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Condenser Liquid Level Influence in a Cryogenic Distillation Column Operation

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The behaviour of the cryogenic distillation column at the influence of an external factor has been studied. For this, it was analyzed the non steady state for the column when exist a variation in the control system from the cooling circuit of the cryogenic distillation plant. It determine the fluctuation of the hydrogen level from the cryogenic distillation column condenser. The column has H height and N_T theoretical stages, with the feed stream bicompound mixture of tritium and deuterium. The mathematical model for the simulation of the process is based on the equations of balance on the column, for the stages and for the condenser. The column is operated at total reflux. The variation of the level from condenser was considered as a sinusoidal function. The results were represented in specific diagrams and plots. The results followed concentrations profiles at any moment of time. Each parameter can offer information about the behaviour of the distillation column operated at total reflux with sinusoidal oscillation of the liquid level in condenser.

Key Words: Hydrogen distillation, Non-steady state, Liquid level, Model, Concentration profile.

INTRODUCTION

The hydrogen distillation is one of the modern methods for hydrogen isotopes separation. It has been observed a great sensibility of the isotopes separation installation owing to the specific process.

To achieve a correct functioning of the distillation column that belongs to a liquid hydrogen isotopic plant, it is necessary to be maintained constant all the functioning parameters correspond to a steady state.

In practice this can not be achieved, so the operating of the column will suffer some perturbations, taking place in a non-steady state. The effect of the functioning in a non-steady state is the low separation power of the column. It has been observed the way that the level of liquid from condenser influences the functioning of the isotopic distillation column[1]. Such a perturbation determines a quick modification of the liquid flow capacities, in time and in length and also a modification in time of the hold up from the condenser on the contact unity.

This work is dwelling on another possible situation, which is, the variation of the liquid level in the column condenser, following the generic behaviour of a cryogenic distillation column for the separation of the hydrogen isotopes with N_T theoretical stages and H_{col} height[2].

Mathematic pattern for studying the non-steady state of a separation column working at total reflux with perturbation in condenser

The perturbation of the flow capacity from the column due to the variation in time of the liquid level from the condenser is absorbed all the way through the column. To this way the boiling vessel functioning from the bottom of column is not influenced by the perturbation. A direct consequence of this observation is that the gas flown throughout the column is going to stay constant in the variation of the flow, caused by the variation level of the liquid from the condenser and is fully taken by the variation of the liquid flow.

The authors make the simplifying theory that the pressure variation from the column does not influence the separation factor α. The variation of the gas holdup from the condenser due to the energy fluctuation which is introduced into the system through the modification of the liquid level from the condenser leads to the variation between the liquid and the gas capacities flow which are circling in contra-current in the column. In a situation like this the distillation column is the represented in Fig. 1.

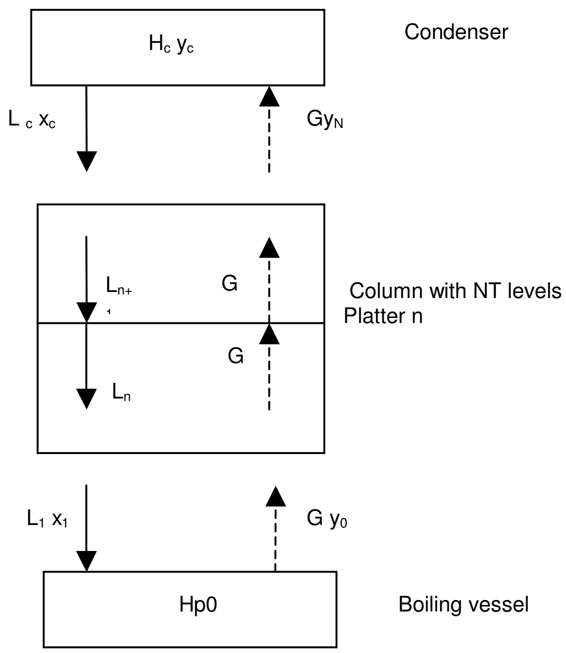

Fig. 1

The holdup from the distillation column filling is uniformly distributed all the way[3,4]. The equilibrium equation for the column:

$$\frac{\partial H_c}{\partial t} + N\frac{\partial H_n}{\partial t} = 0 \quad (1)$$

The total vaporization in the boiling vessel, operated at total reflux, $x_1 = y_0$

Equilibrium equation for plate n for the condenser.

