FLUID DYNAMIC MODEL AND CONTROL OF DISTILLATION COLUMN WITH DISTRIBUTED HEATING

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INTRODUCTION

Distillation columns require well adjusted control systems to quickly reject disturbances. To assist this purpose, a new distributed control strategy using electrical resistances on intermediate plates of a distillation column was proposed. Usually the control of distillation columns is accomplished centralized at the bottom, top and lateral outlets, generating a high transition time when the process is disturbed.
A fluid dynamics study of the liquid vapor flow on the plates of a distillation column was conducted to improve understanding in microscopic level, of the mechanisms that occur in cases of separation and to evaluate the influence of resistance on the hydrodynamics of the trays. The data of the turbulent liquid vapor flow from the CFD technique encouraged the implementation of a control strategy with the use of resistances on the surfaces of the trays since the results showed that these do affect deleteriously tray hydrodynamics. In sequence, experimental studies were conducted implementing PID controllers, widely used in industrial processes, comparing the dynamics of the conventional process with the proposed technique, when disturbances were introduced in the feeding flow.

OBJECTIVE

The objective of this paper is evaluate the influence of the insertion of devices for heating (electrical resistances) in the hydrodynamics of the tray, using the CFX computational package with 3-D model. In sequence to realize experimental studies, assessing the dynamics and control of a pilot scale distillation unit with the new design.

METODOLOGY

Mathematical Model

The model considers the flows of gas and liquid in Eulerian-Eulerian framework, where the phases are treated with transport equations. Mass Continuity and Momentum Equations were used to solve this problem. It was assumed that the fluctuations (turbulence) consist of small swarms to be formed and to be dispersed, and that the Reynolds stresses can be linearly related to the mean velocity gradients (eddy viscosity hypothesis) similar to the relationship between the stress and the strain tensors in laminar Newtonian flow. It was assumed the standard model for k-ε turbulence model for multiphase flow.

Experimental Unit

The pilot distillation unit is composed of 13 trays, processing an ethanol-water mixture with a feed flow rate of 300 L/h. The unit operates continuously, with the feed stream inserted in the 4th tray, with a total height of 2.70m, built in modules with 0.15m height and 0.20m diameter, as shown in Figure 1. PID controllers were adjusted for the temperatures of the bottom and of the last tray, characterizing the conventional control.

Figure 1 - Pilot distillation unit.

Experimental Procedure

For this study disturbances were introduced in the feed flow rate. The performance of the distributed approach (control at the bottom, top and tray 2) was compared with the conventional configuration. Experiments were conducted with ethylic alcohol volumetric feed fractions around 10% (v/v), the feed temperature was controlled around 92ºC, the feed flow rate was 300 L/h and the pressures on the bottom and top varied around 1.25 and 0.25 bar, respectively. Composition measurements were carried out during the experiments. The distributed heating was carried out by means of electrical resistances with maximal power of 3.5 kW each. The controllers used for the bottom level and the feeding flow rate consist of a cascade system composed by a feedback PI and another anticipative (feedforward). To adjust the controllers the classical methods of Cohen-Coon, ITAE and Zieger-Nichols (Seborg et al., 1989) were applied. The configuration of the control loops implemented in the experimental unit is shown in the Figure 1.The distributed control was carried out by using an intermediate tray, tray 2. For the identification of the most sensitive stage for the application of the distributed control sensitivity analysis methods were used: successive plates, sensitivity symmetry and maximum sensitivity, as detailed in Marangoni (2005).

