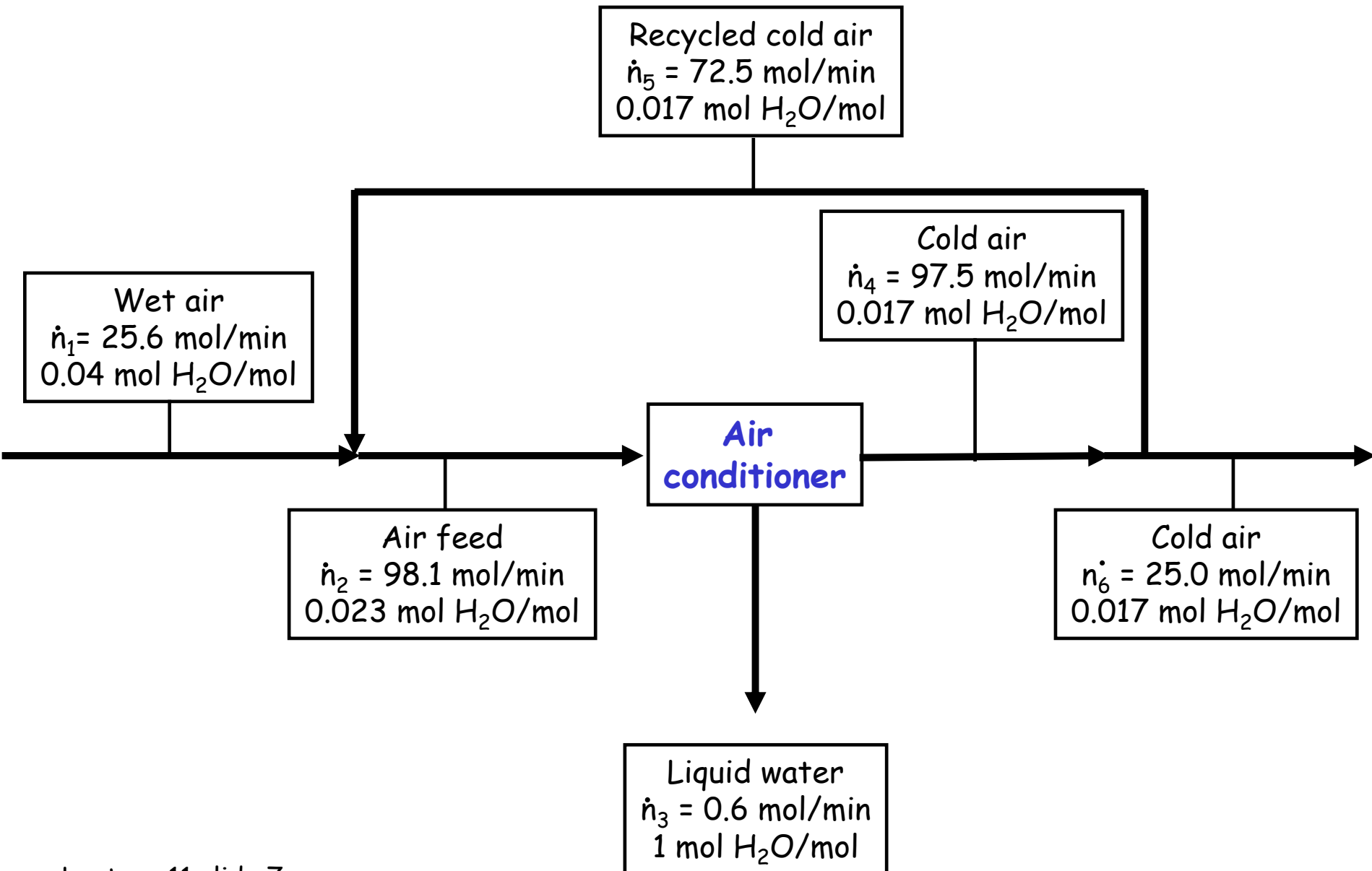
Solving these equations simultaneously: $\dot{n}_2 = 98.1 \cdot \frac{\text{mol}}{\text{min}}$ $\dot{n}_5 = 72.5 \cdot \frac{\text{mol}}{\text{min}}$

Splitter: $\dot{n}_4 = \dot{n}_5 + \dot{n}_6 = 97.5 \cdot \frac{\text{mol}}{\text{min}}$

Aircon unit:

Material balance not needed anymore!

