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DYNAMIC MODELLING AND SIMULATION WITH ECOSIMPRO OF AN ETHANOL DISTILLATION COLUMN IN THE SUGAR INDUSTRY

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Abstract

This paper describes the modelling and simulation of the dynamic behaviour of a distillation column -both in respect of its steady state response and its behaviour in the light of changes in input variables and perturbations- by means of processing physical-mathematical models. The simulation tool we have used is EcosimPro and the object of our work is an ethanol distillation column in the sugar industry.

Key words: Simulation, EcosimPro, object-oriented modelling, distillation operation, vapour-liquid equilibrium.

1 INTRODUCTION

The objective of this work is to demonstrate the advantages of an object-oriented modelling tool like EcosimPro when it comes to modelling and simulating physical-chemical processes such as distillation.

We will begin with an introduction to the distillation processes and the advantages of being able to simulate these operations.

Distillation is probably one of the most widely used operations in the chemical industry, whether to separate different components from a current, or in the purification of intermediate or final products. Its application ranges from the distillation of alcohol to petroleum cracking.

The difficulty of distillation depends on the relative volatility of the components, which therefore makes it more difficult to separate by distillation mixtures whose boiling points lie close to one another.

In order to carry out a distillation operation, or any other separating process, we must have vapour-liquid

equilibrium data or correlations to be able to make adequate estimates.

The majority of distillation columns operate with multicomponent feed, and in the majority of cases binary mix approximations cannot be applied. This makes the resolution of the balances more complex and simplified methods are being developed.

Rigorous calculations can only be carried out with simulation programs which are capable of resolving differential equation systems numerically.

The simulation of operations also enables us to study the dynamic behaviour from the moment the plant is started until it reaches a steady state.

The computerised analysis and simulation of processes presents a series of advantages, among which the following are worth noting:

- The possibility to analyse the behaviour of real processes, imposing certain operating conditions which would be impossible to carry out at site owing to safety or financial reasons.
- The study of existing processes in more detail and faster, in the light of any variation in any of the input variables and perturbations.
- The ability to compare different alternatives without modifying the real plant and, based on the results obtained, to make a decision.

2 HYPOTHESES ABOUT THE MODEL

The mathematical model developed must represent the dynamic behaviour of the real process. A compromise must be reached between the exactitude of the approach used in the model and the similarity between the response of the model and of the process,

based on the resources available for the resolution of the model.

The suppositions that have been made are as follows:

1. Single-plate feed system.
2. The feed enters in the form of saturated liquid, although consideration is being given to its partial or complete vaporisation.
3. Neutral alcohol is extracted laterally onto the penultimate plate.
4. There are no heat losses; the column is adiabatic.
5. The condenser is complete, so therefore the vapour flowing from the top of the column will be the same as that of the reflux and distillate current.
6. While there is no boiling device, there is direct injection of steam.
7. A non-constant vapour flow is considered, and it is calculated on the basis of the energy balance assumed for each of the plates.
8. Total pressure loss of the column is distributed linearly among all the plates.
9. The flow of liquid is calculated on the basis of Francis' formula for sinks.
10. The liquid which accumulates on each plate is incompressible and in a state of perfect mixture; the composition will be the same at all points.
11. The vapour and liquid that flow from the plate are in a state of thermal equilibrium, at the same temperature. They are also at the same pressure.
12. The vapour and liquid that flow from the plate are not in phase equilibrium owing to the definition of a Murphree efficiency.
13. The vapour-liquid equilibrium is represented taking into consideration:
 - Vapour phase as being ideal
 - Liquid phase as being not ideal: Wilson's model is employed to calculate the activity coefficient
14. Neither the dead time in the vapour current which flows from the last plate in the column to the condenser nor in the reflux current to the top of the column are estimated.
15. Consideration is given to the dynamics of the condenser in the development of the distillation column model.
16. No consideration is given to the accumulation of vapour throughout the system.

