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Multivariable Feedback Control of a Binary Fractionation Column

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Abstract

This paper addresses a problem regarding multivariable feedback control system for a binary fractionation column. First, a multivariable fractionation process is analyzed from input-output point of view using Simulink. The results of this analysis concluded that the commands of the process influence the compositions on the crossed channels too, so there is a need for a decoupler. Thus, the next step is the design of the decoupler for this process. The system consisting of the process and the decoupler is also analyzed through simulation. Finally, a multivariable control system with monovariable controllers is proposed.

Key words: *multivariable control, feedback control, decoupling, fractionation column*

Introduction

Processes with only one output being controlled by a single manipulated variable are classified as single-input single-output systems [7]. But most of the real processes do not have such a simple configuration. In these processes there are at least two variables to control. Systems with more than one control loops are multivariable systems.

For multivariable systems, changes in one input usually influence all outputs, meaning, there are interactions between inputs and outputs [5]. If the necessary measures are not taken regarding the design of the control systems, these loop interactions can lead to system instability. The present paper proposes a method to reduce or eliminate loop interactions.

Process Analysis

Fractionation processes are multivariable systems. For a typical fractionation column there are five manipulated variables: the flowrate of the cooling agent from the condenser, the distillate flowrate D, the reflux flowrate L, the flowrate of the heating agent from the reboiler, the bottom product flowrate B. So, five variables can be controlled: column pressure, reflux drum level, column bottom level, distillate composition x_D, and bottom product composition x_B [2]. The last two variables (the compositions) are very important. It is considered that, for stabilizing the column, the inventory control loops must be closed; usually the pressure is controlled using the flowrate of the cooling agent from the condenser, and the two levels, from the reflux drum and the column bottom, are controlled using a combination of flowrates L, D, B, and V [3]. For the study in this paper it was considered that the top level is controlled using D and the bottom level is controlled using *V*. It remains, for composition control, the reflux and the bottom product flowrates, thus determining the *LB* control configuration [6].

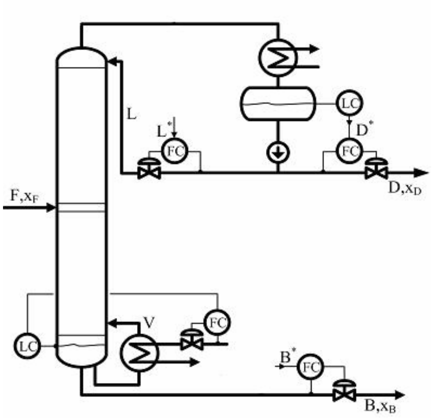

Fig. 1. *LB* configuration.

For the analyzed column associated with the propylene-propane separation process, the specification for the top composition is of rigid type (x_D^i = 92 mole %) and the bottom specification is more flexible ($x_B^i \in [1 \ldots 12]$ mole %).

The studied fractionation process is a multivariable system with two inputs (the flowrates *L* and *B*) and two outputs (the compositions x_D and x_B) (fig. 2).

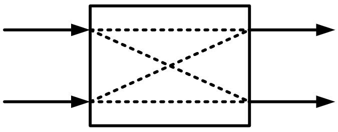

Fig. 2. Process input-output view.

The process model used in this study is a linear approximation of a mathematical model from literature [4, 5].

The analysis of this process was made by simulation in Simulink. The two inputs (*L*, *B*) were modified with ±5% step variation and the evolutions of the two compositions were recorded.

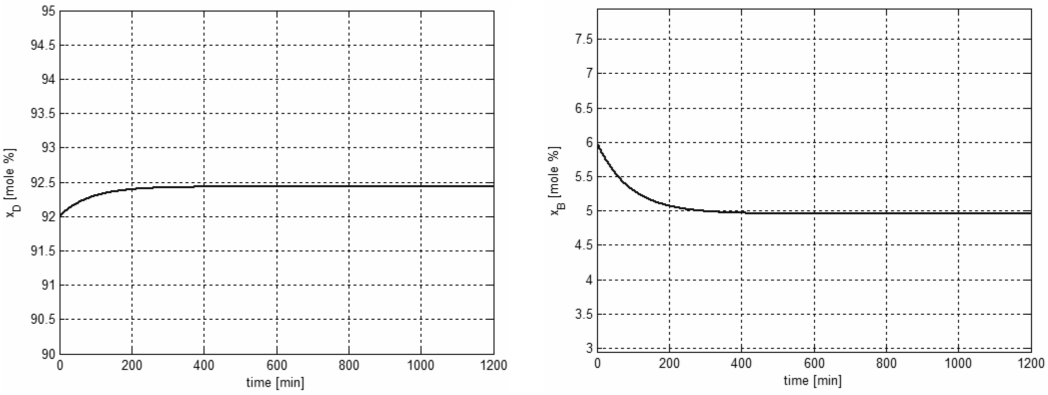

Fig. 3. Compositions evolutions to a +5% change in *L*.