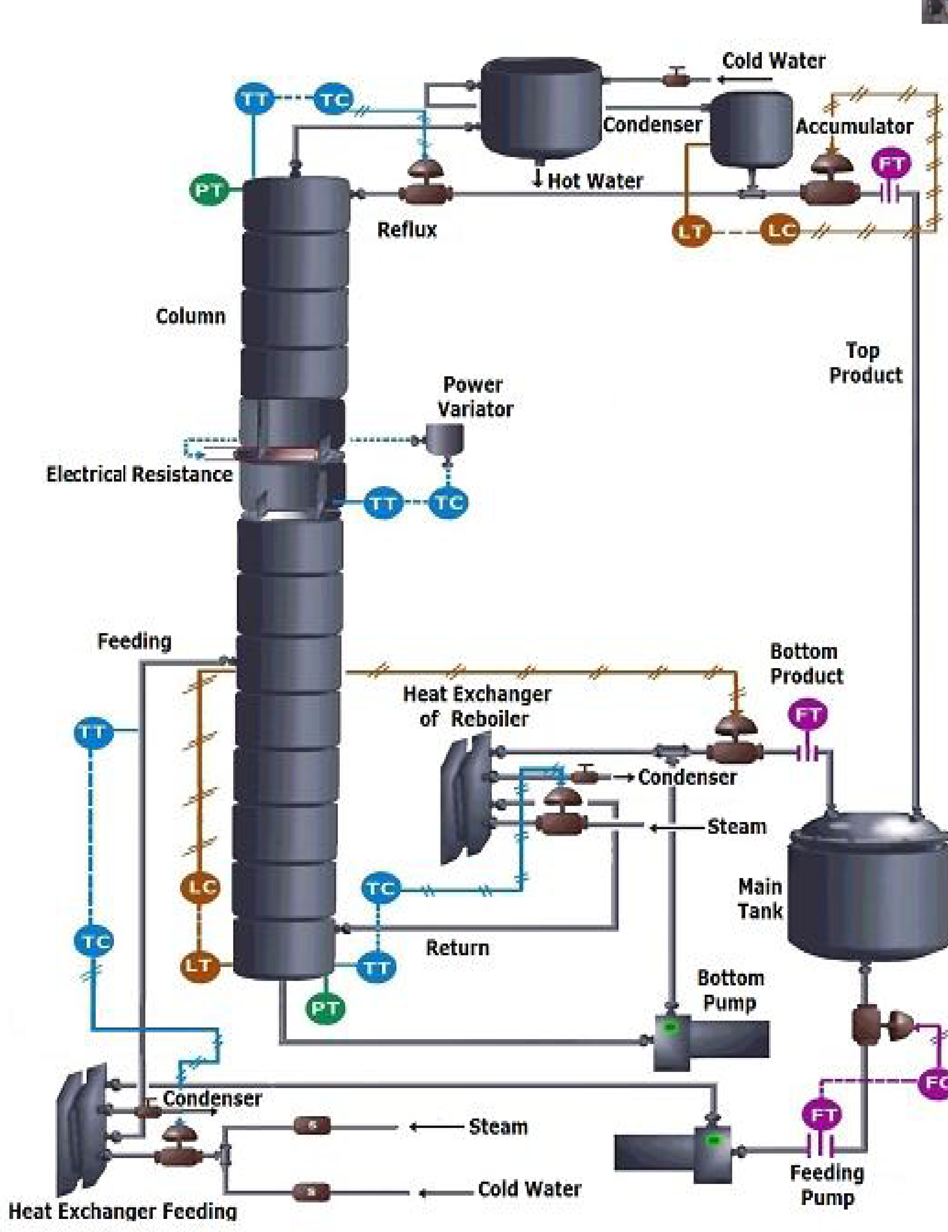
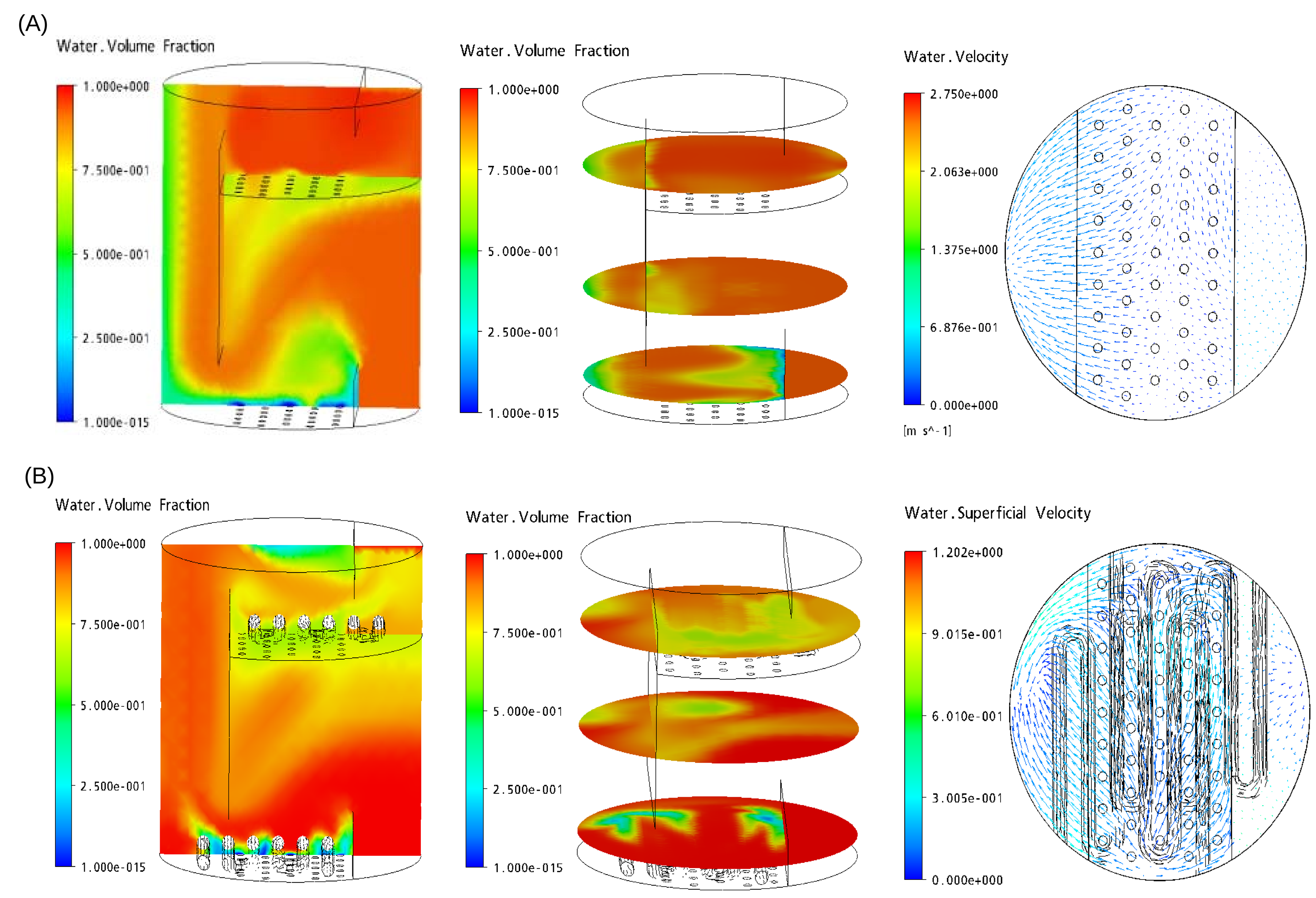