Evaluation of material balances - III



Answering the questions

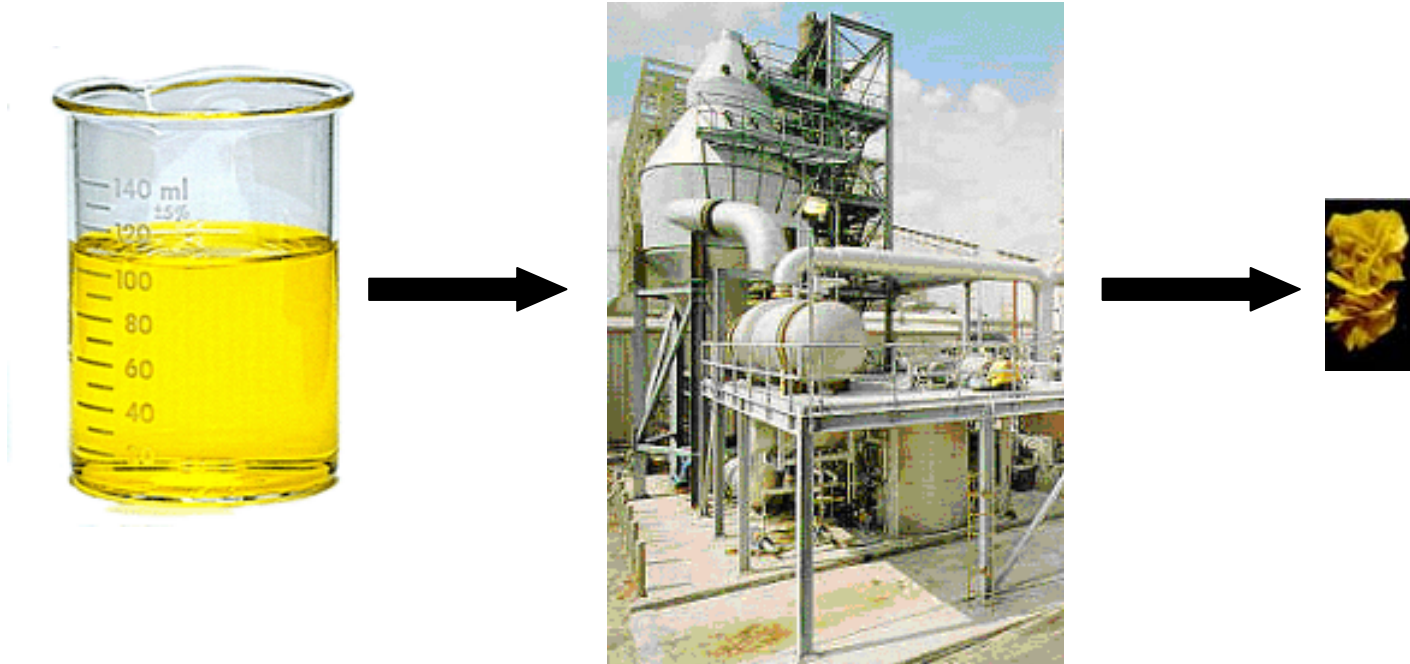
Fresh feed rate:	25.6 mol/min
Rate of water condensation:	0.6 mol/min
Rate of recycled dehumidified air:	72.5 mol/min

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Cristalización del cromato de potasio, K_2CrO_4



Principle of crystallisation/precipitation

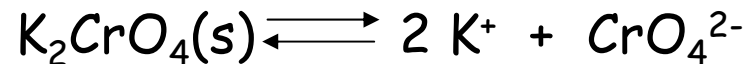
Crystallisation/precipitation:

Recovery of materials in solution as a solid.

Governing principle:

Solubility product, K_{SP}

For an ionic compound, such as K_2CrO_4 , solubility is given by:



and the solubility product is defined as:

$$K_{SP} = [K^+]^2 \cdot [CrO_4^{2-}]$$

Often *in literature* solubility is given in g/100 g H_2O . This is the amount of pure salt dissolved in pure water. The solubility of K_2CrO_4 is 62.9 g/100 g water at 20°C. Thus,

$$[K^+] = 2 \cdot \frac{62.9 \cdot g}{100 \cdot g} \cdot \frac{1}{194.19} \cdot \frac{mol}{g} \cdot \frac{100 \cdot g}{0.1 \cdot litre} = 6.5 \cdot \frac{mol}{litre}$$