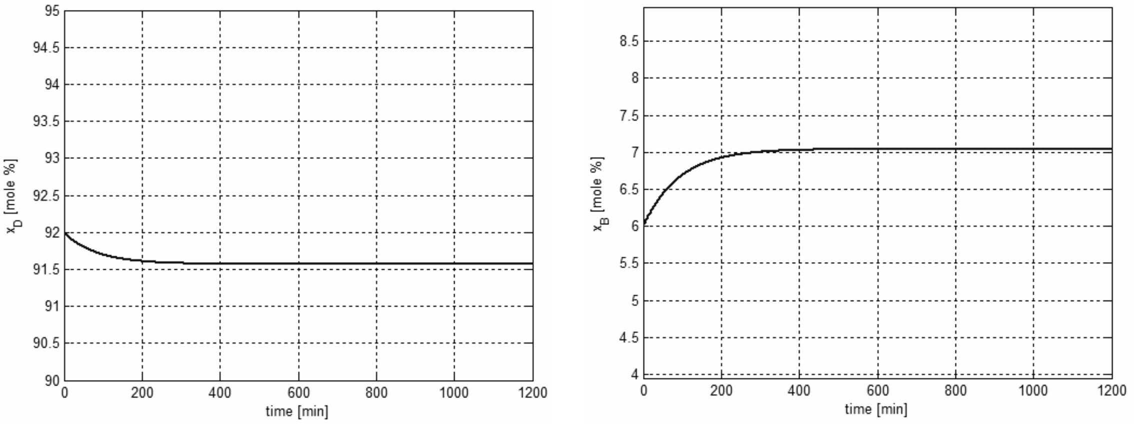

Fig. 4. Compositions evolutions to a -5% change in *L*.

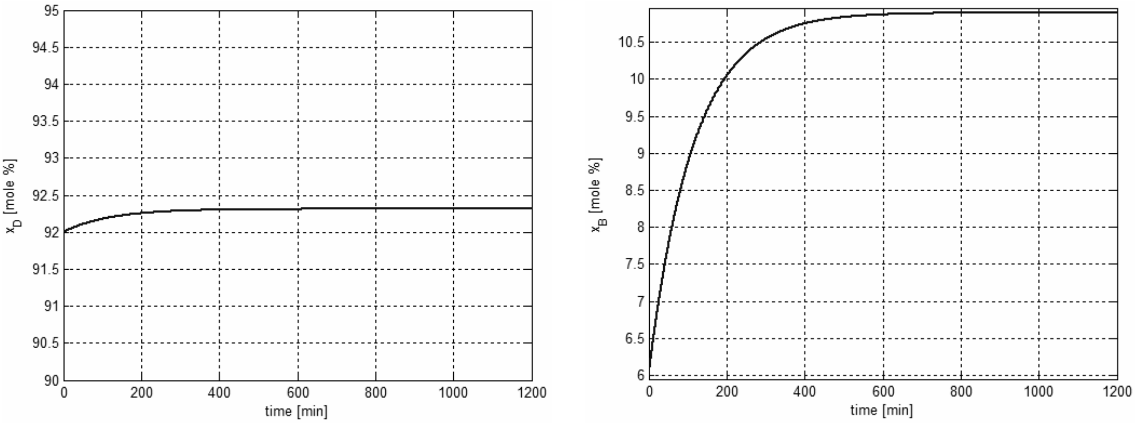

Fig. 5. Compositions evolutions to a +5% change in *B*.