3 PHYSICAL-MATHEMATICAL MODEL OF THE DISTILLATION COLUMN

In problems of multiple-stage separation for systems in which different phases and different components play a part, we have to resort to the simultaneous or iterative resolution of hundreds of equations.

This means that it is necessary to specify a sufficient number of design variables so that the number of unknown quantities (output variables) is exactly the same as the number of equations (independent variables).

The following is a sketch of the process which will help to understand the explanations that follow:

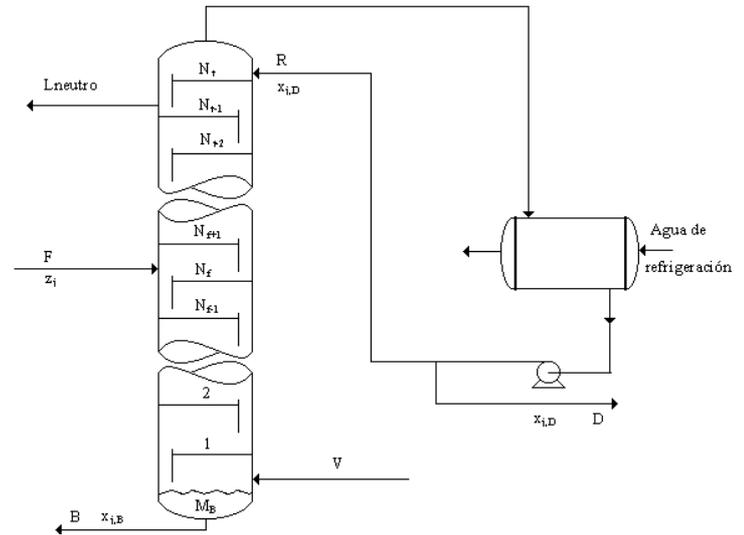


Figure 1: Simplified sketch of the Neutral Alcohol Distillation Column

3.1 BALANCES AT THE BOTTOM OF THE COLUMN

The liquid from the top plate and the vapour descend to the bottom of the column. The flow of the current at the bottom is not constant because it is the variable which is manipulated to control the level of liquid at the bottom of the column.

The following is a representative sketch:

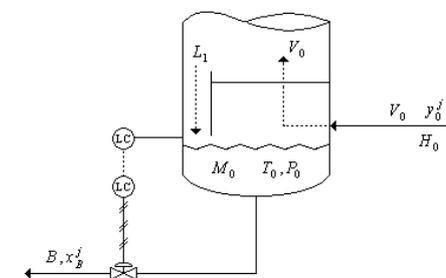


Figure 2: Sketch of the Bottom of the Column

□ Overall balance of matter:

$$\frac{dM_0}{dt} = L_1 - B \quad (1)$$

where:

M_0 = liquid mass accumulated at the bottom (kg)

L_1 = mass flow of liquid from plate 1 (kg/s)

B = mass flow of outgoing liquid (kg/s)

□ Overall balance at component j :

$$\frac{d(M_0 x_0^j)}{dt} = L_1 x_1^j - B x_B^j \quad (2)$$

where:

x_1^j = molar fraction of the component j in the flow of liquid from the top plate

$x_0^j = x_B^j$ = molar fraction of the component j in the mass of liquid accumulated in the bottom and in the bottom product

The balance of matter is calculated for $(n-1)$ components, and the molar fraction of one of the components is calculated as follows:

$$x_B^j = 1 - \sum_{j=1}^{j=n-1} x_B^j \quad (3)$$

□ Overall energy balance:

Taking into consideration that the flow of vapour is not constant throughout the column, the energy balance has to be calculated. Since the column is considered to be adiabatic, we obtain the following:

$$\frac{d(M_0 h_0)}{dt} = L_1 h_1 - B h_0 \quad (4)$$

where:

h_1 = enthalpy of the liquid from plate 1 (kJ/kg)

h_0 = enthalpy of the liquid in the bottom (kJ/kg)