Figure 2 - Scheme of the control system of the pilot distillation unit.

RESULTS AND DISCUSSION

The results are presented in two sections, the first showing results obtained from the simulations carried out to study the influence of the resistance on the hydrodynamics on the plates of the distillation column, and the second with the results of the experimental part evaluating the process dynamics with the proposed control strategy.

Simulations - Figure 3 (A, B) shows the simulation results including the distribution of volumetric fraction of liquid and the behavior of the speed vectors on the surface of the tray for a multiphase flow. The speed used for the liquid feed was 0.3 (m/s) and 0.1 (m/s) for the gas. The hydrodynamics of the liquid flow in the steam-distillation plate in two domains of drainage might be observed with and without the presence of the resistance on the surface of the trays.



Profile Volumetric Fraction of the Plan XY multiphase

Profile Volumetric Fraction of the Plan XZ for three levels of height multiphase

Velocity vectors on the surface of the plate multiphase

Figure 3. Simulation results for multiphase flow (A) conventional (B) distributed heating.

Comparing results with and without the resistance is observed the hydrodynamics of the plate is affected by the resistance. It is also noted in Figure 2 (Plan XZ) that the presence of the resistance favors the formation of regions of higher mixing.

Experimental Tests - The disturbance introduced in the feed flow rate for both control configurations was a positive step with amplitude of 150 L/h, the set point feed flow rate being modified from 300 to 450L/h of drainage might be observed with and without the presence of the resistance.