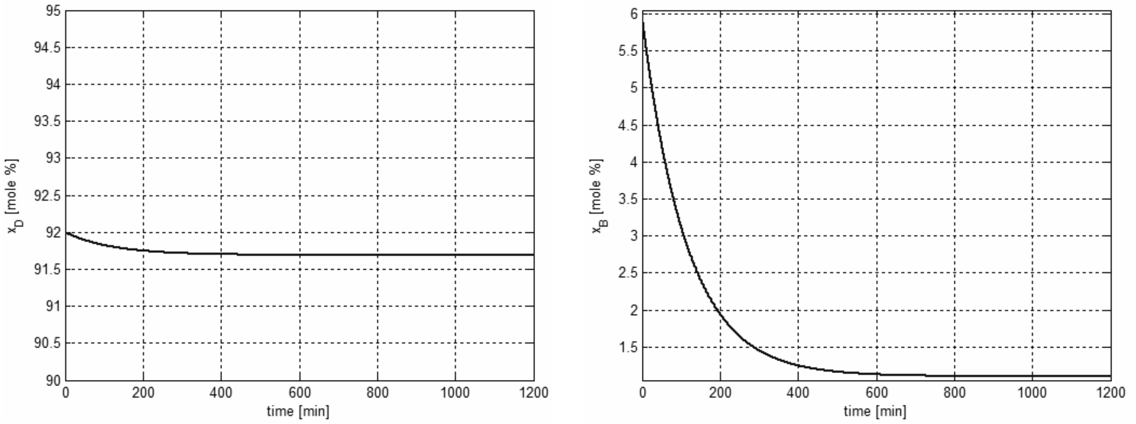

Fig. 6. Compositions evolutions to a -5% change in *B*.

Analyzing the figures 3-6 it can be observed that the two flowrates (*L* and *B*) influence the compositions on the crossed channels too, not only on the direct channels. Consequently, the use of a decoupler is necessary.

Decoupler Design and Analysis

The decoupling problem refers to the design of a decoupler inserted before the multivariable process. The decoupler must have a number of inputs equal with the number of process outputs, so the resulting system is formed, ideally, only from channels with direct interaction.

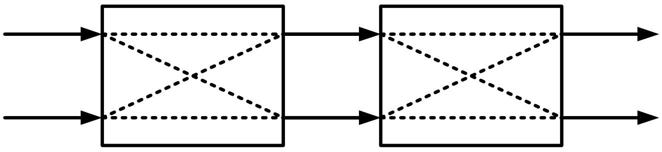

Fig. 7. Decoupling scheme.

For this fractionation process the direct channel $L \rightarrow x_D$ is faster than the crossed channel $B \rightarrow x_D$, and the direct channel $B \rightarrow x_B$ is slower than the crossed channel $L \rightarrow x_B$. In these conditions, the decoupler has the following form [1]:

$$G_D(s) = \begin{bmatrix} \dfrac{1}{T_{11}s+1} & \dfrac{k_{12}}{T_{12}s+1} \\ k_{21} & 1 \end{bmatrix}. \tag{1}$$

Decoupler

c1

L

The decoupler gains are computed like this: $k_{12} = - c_{12}/c_{11}$, $k_{21} = - c_{21}/c_{22}$, where c_{11}, c_{12}, c_{21} and c_{22} are the process gains.

c2

B

For this type of decoupler the time constants are given by: $T_{11} = T_{p22} - T_{p21}$, $T_{12} = T_{p12} - T_{p11}$, where T_{p11}, T_{p12}, T_{p21} and T_{p22} are the process time constants.

In the following, the fractionation process - decoupler ensemble is analyzed by modifying the commands c_1 and c_2, and recording the composition evolutions.