□ Total pressure on the bottom:

$$P_B = P_1 + \Delta P \quad (5)$$

where:

P_B = total pressure on the bottom (bar)

P_1 = total pressure on plate 1 (bar)

ΔP_n = pressure drop (bar)

3.2 BALANCES OF A GENERIC PLATE

The equations that represent the behaviour of a generic plate are the same for the complete column. The following is a representative sketch of any of these plates:

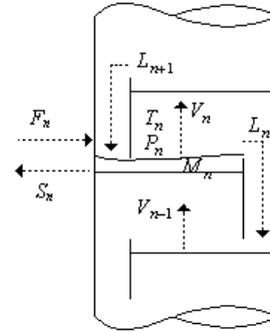


Figure 3: Sketch of a Generic Plate

□ Balance of matter:

$$\frac{dM_n}{dt} = L_{n+1} + V_{n-1} + F_n - L_n - V_n - S_n \quad (6)$$

where:

M_n = liquid mass accumulated on plate n (kg)

L_{n+1} = liquid that overflows onto plate n from plate $n+1$ (kg/s)

V_{n-1} = vapour flow from plate $n-1$ (kg/s)

L_n = liquid flowing from plate n (kg/s)

V_n = vapour flow flowing from plate n (kg/s)

F_n = feed flow from plate n (kg/s)

S_n = lateral extraction onto plate n (kg/s)

□ Overall balance at component j :

$$\frac{d(M_n x_n^j)}{dt} = L_{n+1} x_{n+1}^j + V_{n-1} y_{n-1}^j + F_n z_n - L_n x_n^j - V_n y_n^j - S_n x_n^j \quad (7)$$

where:

x_n^j = molar fraction of component j in the liquid from plate n

x_{n+1}^j = molar fraction of component j in the liquid current from plate $n+1$

y_{n-1}^j = molar fraction of component j in the vapour current from plate $n-1$

y_n^j = molar fraction of component j in the vapour current from plate n

z_n^j = molar fraction of component j in the feed current from plate n

The previous balance is taken for all the components, with the exception of one which is calculated on the basis of:

$$x_N^j = 1 - \sum_{j=1}^{j=n-1} x_N^j \quad (8)$$

□ Overall energy balance:

$$\frac{d(M_n h_n)}{dt} = L_{n+1} h_{n+1} + V_{n-1} H_{n-1} + F_n h_f - L_n h_n - V_n H_n - S_n h_n \quad (9)$$

where:

h_n = enthalpy of the liquid from plate n (kJ/kg)

h_{n+1} = enthalpy of the liquid from plate n+1 (kJ/kg)

H_n = enthalpy of the vapour from plate n (kJ/kg)

H_{n-1} = enthalpy of the vapour from plate n-1 (kJ/kg)

The changes in the specific enthalpy of the liquid phase are generally very small compared with the total enthalpy of the plate. This means that, normally, the energy balance can be reduced to an algebraic equation which is used as the basis to calculate the flow of vapour from the plate. Finally, therefore, the energy balance is as follows:

$$\begin{aligned} L_{n+1} h_{n+1} + V_{n-1} H_{n-1} + F_n h_{f,n} - \\ L_n h_n - V_n H_n - S_n h_n = 0 \end{aligned} \quad (10)$$

□ Temperature calculation

The temperature on each plate is not calculated on the basis of the energy balance as it is for the bottom of the column; instead, the bubble temperature is calculated. The bubble temperature is that which is in equilibrium with a known composition of the liquid at a determined pressure which is also known.