Balance for stage n:

$$\frac{\partial H_n}{\partial t} = L_{n+1} - L_n \quad (2)$$

$$\frac{\partial (H_n y_n)}{\partial t} = G(y_{n-1} - y_n) + L_{n+1}x_{n+1} - L_n x_n \quad (3)$$

For condenser:

$$\frac{\partial H_c}{\partial t} = G - L_c \quad (4)$$

$$\frac{\partial (H_c y_c)}{\partial t} = G y_N - L_c x_c \quad (5)$$

It is considered a sinusoidal variation in the condenser, after the equation:

$$H_c = H_{c0} + A \sin \omega\, t \quad (6)$$

where A is the amplitude with the following values:

$$A(t) = \begin{cases} 0 & \text{for } t = 0 \\ A & \text{for } t > 0 \end{cases} \quad (7)$$

After the calculation it is obtained:

$$L_n = L_{n+1} + \frac{A\omega}{N}\cos\omega\, t \quad (8)$$

For the last plate it can be written:

$$L_N = G - \frac{N-1}{N} A\omega \cos\omega\, t \quad (9)$$

$$L_n = G - \frac{n-1}{N} A\omega \cos\omega\, t \quad \text{For the stage n} \quad (10)$$

Making the next calculation it can be obtained the concentrations throughout the column. Applying the method of fixed differences, the gas phase concentration throughout the column, on each different stage:

$$y_{n,m+1} = \left(1 + \frac{A\omega}{N}\frac{\Delta t}{H_n}\cos\omega t\right)y_n + \frac{G\cdot\Delta t}{H_n}\left(y_{n-1} - y_n\right) + \frac{L_{n+1}\Delta t}{H_n}x_{n+1} - \frac{L_n\Delta t}{H_n}x_n \qquad (11)$$

The liquid phase concentration results from the relation of separation factor:

$$x_{n,m+1} = \frac{\alpha\cdot y_{n,m+1}}{1 + y_{n,m+1}(\alpha - 1)} \qquad (12)$$

In a similar way, for the condenser:

$$y_{c,m+1} = \frac{G\cdot\Delta t}{H_c}y_N + (1 - \frac{A\omega\Delta t\cos\omega t}{H_c})y_c - \frac{(G - A\omega\cos\omega t)\Delta t}{H_c}\cdot x_c \qquad (13)$$

$$x_{c,m+1} = \frac{\alpha\cdot y_{c,m+1}}{1 + y_{c,M+1}(\alpha - 1)} \qquad (14)$$

The equation system that describes the process which takes place in the column at the liquid level variation in the condenser is formed of the eqns. 10-14, which together with the functions that describe the variation of the hold up in the condenser on each plate will be resolved for the determination throughout the column. The program is developed under the logical diagram described in Fig. 2.

RESULTS AND DISCUSSION

For the analysis of the perturbation influence owed to the variation of the liquid level in distillation column condenser operated at total reflux, we considered the following cases:

(i) initial concentrations of 25 and 50 % tritium in the tritium-deuterium mixture

(ii) variable sinusoidal amplitude function between 0 and 40 % from H_{co}

(iii) sinusoidal function period between 0 and 30 min.

The rolling results are presented in diagrams. In Figs. 3 and 5 there are the concentration profiles along the column at the entrance in steady state for the case when the initial concentration is 25 % T/T+D, for different values of amplitude and the period is kept constant at 15 min.

In the same way, we dealt the situation when amplitude was kept constant at a value of 10 % and takes place a variation of the perturbation frequency: 10, 15 and 30 min. The same situation is dealt in the case when initial concentration is 50 %, in Figs. 4 and 6.