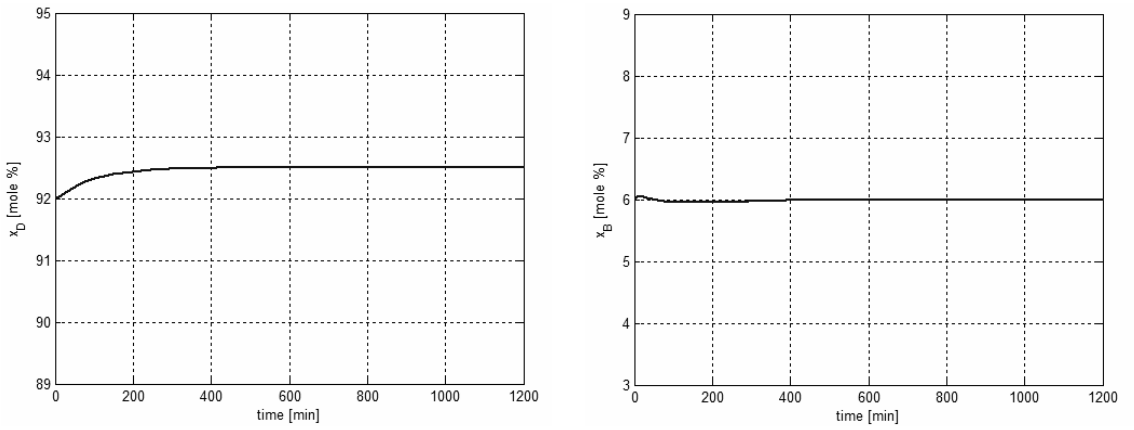

Fig. 8. Compositions evolutions to a +5% change in c_1.

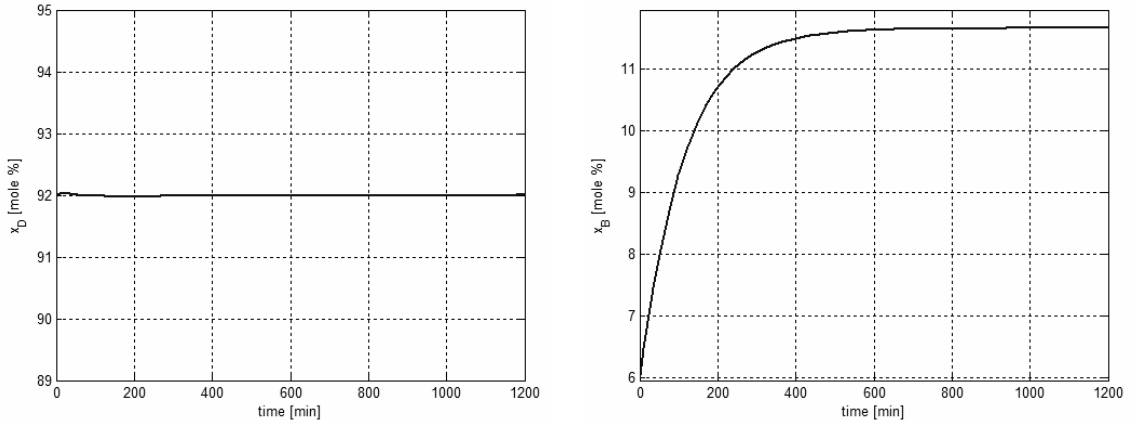

Fig. 9. Compositions evolutions to a +5% change in c_2.

The above evolutions state that on the crossed channels command c_1 does not influence the second output (x_B) and the first output (x_D) is not influenced by the command c_2.

Multivariable Control System

The control system for the studied fractionation process uses two monovariable controllers (C1 and C2) and has a structure like in fig. 10.

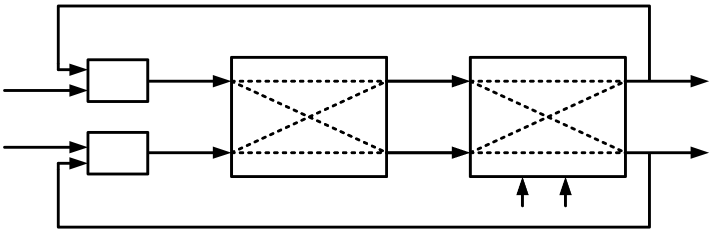

Fig. 10. The multivariable control system.

Using this structure the system was analyzed by modifying the set-points for x_D and x_B, and also the disturbances (F and x_F), and recording the evolutions of the compositions.