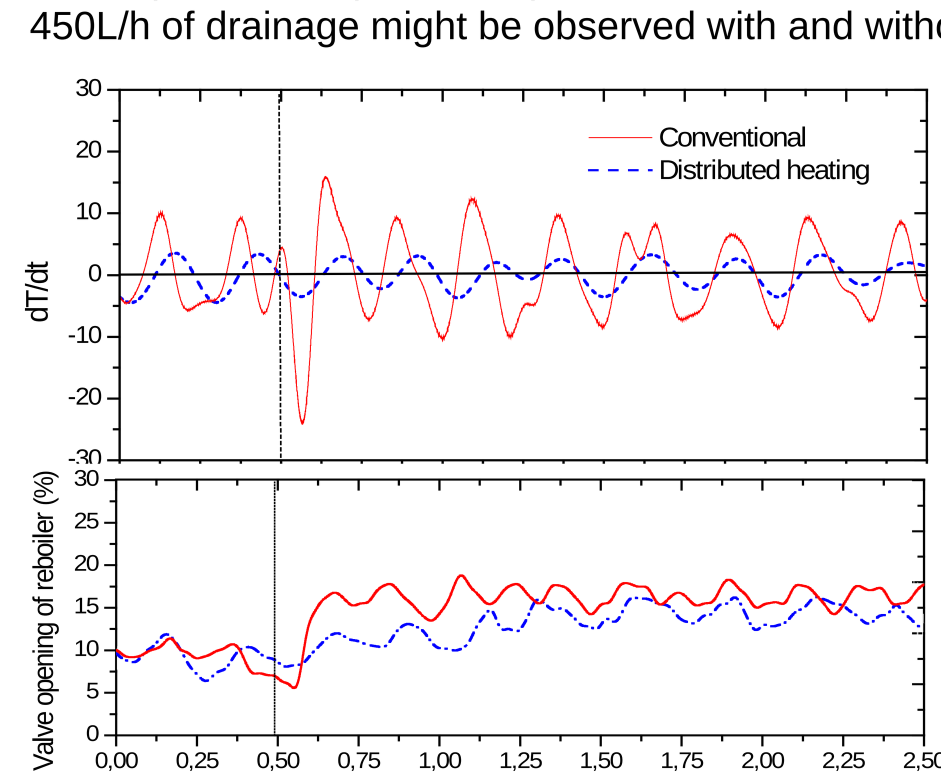


Figure 4 - Derivative of the temperature of the reboiler and response of the control loop.

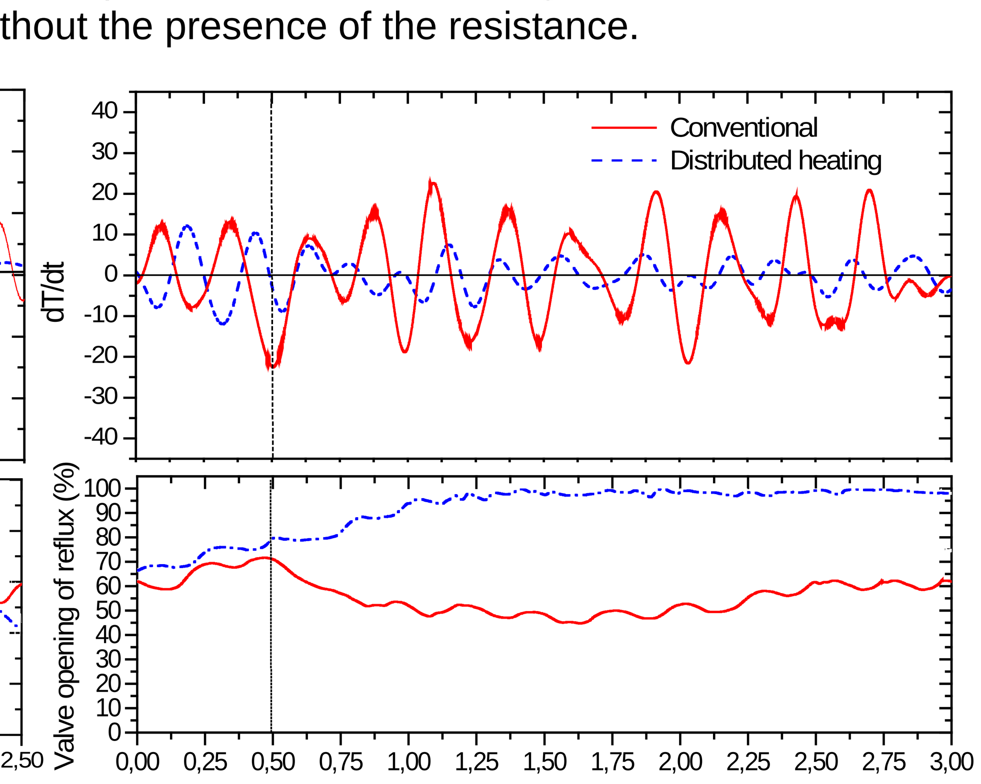


Figure 5 - Derivative of the temperature of the last stage and response of the control loop.

After the disturbance, it is possible to observe larger oscillations in the temperature of the reboliler and 13th tray in the conventional control in relation to the distributed control. This oscillation can be observed by means of the derivative of the temperature of the reboiler and of the last stage, as illustrated in Figures 4 and 5, respectively.

CONCLUSIONS

The presence of a resistance on the surface of the tray positively affect in a way the hydrodynamics of the distillation trays, favoring the homogeneous mixture on the surface of the plate. In addition, several advantages of the distributed control approach compared to the conventional process were observed when a disturbance is introduced in the column feed rate: reduction of the operation transient; better performance of the controllers with a less oscillatory behavior of most of the control loops. Thus, the introduction of the distributed heating along the column has shown itself as a valid option for the transient reduction, enabling faster and less oscillatory dynamics.

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