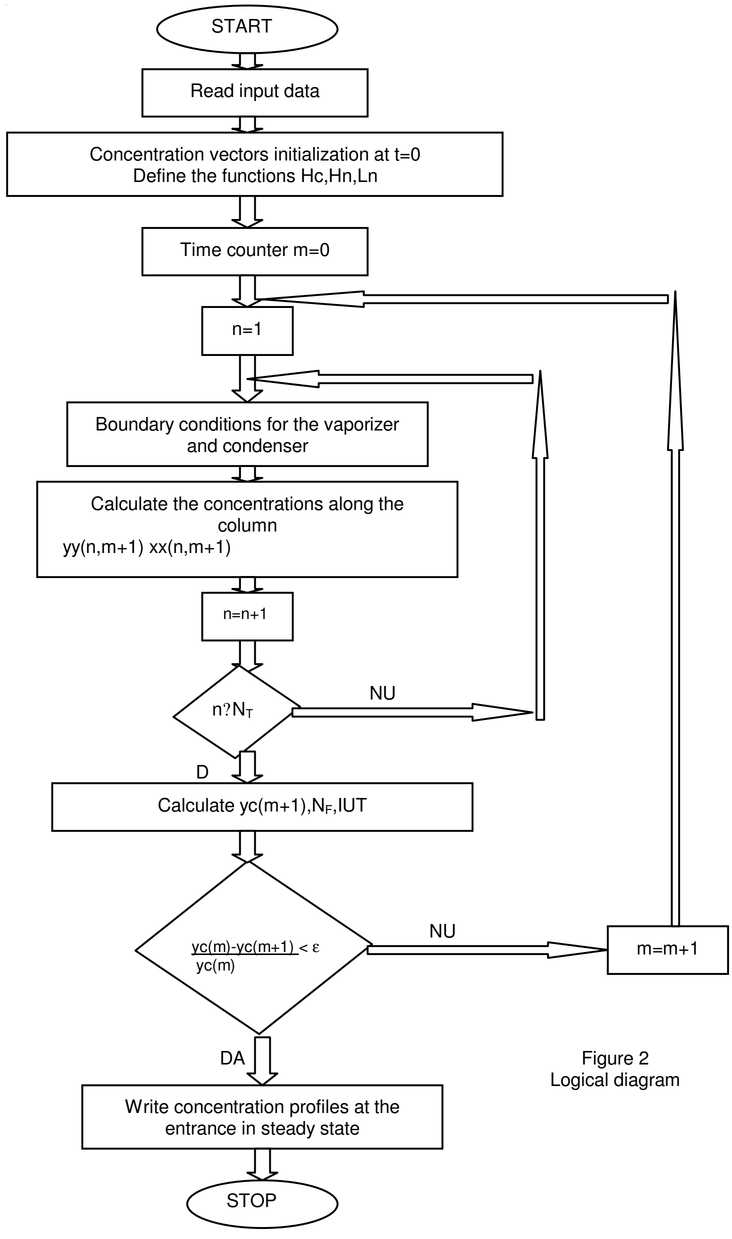

Fig. 2.

For these situations with the growth of the amplitude value, the profile displaces in the way of decreasing the separation capacity has been observed. As a consequence, the amplitude value grows, the more detrimental the situation is. The profiles drawn in Fig. 4 is noted and there is observed that after 30 % amplitude an inversion of the concentration curvature profile

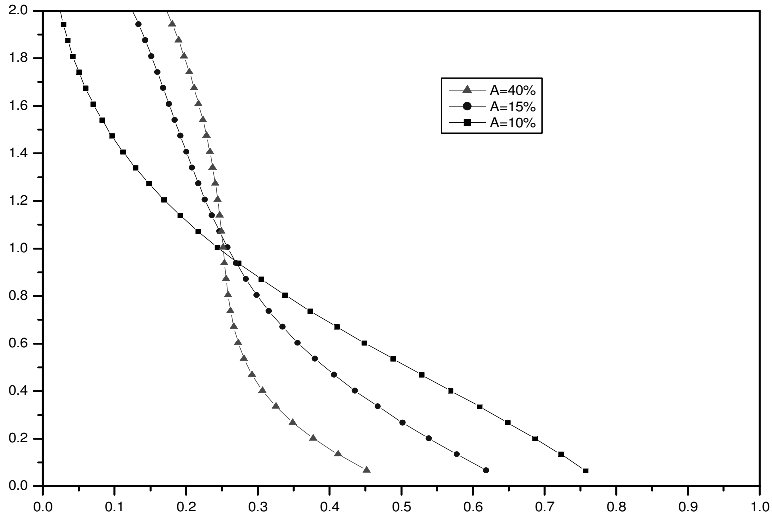

Fig. 3. Concentration profile along the column at different amplitudes and T = 0.25 h, initial concentration is 25 %

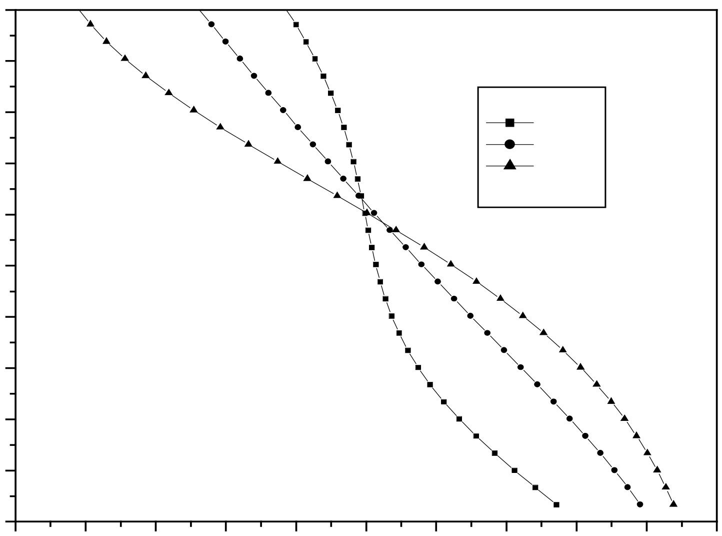

Fig. 4. Concentration on gaseous phase along the column the entrance in steady state Different values of amplitude and the period T = 0.5 h, initial concentration is 50 %

has been take place. Considering that this result gets out of normality there is recommended to avoid to achieve or to overcome the value of 30 % amplitude function which represents the perturbation from the distillation column condenser.