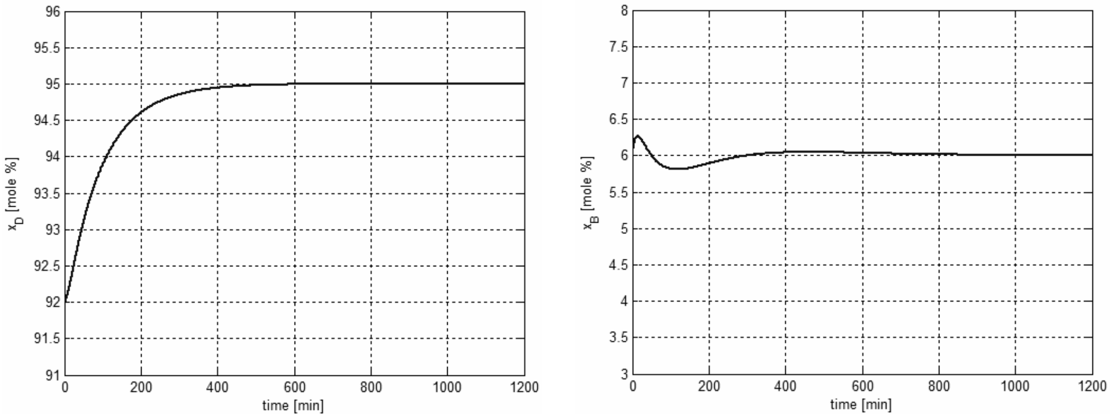

Fig. 11. Compositions evolutions when x_D^i changes with +3 mole %.

Decouple

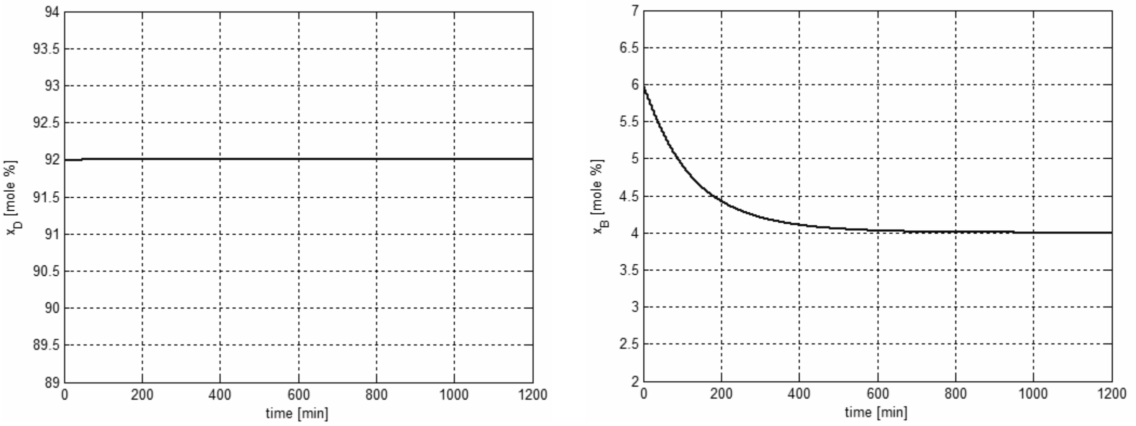

Fig. 12. Compositions evolutions when x_B^i changes with -2 mole %.

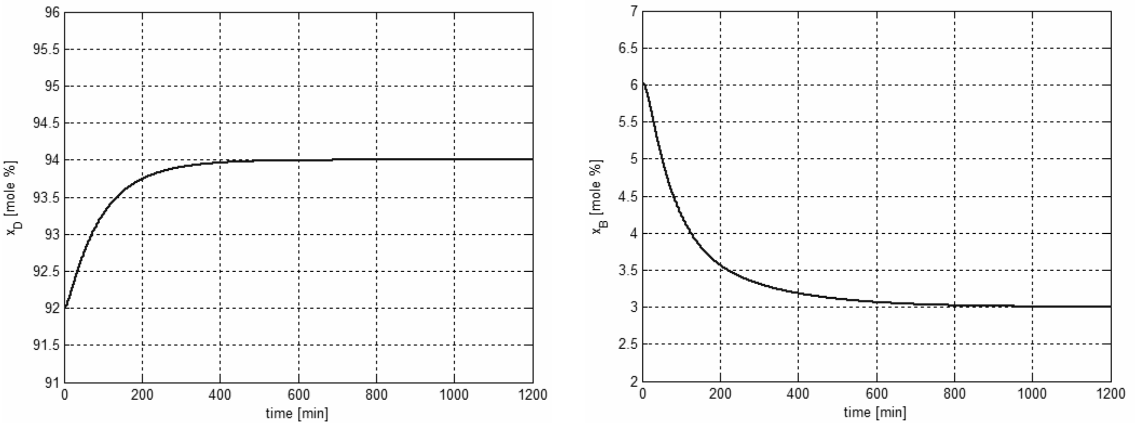

Fig. 13. Compositions evolutions when x_D^i changes with +2 mole% and x_B^i with -3 mole%.