Therefore, on each plate, the calculation algorithm iterates on the temperature until the sum of the compositions of the vapour phase of plate N is equal to one unit.

$$1 - \sum_{j=1}^n y_j^N = 0 \quad (11)$$

□ Equilibrium ratio between vapour-liquid phases:

$$y_{n,j}^* = \frac{g_n^j P_{n,j}^{sat}}{P_n} x_n^j \quad (12)$$

where:

$y_{n,j}^*$ = molar fraction of component j on plate n in equilibrium with x_n^j

g_n^j = activity coefficient of component j on plate n

$P_{n,j}^{sat}$ = vapour pressure of component j on plate n (bar)

P_n = total pressure on plate n (bar)

x_n^j = molar fraction of component j in the liquid from plate n

□ Total pressure on plate n:

$$P_n = P_{n+1} + \Delta P \quad (13)$$

where:

P_n = total pressure on plate n (bar)

P_{n+1} = total pressure on plate n+1 (bar)

ΔP_n = pressure drop between plate n and n+1 (bar)

□ Pressure drop on the plate

The distribution of the pressure drop is considered to be linear throughout the column and directly proportional to the flow of live steam.

$$\Delta P = \left(\frac{V_0}{K} \right)^2 \quad (14)$$

where:

V_0 = flow of live steam (m³/h)

K = constant of proportionality (m³/bar·h)

□ Flow of liquid from plate n:

The flow of liquid is calculated on the basis of Francis' formula for segmented sinks:

$$h_{ow} = 664 \cdot \left(\frac{Q}{L_w} \right)^{2/3} \quad (15)$$

where:

h_{ow} = height of the liquid above the crest of the sink (mm)

Q = liquid which falls from the sink (m³/s)

L_w = length of the sink (m)

Therefore, the flow of liquid from one plate onto the plate below is:

$$Q_n = 1.8482 L_w (h_{ow,n})^{1.5} \quad (16)$$

where:

Q_n = liquid that flows from plate n (m³/s)

L_w = length of the sink (m)
 $h_{ow,n}$ = height of the liquid above the crest of the sink (m)

Calculated by means of the following expression:

$$h_{ow,n} = \frac{Vol_n - V_{plato}}{A_{plato}} \quad (17)$$

where:

Vol_n = volume of liquid on plate n (m³)

V_{plato} = volume of the plate (m³)

A_{plato} = active area of the plate (m²)

□ *Flow of vapour from plate n:*

As mentioned previously, the flow of vapour onto the next plate is calculated on the basis of the steady state energy balance:

$$V_n = \frac{L_{n+1}h_{n+1} + V_{n-1}H_{n-1} + F_n h_{f,n} - L_n h_n - S_n h_n}{H_n} \quad (18)$$

4 PHYSICAL-MATHEMATICAL MODEL OF THE CONDENSER

The vapour rising from the last plate enters into the condenser where it completely condenses. It is a horizontal condenser which uses the process water circulating through the shell as the cooling fluid.

When we are ready to run the simulation, we establish both the flow and the inlet temperature (20°C) of the coolant.

The following is a representative sketch:

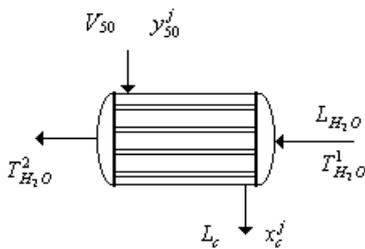


Figure 4: Sketch of the Condenser at the Top of the Column

□ *Overall balance of matter:*

$$\frac{dM_c}{dt} = V_{50} - L_c \quad (19)$$

where:

M_C = condensate mass accumulated in the condenser (kg)

V_{50} = vapour flowing from plate 50 (kg/s)

L_C = condensate flow (kg/s)

□ *Overall balance at component j:*

When the vapour that flows from the last plate in the column condenses completely, the composition of the condensate is the same as that of the vapour.

$$x_c^j = y_{50}^j \quad (20)$$

□ *Energy balance:*

- *at the condensate mass:*

it is assumed that the inlet temperature is the same as the outlet temperature which will give us a saturated liquid and this balance is not calculated.