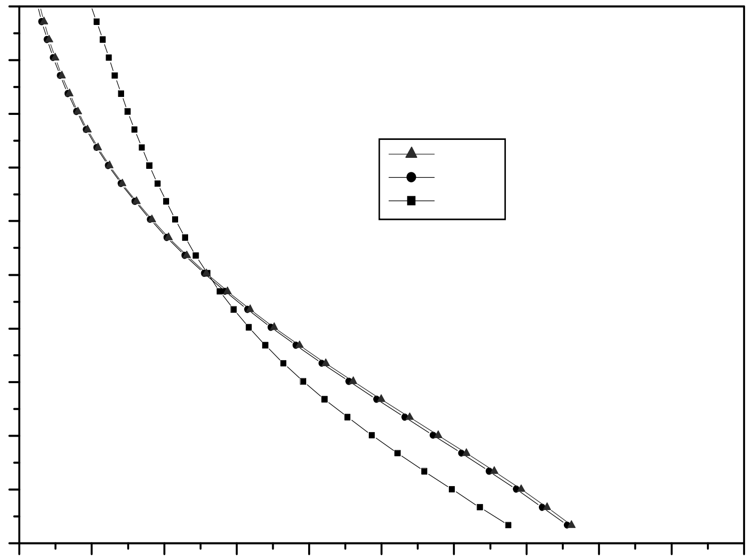

Fig. 5. Concentration profile along the column on gaseous phase. Amplitude A = 10 % and different periods, initial concentration 25 %

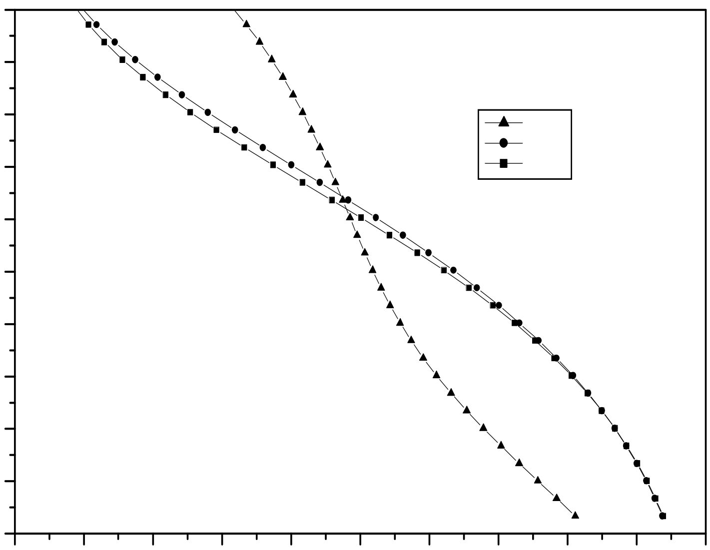

Fig. 6. Concentration on gaseous phase along the column at the entrace in steady state. Amplitude A = 10 % and different periods, initial concentration 50 %

When the amplitude is maintained constant but the frequency varies, it is not recommended to get or to overcome the value of 40 % of the amplitude function that represents the perturbation from the distillation column condenser.

For the case when the amplitude is maintained constant but perturbation frequency varies, from the calculations. It is concluded that for acceptable values of the perturbation frequency at a frequency of 2-4 times per hour. The concentration profile at the entrance in steady state is almost the same, while once overcome the frequency of 4 times per hour takes to a deep lack of balance, case when the distillation column manipulation becomes difficult and to achieve the time of steady state is further.

The liquid level variation from the distillation column condenser takes to the decrease of the separation capacity of the column, this one being lower as the perturbation is stronger.

The graphic representations can give information about the running of a distillation column operated in the conditions of non-steady state. It resulted as a consequence of perturbation in sinusoidal shape of the liquid level in condenser. In this way, it can be observed the concentrations profiles along the column at its evolution in time, but most of all, at the entrance in steady state, there can be determined different values as S separation, Fenske number N_F or the height of the transfer unit IUT. Every measure, by itself, may offer information upon the behaviour of the distillation column operated at total reflux when the perturbation from condenser is described by sinusoidal function.

The model allows the representation of this profile at any time, the file of *.dat kind containing the necessary data for this kind of representations, if we want to analyze the evolution in time of the concentrations along the column. The profiles represented in the previous figures represent the moment of entrance in steady state.

The models of calculation realized can be used to study more aspects of the evolution of the non-steady state in the distillation plant.

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