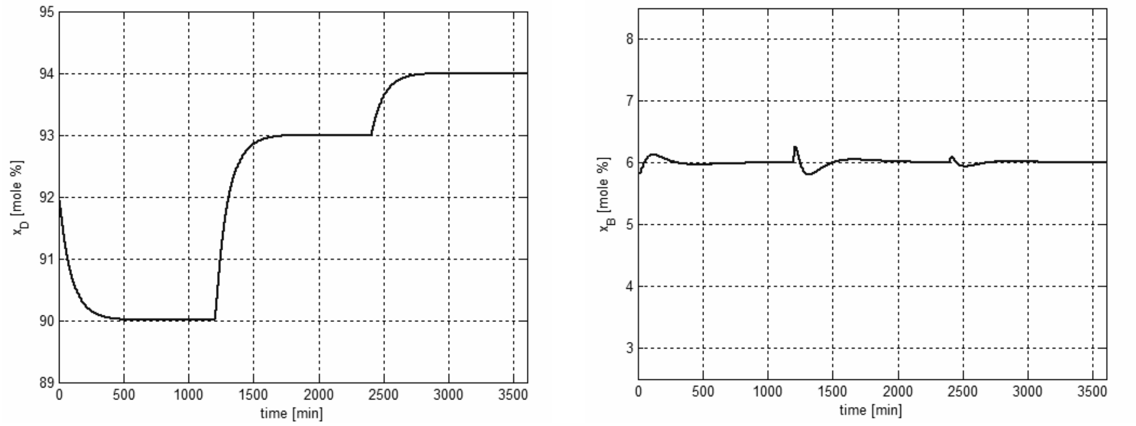

Fig. 14. Compositions evolutions when x_D^i is changed successively.

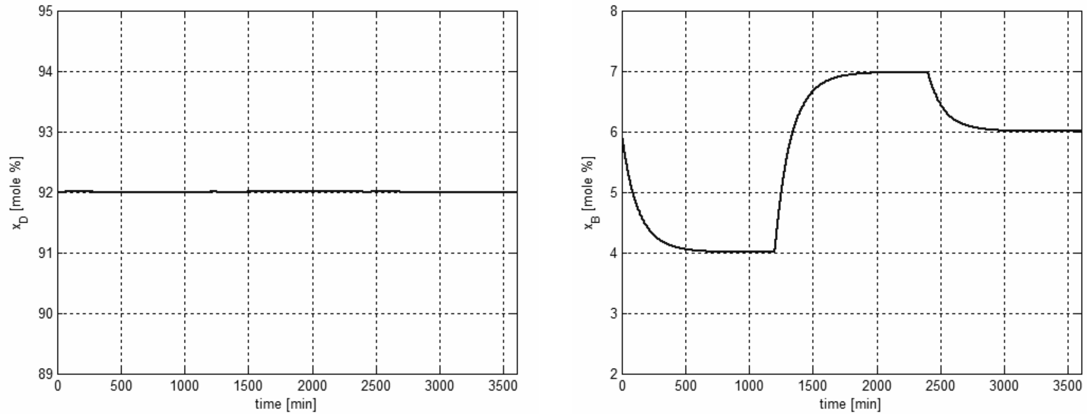

Fig. 15. Compositions evolutions when x_B^i is changed successively.

The set-points were modified individually (only x_D^i or x_B^i, one time or successively for three times) and together (both x_D^i and x_B^i).

From figures 11-15 it can be observed that the control system manages to bring the controlled variables (x_D and x_B) at the desired values. Also, it can be seen that the variables on crossed channels are not modifying, that being a consequence of a well designed decoupler.