$$[CrO_4^{2-}] = 3.2 \cdot \frac{mol}{litre}$$

$$K_{SP} = 136 \cdot \frac{mol^3}{litre^3}$$

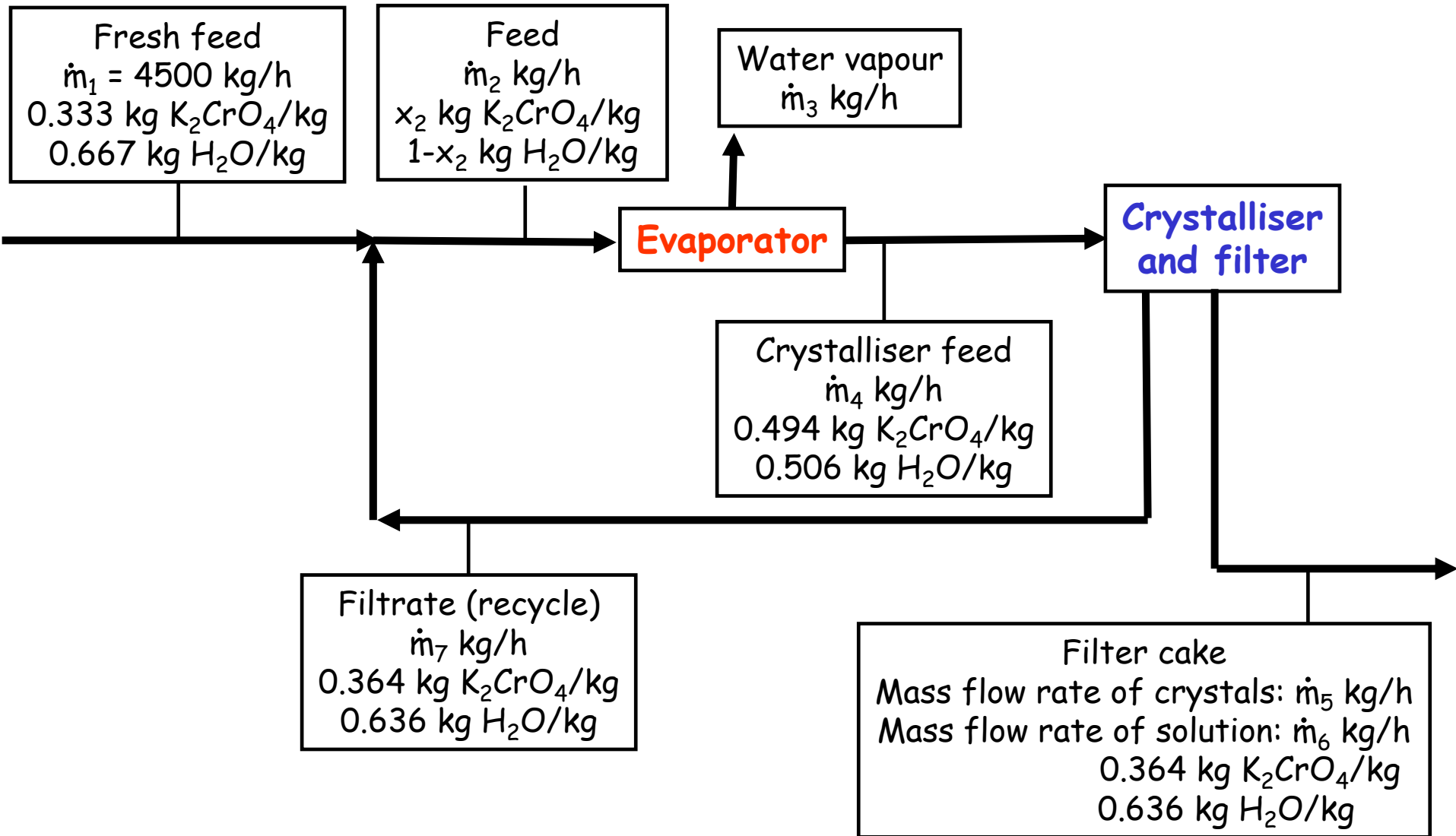
Problem statement

A solution containing 33.3 wt.-% of K_2CrO_4 (4500 kg/h) is to be fed to an evaporative crystallisation process. Before entering the evaporator, the fresh feed is mixed with a recycle stream containing 36.4 wt% K_2CrO_4 . The stream leaving the evaporator, which contains 49.4 wt% K_2CrO_4 , is fed to the crystalliser, in which the solution is cooled and crystals are formed. The filter cake removed from the crystalliser consists of K_2CrO_4 crystals and a solution containing 36.4 wt% K_2CrO_4 . The crystals account for 95% of the total mass of the filter cake. The solution passing the filter, which also contains 36.4 wt% K_2CrO_4 , is recycled back.

Calculate the rate of evaporation, the rate of production of crystalline K_2CrO_4 , the feed rates that the evaporator and the crystallizer need to handle, and the recycle ratio.

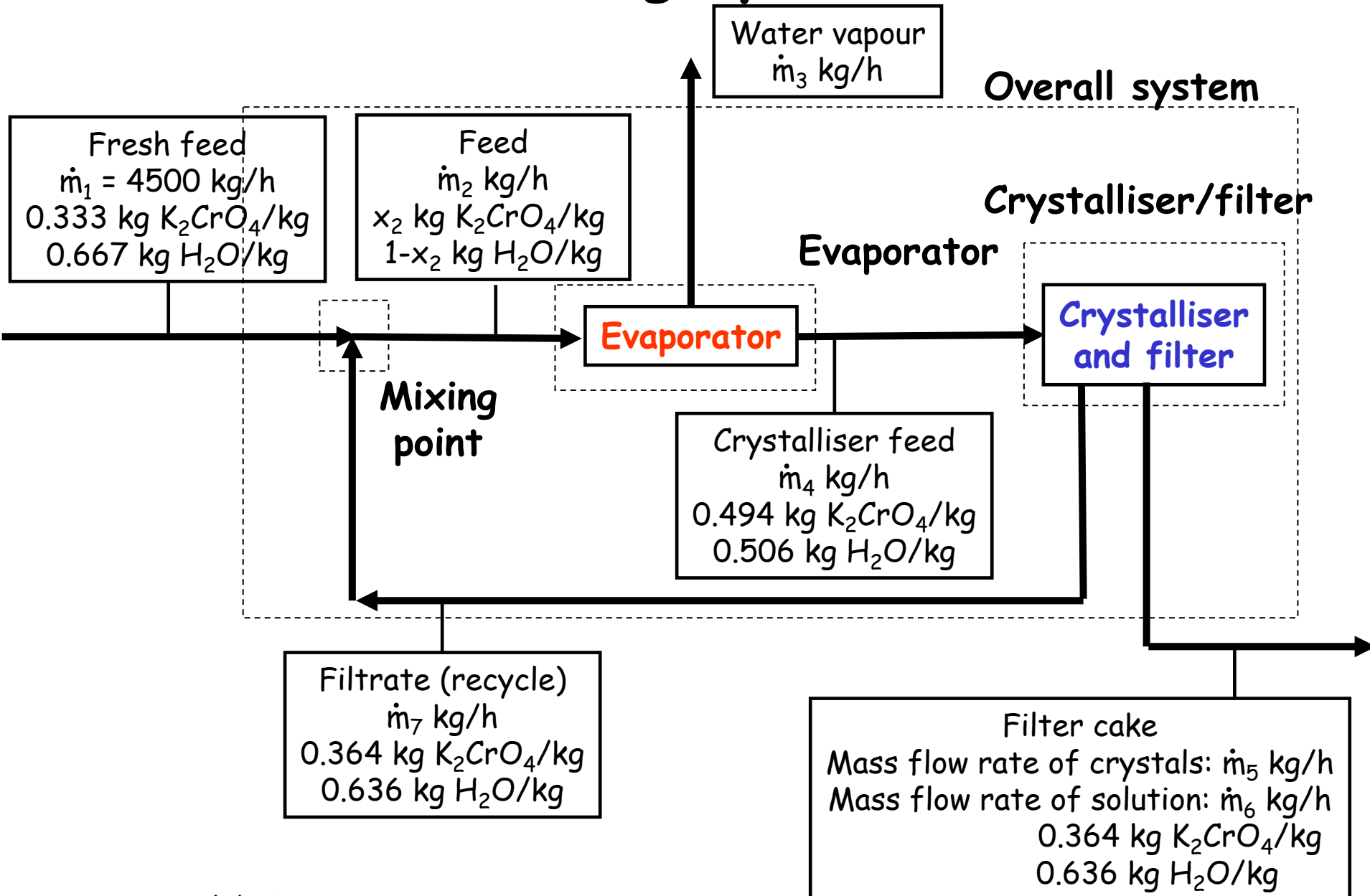
What are the benefits of recycling?