- *at the coolant mass:*

$$\frac{d(M_r h_r)}{dt} = L_r (h_r^i - h_r) + Q \quad (21)$$

where:

M_r = coolant mass (kg)

h_r = coolant enthalpy (kJ/kg)

h_r^i = enthalpy of the coolant inlet (kJ/kg)

L_r = condensate flow (kg/s)

Q = heat transferred in condensation (kJ/s)

□ *Calculation of the condensate flow:*

$$L_c = \frac{Q}{I} \quad (22)$$

where:

λ = latent heat of the mixture (kJ/kg)

□ *Calculation of the heat transferred:*

$$Q = UA(\Delta T)_{ln} \quad (23)$$

where:

U : overall coefficient of heat transfer (kJ/m²s)

A : area of heat transfer (m²)

$(\Delta T)_{ln}$: logarithmic temperature differences

5 VAPOUR-LIQUID EQUILIBRIUM MODEL

As mentioned previously, we must have correlations in order to be able to calculate the activity coefficient of the ratio of equilibrium between the vapour-liquid phases. To this end, each of the phases is analysed:

- Vapour phase:

The system with which it works is mainly composed of ethanol and water, the behaviour of which is far from ideal. However, it operates at a pressure very close to atmospheric pressure, which enables us to simplify the equilibrium by admitting an ideal vapour phase and applying the equation of ideal gases for the calculation.

- Liquid phase:

Ideal behaviour cannot be assumed in this case because the ethanol-water liquid mixtures are extremely polar and the activity coefficients are far from being a unit.

As we do not have a state equation which adequately represents the liquid phase, the transitory nature of the liquid-phase components will be calculated on the basis of the activity coefficients.

In view of the foregoing, we are going to consider the vapour phase as ideal and the liquid phase as not ideal, using Wilson's model for the calculation.

In accordance with Wilson's model, the liquid phase activity coefficients are calculated on the basis of the following expression:

$$\ln g_i = -\ln \left(\sum_{j=1}^m x_j \Lambda_{ij} \right) + 1 - \sum_{k=1}^m \frac{x_k \Lambda_{ki}}{\sum_{j=1}^m x_j \Lambda_{kj}} \quad (24)$$

where:

x_j = molar fraction of the component j in the liquid phase

Λ_{kj} = binary interaction parameters

$$\Lambda_{ij} = \frac{V_j^L}{V_i^L} \exp \left(\frac{-I_{ij}}{RT} \right) \quad (25)$$

$$\Lambda_{ii} = \Lambda_{ii} = 1 \quad (26)$$

where:

V_j^L , V_i^L = molar volumes of the j and i components

as pure liquids at temperature T . They depend slightly on the temperature, but to facilitate the calculations a constant value has been considered [8]

R = constant of the ideal gases (cal/mol·K)

T = temperature (K)

I_{ij} = binary interaction constants [7]

6 PORTS AND LIBRARY OF PHYSICAL-CHEMICAL PROPERTIES

6.1 PORTS

Finally, the following components are modelled:

- distillation column
- complete condenser
- steam pipes
- live steam and feed sources
- heat sinks

Once the different components have been modelled, a series of ports are defined in order to connect the different components. These ports are used to pass the values of the variables defined in them from one component to another.

The variables can be defined as REAL, EQUAL, SUM, etc.

The ports we use are:

- Vapour port
- Liquid port
- Gas port

The following is the code for the gas port, written in EL:

```
-----
PORT gas (SET_OF(Chemical)Mix)

SUM REAL W RANGE 0.,Inf "Flujo másico (Kg/h)"
SUM IN REAL Wi[Mix] RANGE 0.,Inf "Flujo másico
componente (Kg/h)"
EQUAL OUT REAL C[Mix] RANGE 0.,1.
"Concentraciones (%1 en peso)"
REAL x[Mix] RANGE 0.,1. "Concentración (fracc
molar:%1 moles)"
EQUAL REAL P RANGE 0.,Inf "Presión (bar)"
REAL T RANGE -273.,Inf "Temperatura (°C)"
EQUAL OUT REAL H "Entalpía específica (KJ/Kg)"
SUM IN REAL f_energ "Flujo de entalpía (KJ/h)"
REAL Rho_g RANGE 0.,Inf "Densidad (Kg/m^3)"
REAL F RANGE 0.,Inf "Flujo volumétrico (m3/h)"

CONTINUOUS
1. = SUM (j IN Mix ; C[j])
EXPAND(j IN Mix EXCEPT setofElem(Mix,1))
Wi[j] = C[j] * W
W = SUM(j IN Mix;Wi[j])
H = entalp_gas (Mix,T,x)
f_energ = W * H
Rho_g = dens_gas (Mix,T,P,x)
F = W/Rho_g

-- relación entre concentración en peso (C) y en fracción
molar (x)
EXPAND (j IN Mix)
x[j] = (C[j]/Mmolec[j]) / SUM (i IN Mix;
(C[i]/Mmolec[i]))

END PORT
-----
```

6.2 LIBRARY OF PHYSICAL-CHEMICAL PROPERTIES

To run the simulation we must first individually implement a series of physical properties of each one of the components, as well as the functions of average properties of mixtures and overall constants.

For this purpose, we have developed a library in which the following properties are calculated on the basis of the corresponding arguments (temperature, pressure, concentrations), either in the form of equations or tables:

- Saturation pressure
- Saturation temperature
- Density of the liquid
- Density of the vapour
- Specific heat of the liquid
- Specific heat of the vapour

The following is an example of the calculation of the calorific capacity of the ethanol vapour:

```
-----
FUNCTION REAL cp_v_etoh (REAL T)
DECLS
  REAL Cp_vapor
BODY
  Cp_vapor=((A_cp_etoh+B_cp_etoh*(T+273.15)+
  C_cp_etoh*(T+273.15)**2+
  D_cp_etoh*(T+273.15)**3)/(Mmolec_EtOH)
  RETURN Cp_vapor
END FUNCTION
-----
```

In addition, the chemical components of the process are defined in this library in an "enumerated" statement (ENUM statement of the EcosimPro code):

```
-----
--Componentes genéricos
ENUM Chemical = {H2O, azucar, marco, impz, CaO,
CaOH2, O2, N2, CH4, C3H8, CO, CO2, EtOH, PrOH, Iso}
--Subgrupo de componentes de la destilación
SET_OF(Chemical)destila = {H2O,EtOH,PrOH}
SET_OF(Chemical)agua = {H2O}
-----
```

7 COLUMN COMPONENT

This is the main component and it contains all the equations of the mathematical model described previously, implemented in EcosimPro.

It is a component which has been defined with three In ports (one vapour port and two liquid ports), and three Out ports (two liquid ports and one gas port).

PORTS

```
-----
IN      vapor      vapor_in
IN      liquido(destila) alim_in
IN      liquido(destila) refluj_in
OUT     liquido(destila) neutro_out
OUT     gas(destila)   vapor_out
OUT     liquido(destila) fondo_out
-----
```

Another important aspect of this component is the data on the basis of which the input conditions of the process can be changed:

```
-----
REAL vplato      "Volumen del plato (m3)"
REAL aplato      "Área del plato (m2)"
REAL lw          "Longitud de la presa del plato(m)"
REAL Efm         "Eficacia de Murphry"
REAL PER         "Cte para calcular la pérd carga"
REAL r_col       "Radio int de la columna (m)"
REAL altbase_max "Altura máx de la base (m)"
REAL lneuro      "Caudal de alcohol neutro (m3/s)"
REAL P_cab       "Presión en cabezas fija (bar)"
REAL refbase     "Referencia del nivel en%"
REAL kbasepi     "Ganacia del PI"
REAL Tibasepi    "Tiempo integral (s)"
REAL rangob1     "Rango superior (1.11e-2m3/s)"
REAL rangob2     "Rango inferior (0m3/s)"
REAL autobase    "Automático"
REAL manbase     "Manual"
-----
```

Of all the sentences of the EL language, EXPAND_BLOCK is of special interest because, thanks to this sentence, all the equations which are repeated on each of the column plates are only implemented once and can then expand for *n*-plates.