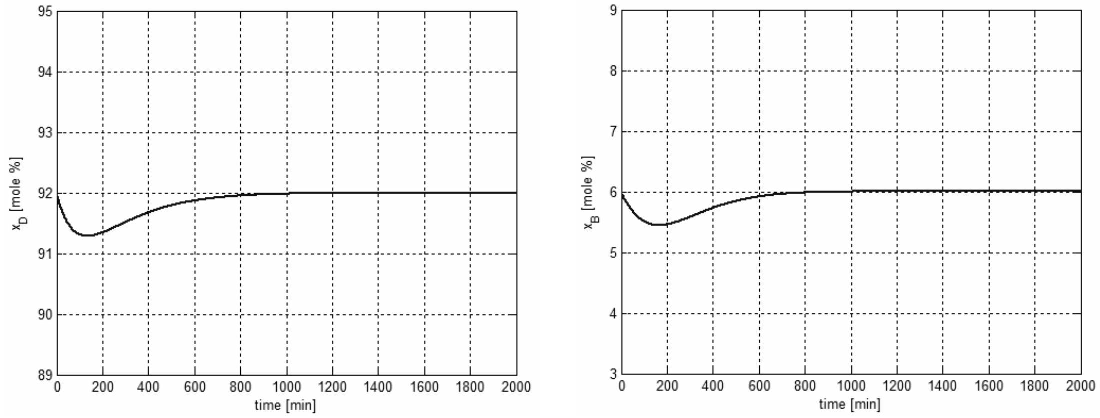

Fig. 16. Compositions evolutions to a +3% change in disturbance F.

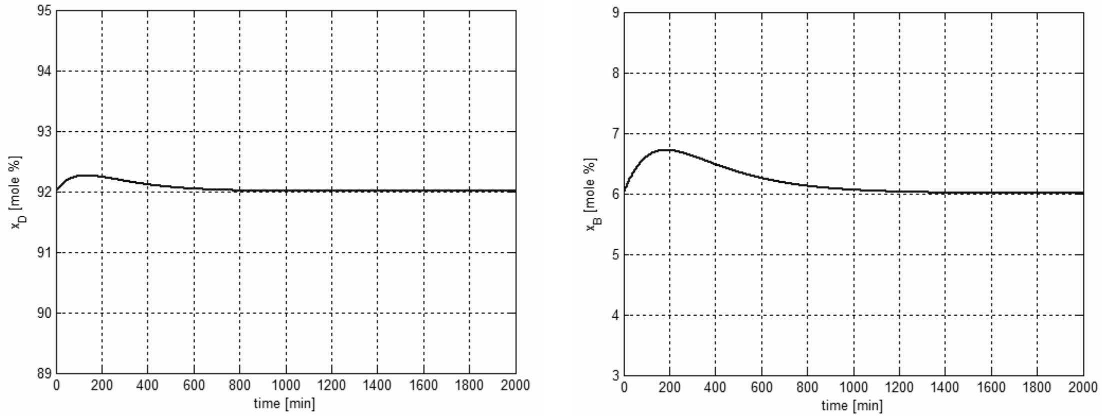

Fig. 17. Compositions evolutions to a +2% change in disturbance x_F.

In figures 16, 17 are presented the compositions evolutions to changes in the two disturbances (F and x_F). It can be observed that the control system manages to eliminate the deviation produced by the disturbances effects on the two compositions.

Conclusions

Present paper had as purpose the analysis of a multivariable control system for a binary fractionation column. Such a column can be considered a 2x2 multivariable system. The inputs of this system are the flowrates L and B, and the outputs are the two compositions x_D and x_B. The fractionation process was studied by simulation in Simulink. There were presented graphically the responses of the top and bottom compositions to changes in the flowrates L and B. Because the two flowrates influence the compositions not only on the direct channels but on crossed channels too, the introduction of a decoupler was needed. The next step was the design and test of the decoupler. From the obtained results it was noticed that the crossed interactions were reduced close to elimination. The following stage of the analysis was the design of the control system for the fractionation process. After the tuning parameters were computed the system was studied by modifying the set-points for the compositions (x_D^i and x_B^i) and also the disturbances associated with the process (F and x_F). The obtained responses were good; the control system manages to bring the controlled variables (x_D and x_B) at the desired values, and also eliminates the deviation produced on the compositions by the disturbances effects.

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Reglarea multivariabilă a unei coloane de fracționare binară

Rezumat

În această lucrare este studiată problema reglării multivariabile a unei coloane de fracționare binară. Mai întâi, este analizat un proces de fracționare multivariabil din punct de vedere intrare-ieşire utilizând Simulink. Rezultatele acestei analize au condus la concluzia că cei doi agenți de reglare ai procesului influențează compozițiile şi pe canalele încrucişate, fiind nevoie în acest caz de un decuplor. Astfel, următorul pas este proiectarea decuplorului asociat acestui proces. Sistemul format din proces şi decuplor a fost de asemenea analizat prin simulare. În final, este propus un sistem de reglare multivariabil cu regulatoare monovariabile.