Flow sheet for evaporative crystalliser



Process is completely labelled (all component flow rates can be expressed in terms of given quantities)

Defining systems



Evaluation of material balances - I

Overall system:

Overall mass balance: $4500 = \dot{m}_3 + \dot{m}_5 + \dot{m}_6$

Mass balance on K_2CrO_4 : $0.333 \cdot 4500 = 0 \cdot \dot{m}_3 + 1 \cdot \dot{m}_5 + 0.364 \cdot \dot{m}_6$

Process specification: $\dot{m}_5 = 0.95 \cdot (\dot{m}_5 + \dot{m}_6)$

$$\dot{m}_3 = 2950 \cdot \frac{\text{kg}}{\text{h}}; \dot{m}_5 = 1470 \cdot \frac{\text{kg}}{\text{h}}; \dot{m}_6 = 77.5 \cdot \frac{\text{kg}}{\text{h}}$$

Evaporator/filter:

Overall mass balance: $\dot{m}_4 = \dot{m}_5 + \dot{m}_6 + \dot{m}_7$

Mass balance on K_2CrO_4 : $0.494 \cdot \dot{m}_4 = 1 \cdot \dot{m}_5 + 0.364 \cdot \dot{m}_6 + 0.364 \cdot \dot{m}_7$

Result from overall system: $\dot{m}_5 = 1470 \cdot \frac{\text{kg}}{\text{h}}$

$$\dot{m}_6 = 77.5 \cdot \frac{\text{kg}}{\text{h}}$$

$$\dot{m}_4 = 7440 \cdot \frac{\text{kg}}{\text{h}}; \dot{m}_7 = 5890 \cdot \frac{\text{kg}}{\text{h}}$$

Evaluation of material balances - II

Mixing point:

Overall mass balance: $4500 + \dot{m}_7 = \dot{m}_2$

Mass balance on K_2CrO_4 : $0.333 \cdot 4500 + 0.364 \cdot \dot{m}_7 = x_2 \cdot \dot{m}_2$

Result from crystalliser/filter: $\dot{m}_7 = 5890 \cdot \frac{kg}{h}$

$$\dot{m}_2 = 10400 \cdot \frac{kg}{h}; x_2 = 0.35$$

Now all streams in the system are fully quantified.

Rate of evaporation:

$$\dot{m}_3 = 2950 \cdot \frac{kg}{h}$$

Rate of production of crystalline K_2CrO_4 :

$$\dot{m}_5 = 1470 \cdot \frac{kg}{h}$$

Feed rates to the evaporator:

$$\dot{m}_2 = 10400 \cdot \frac{kg}{h}$$

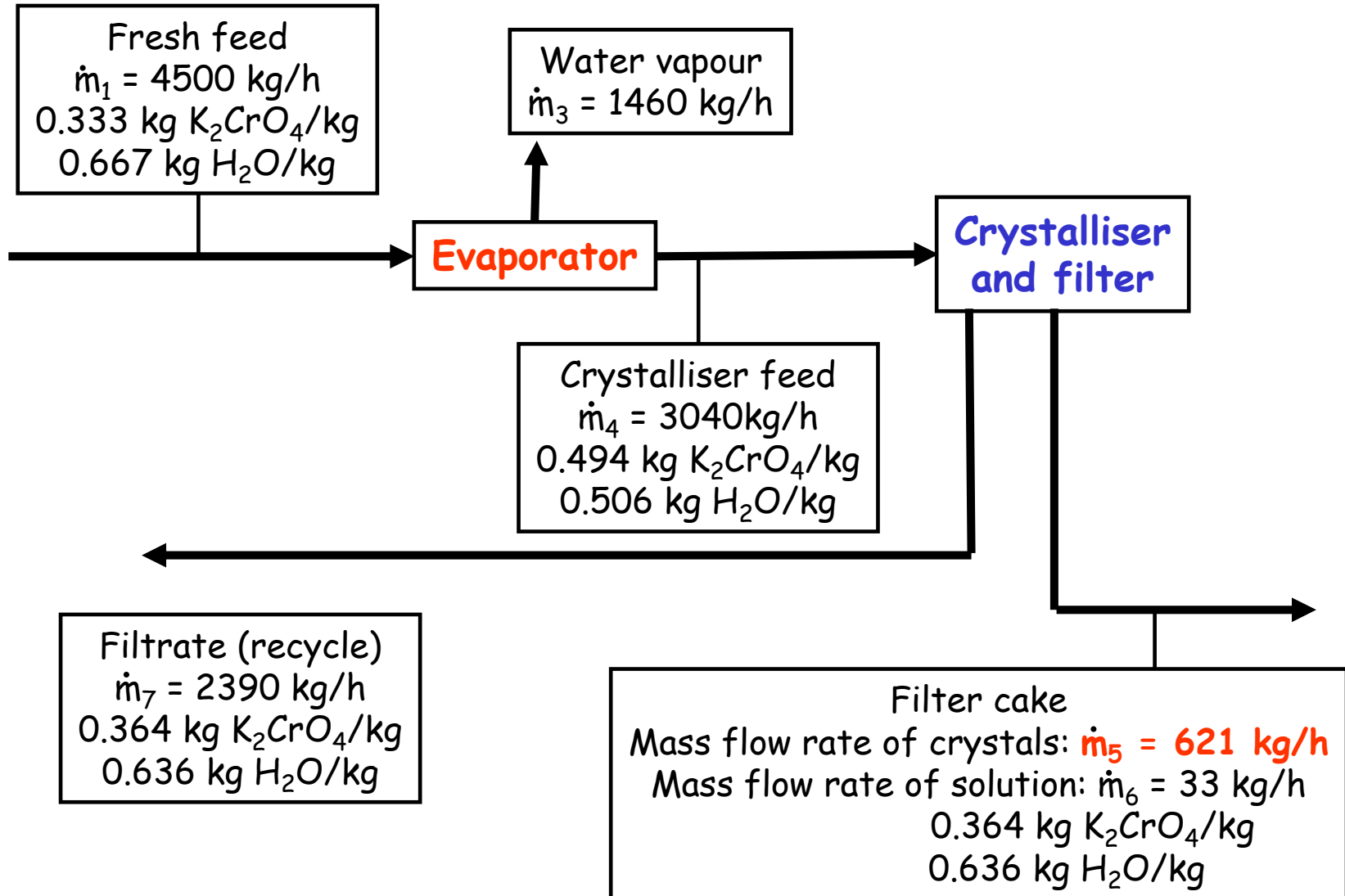
Feed rate to the crystallizer:

$$\dot{m}_4 = 7440 \cdot \frac{kg}{h}$$

Recycle ratio: $\text{Re cycle ratio} = \frac{\dot{m}_7}{\dot{m}_1} = \frac{5890}{4500} = 1.31$

Why recycle?

Process without recycle:



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Extracción del aceite a partir de la soya



Principle of extraction

Extraction is based on distribution of a compound or compounds over two immiscible phases (e.g. a solid and a liquid or two immiscible liquids).

The process is governed by the distribution coefficient over the two phases:

$$K = \frac{Y_{i,\text{Phase I}}}{Y_{i,\text{Phase II}}}$$

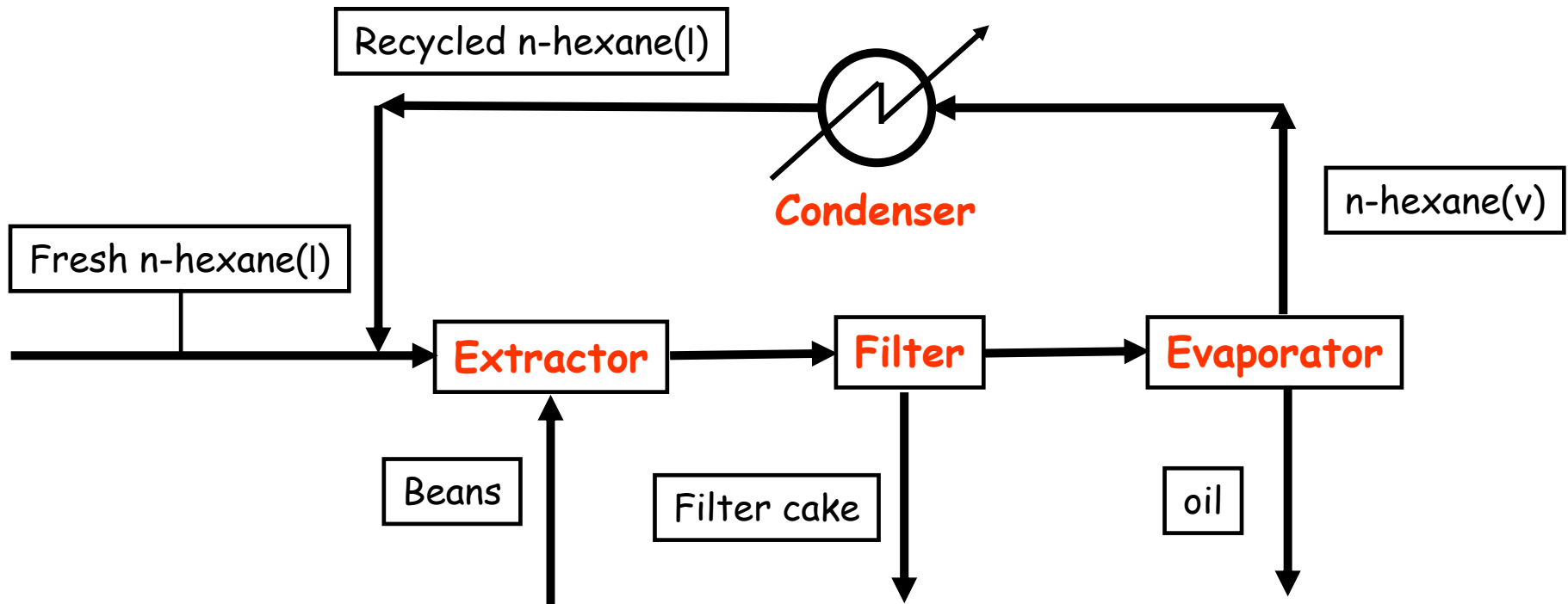
Extraction processes are widely applied in the food industry (e.g. sugar production, soya oil production, production of decaffeinated coffee, etc.)

Problem statement

In the production of soya bean oil, beans containing 13.0 wt.% oil and 87.0% solids are ground and fed to a stirred tank (the extractor) along with a recycled stream of n-hexane. The feed ratio is 3 kg n-hexane/kg beans. The ground beans are suspended in the liquid, and essentially all of the oil in the beans is extracted into n-hexane. The extractor effluent passes to a filter. The filter cake contains 75.0 wt% bean solids and the balance bean oil and n-hexane. The latter two in the same ratio in which they emerge from the extractor. The filter cake is discarded and the liquid filtrate is fed to a heated evaporator in which n-hexane is vapourised and the oil remains as a liquid. The oil is stored in drums and shipped. The n-hexane is subsequently cooled and condensed, and the liquid n-hexane condensate is recycled to the extractor

Calculate the yield of bean oil product per kg beans fed, the required fresh hexane feed and the recycle ratio of n-hexane.

Flow sheet for extraction process



Process is completely labelled (all component flow rates can be expressed in terms of given quantities)

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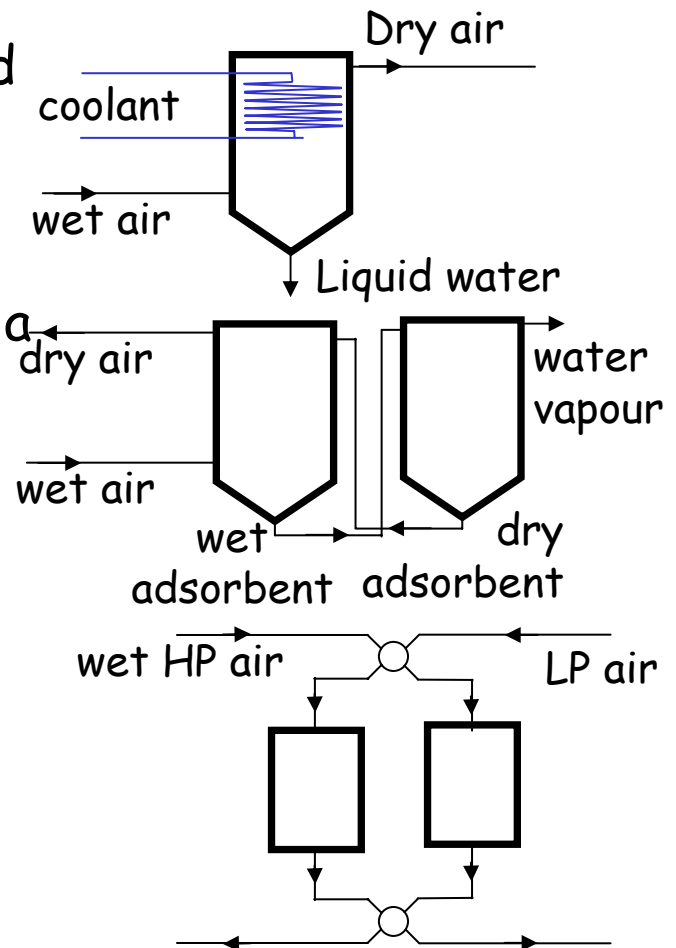
Caso

Balance de materia en un secador de aire

For certain processes dry air is required.

Water vapour present in air can be removed by:

1. Cooling down the air stream and condensing water out
2. Absorbing water in a polar solvent with a low boiling point (e.g. poly ethylene glycol). The water is subsequently released by heating the solvent loaded with water.
3. Adsorbing water on a hydrophilic material. The water is subsequently removed by depressurizing the adsorbent.