The following is an example of the code:

```
-----
EXPAND_BLOCK (i IN destila)
  EXPAND_BLOCK (n IN 2,k-1)
  gamma[i,n]=exp(-log(SUM(j IN destila; x_l[j,n]*A[i,j,n]))
+1 - SUM(k IN destila; (x_l[k,n]*A[k,i,n]) / SUM(j IN
destila; x_l[j,n]*A[k,j,n])))
  y_v[i,n]=Efm*(y_eq[i,n]-y_v[i,n-1])+y_v[i,n-1]
  END EXPAND_BLOCK
END EXPAND_BLOCK
-----
```

8 RESULTS

The following input data was used for the simulation:

- No. of plates in the column: 50
- Flow: $5.56 \cdot 10^{-3} \text{ m}^3/\text{s}$ (20 m^3/h)
- Components (percentage weight):
 - Ethanol: 11.7% (14.71°GL)
 - Water: 86.75%
 - Propanol: 55%
- Temperature: 87.76°C
- Pressure: 1 bar
- Flow of live steam: 2 m^3/s
- Pressure: 1.77 bar
- Temperature: 210°C

8.1 STEADY STATE VALUES AND PROFILES

Once a steady state has been reached, the following results are obtained:

- *Bottom of the column:*
 - Flow: 23.6 m^3/h
 - Compositions:
 - ethanol: 2.26% (2.7°GL)
 - water: 96.34%
 - propanol: 1.39%
 - Temperature: 102.85°C
 - Pressure: 1.85 bar
- *Lateral extraction of neutral alcohol:*
 - Flow: 2.6 m^3/h
 - Compositions:
 - ethanol: 94.4% (96.4°GL)
 - water: 5.4%
 - propanol: $1.4 \cdot 10^{-6}\%$
 - Temperature: 88.5°C
 - Pressure: 1.51 bar

In Figure 5 we can see how the ethanol concentration (the most volatile component) tends towards zero on the plates at the bottom of the column, and increases as it rises towards the top of the column (at most an azeotropic composition can be reached):

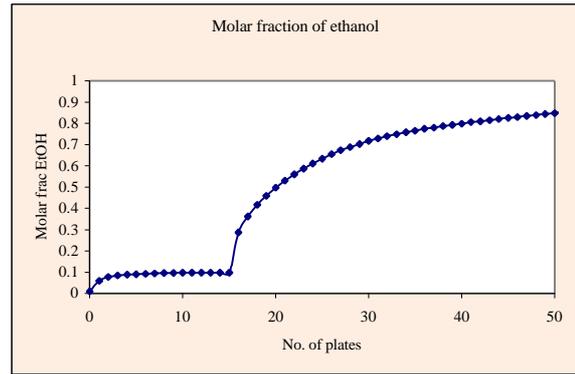


Figure 5: Profile of steady state ethanol concentration

With regard to the propanol (Fig 6), we can see that it accumulates on some plates above the incoming feed, in the area where the ethanol concentration is approximately 80°G.L:

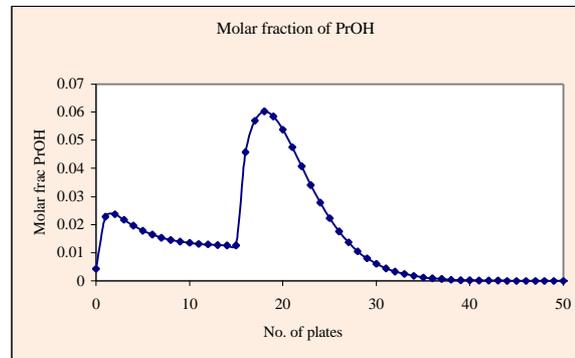


Figure 6: Profile of steady state propanol concentration

In the profile in Figure 7, we can see how the temperature decreases the higher we go up the column.