Physical principle behind drying

Drying can take place as long as:

The vapour pressure of the compound to be removed is larger than the equilibrium pressure (saturation pressure):

$$p_i > p_i^{\text{sat}}(T)$$

with $p_i = y_i \cdot p_{\text{total}} = x_i \cdot p_i^{\text{sat}}$ (Raoult's law)

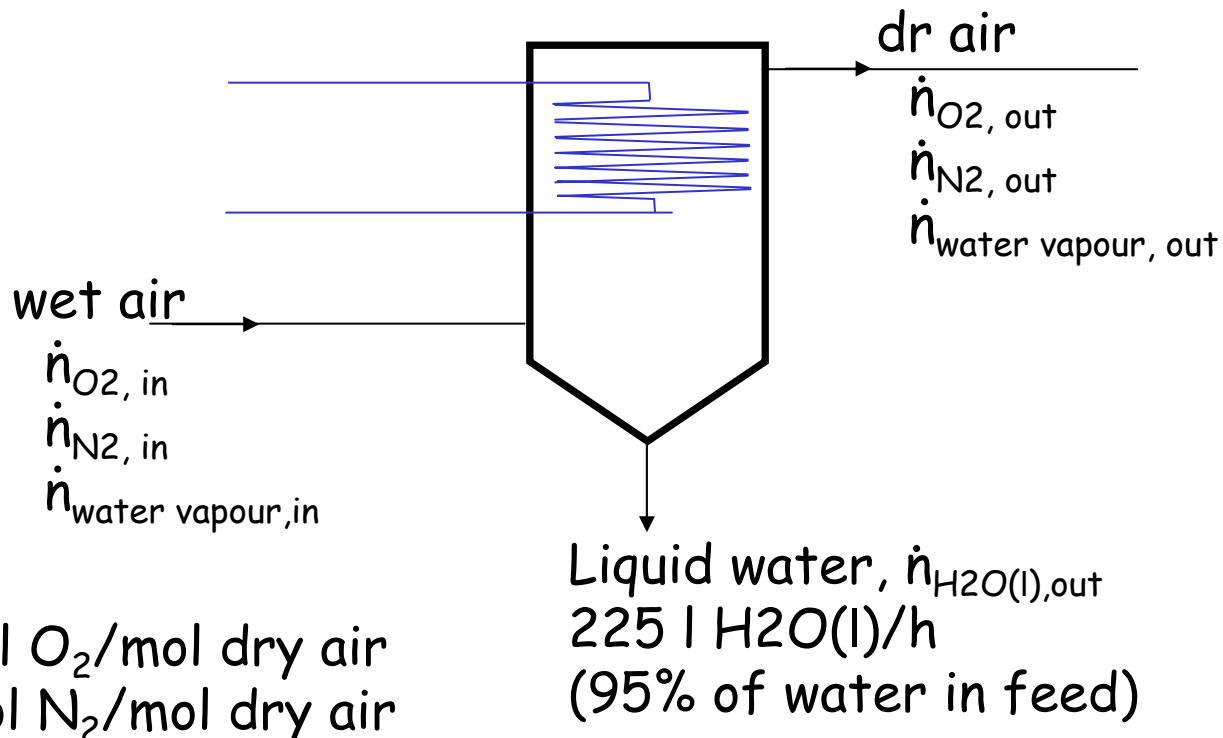
Or otherwise formulated, drying takes place as long as the vapour pressure of the compound is higher than its bubble point (= saturation pressure)

The saturation pressure of a compound is only a function of temperature (not pressure!) and can be given by the Antoine equation

$$\log(p_i^{\text{sat}}) = A - \frac{B}{T + C}$$

Problem statement

A stream of humid air enters a condenser, in which 95% of the water vapour in the air is condensed. The flow rate of the condensate (the liquid leaving the condenser) is measured and found to be 225 L/h. Dry air may be taken to contain 21 mole-% O_2 with the balance N_2 . Calculate the flow rate of the gas stream leaving the condenser and the mole fraction of oxygen, nitrogen and water in this stream.



Solving the problem I

Most information is available on water, so start there!

$$\dot{n}_{\text{water vapour},in} = \dot{n}_{\text{water vapour},out} + \dot{n}_{\text{water}(\ell),out}$$

$$\dot{n}_{\text{water}(\ell),out} = 0.95 \cdot \dot{n}_{\text{water vapour},in}$$

$$\dot{n}_{\text{water vapour},in} = \dot{n}_{\text{water vapour},out} + 0.95 \cdot \dot{n}_{\text{water vapour},in}$$

$$\dot{n}_{\text{water vapour},out} = 0.05 \cdot \dot{n}_{\text{water vapour},in}$$

$$\begin{aligned}\dot{n}_{\text{water}(\ell),out} &= \frac{\rho_{\text{water}(\ell)}}{M_{\text{water}}} \cdot \dot{V}_{\text{water}(\ell),out} \\ &= \frac{1 \cdot \text{kg/litre}}{0.018 \cdot \text{kg/mol}} \cdot 225 \cdot \text{litre/h} = 12500 \cdot \text{mol/h}\end{aligned}$$

$$\dot{n}_{\text{water vapour},in} = \frac{\dot{n}_{\text{water}(\ell),out}}{0.95} = \frac{12500}{0.95} = 13160 \cdot \text{mol/h}$$

$$\dot{n}_{\text{water vapour},out} = 0.05 \cdot 13160 = 660 \cdot \text{mol/hr}$$

Solving the problem II

$$\dot{n}_{\text{water vapour, in}} = 0.1 \cdot (\dot{n}_{\text{O}_2, \text{in}} + \dot{n}_{\text{N}_2, \text{in}} + \dot{n}_{\text{water vapour, in}})$$

$$\dot{n}_{\text{O}_2, \text{in}} + \dot{n}_{\text{N}_2, \text{in}} = 9 \cdot \dot{n}_{\text{water vapour, in}} = 9 \cdot 13160 = 118400 \text{ mol/hr}$$

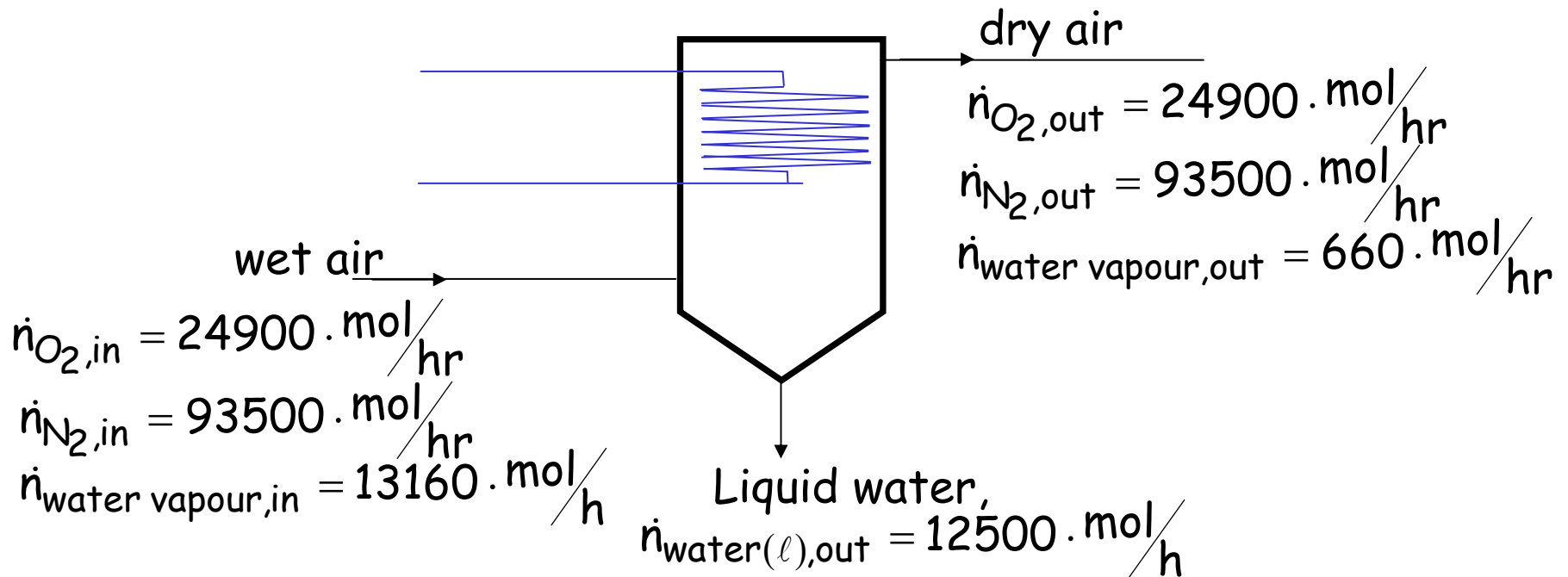
$$\dot{n}_{\text{O}_2, \text{in}} = 0.21 \cdot (\dot{n}_{\text{O}_2, \text{in}} + \dot{n}_{\text{N}_2, \text{in}}) = 0.21 \cdot 118400 = 24900 \text{ mol/hr}$$

$$\dot{n}_{\text{N}_2, \text{in}} = 0.79 \cdot (\dot{n}_{\text{O}_2, \text{in}} + \dot{n}_{\text{N}_2, \text{in}}) = 0.79 \cdot 118400 = 93500 \text{ mol/hr}$$

$$\dot{n}_{\text{O}_2, \text{out}} = \dot{n}_{\text{O}_2, \text{in}} = 24900 \text{ mol/hr}$$

$$\dot{n}_{\text{N}_2, \text{out}} = \dot{n}_{\text{N}_2, \text{in}} = 93500 \text{ mol/hr}$$

Summarizing the solution



Answering the question:

Answering the question

Calculate the flow rate of the gas stream leaving the condenser

$$\dot{n}_{\text{gas, out}} = \dot{n}_{\text{O}_2, \text{out}} + \dot{n}_{\text{N}_2, \text{out}} + \dot{n}_{\text{water vapour, out}} =$$

$$24900 + 93500 + 660 = 119100 \cdot \text{mol/hr}$$

and the mole fraction of oxygen, nitrogen and water in this stream.

Compound	in incoming gas stream	in outgoing gas stream	in liquid
Water	10.0%	0.6%	100%
O ₂	18.9%	20.9%	-
N ₂	71.1%	78.6%	-