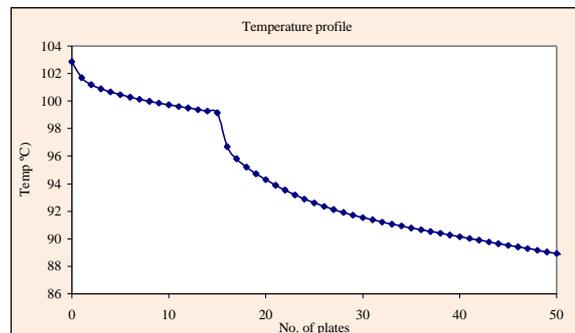


Figure 7: Steady state temperature profile

8.2 DYNAMIC RESPONSE IN THE LIGHT OF A 10% INCREASE IN LIVE STEAM FLOW

The following results are obtained after increasing the live steam flow by 10% once a steady state has been reached (2500 s):

In the following figure, we can see how the ethanol concentration increases at the top of the column and decreases at the bottom.

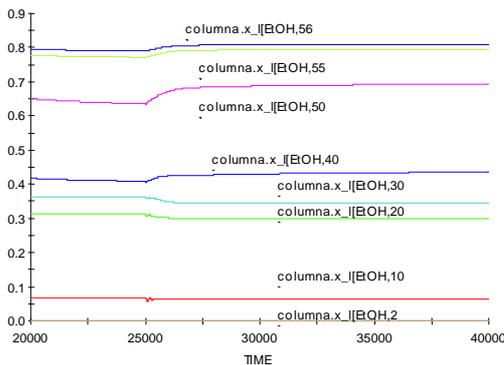


Figure 8: Profile of ethanol concentration vis-à-vis a 10% increase in live steam

In Figure 9, we can see that the temperature increases on all the plates in the column:

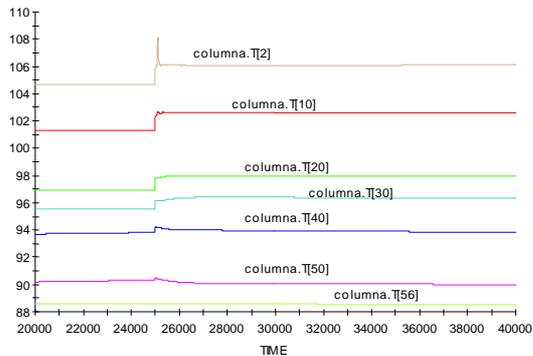


Figure 9: Profile of temperature vis-à-vis a 10% increase in live steam

9 CONCLUSIONS

EcosimPro is a tool which adapts well to the modelling of these types of systems.

The following is a summary of problems and solutions when it comes to simulating a distillation column:

- The mass and energy balances must be calculated for all the plates in the column and for all the components. As the column contains 50 plates, the number of differential equations that has to be resolved is considerable. EcosimPro allows you to formulate each one of these balances with a single equation using the sentence EXPAND_BLOCK.
- The flows of vapour from each plate have not been considered constant; instead they are calculated on the basis of the steady state energy balance. With this approach to modelling, the bubble temperature on each plate is calculated iteratively so that the fractions of the component in the vapour phase total the **unit**. As it partitions the model, EcosimPro detects a loop on each of the plates and it so happens that it selects the temperature on each plate as a variable to break each loop.
- The formulation of the vapour-liquid equilibrium calculation (Wilson's model) is also made simple by using the sentence EXPAND_BLOCK.
- The column is presently modelled for three components (water, ethanol and propanol) and with 50 plates. However, an increase in the number of components would not signify any change in the column model and it would suffice to add the new components to the **enumerator [el enumerado??]** (ENUM and SET_OF sentences) as well as their physical properties. The same would apply if we wanted to modify the number of plates or the plate where the feed is introduced, or to add or subtract lateral extractions.

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