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A new approach to control distillation column: Use of intermediate action

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Even a well adjusted control system of distillation process is not sufficient to eliminate the operation transients since this is an intrinsic feature of the process. One aspect that contributes to this situation is the centralization of the control action on the variables at the bottom and top of the column. In this work, a change in this control configuration is proposed through the introduction of heating points distributed among the trays throughout the column. The new approach was tested in a experimental distillation process where temperature feed disturbances occur with an ethanol-water mixture applying a conventional approach (control at bottom and top only) and the proposed distributed configuration (bottom, top and column trays). Results showed a significant reduction in the time required for the column to stabilize after the disturbance, if compared with the conventional approach, making faster dynamics possible.

1. Introduction

The control of distillation columns is widely studied. However, even with several researches in more and more complex control approaches we can observe that few available in literature shown the transient minimization study according the column dynamics. The transient formation in a distillation column occurs when the process is disturbed and its features limit the control system efficiency or when an external factor induces to the modification of the unity operation point. Although the delay and the time constant are small for each tray (in seconds), the column dynamics is all slow. The separation is performed in stages and when the process is disturbed, modifications in each tray are made giving a new balance point. This behavior is spread out through the entire column by the liquid and vapor phases. And the final result consists in very high time of response. Figure 1 shows as a composition change and its influence on liquid and vapor phases, responsible for the time increase effect.
It is well known that a product quality improvement is reached through a fast changing adaptation. In this regard, the solution approach most commonly employed to minimize the operation transients of a distillation column is the implementation of advanced control techniques (Hurowitz, 2003). In this sense, several studies can be cited, with controller based on process models (Bezzo, 2005, Jana, 2005, Karancan, 2003). Even in these (and other) studies, the quality (composition or temperature) controllers are focused at one or two points causing the centralization of corrective action.

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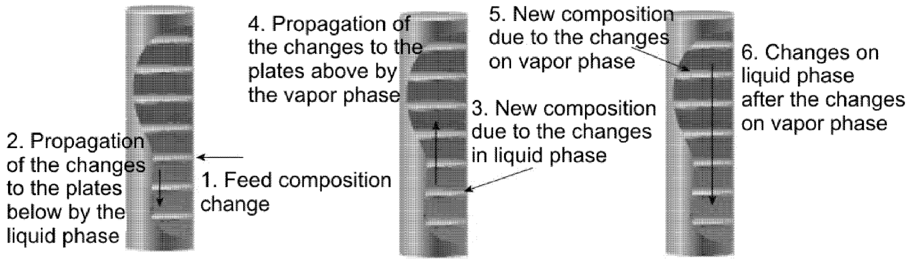

Figure 1. Propagation of the changes on liquid and vapor phases result in a great column time response.

An alternative that has been proposed is the modification of the conventional configuration of the column in order to improve the process and consequently the controller performance (Caballero, 2004). One example of a different column configuration, which is widely studied nowadays, consists of diabatic distillation columns (Björn et al, 2002). The goal of these units is to save energy in the process through heat introductions and withdrawals in the column. But in this regard, no studies have focused on a control strategy.

Based on the heat distribution in the diabatic distillation column, this paper proposes the use of heating in the trays as a new control approach to minimizing the operation transients caused by feed disturbances. The objective of this study is to implement a new distributed control strategy and to compare it with a conventional one. The new approach was tested in a distillation process where temperature feed disturbances occur.

2. Material and Methods

Experiments were carried out in a pilot unit processing an ethanol-water mixture. The entire unit, illustrated in Figure 2, operates in a continuous regime. The column has 13 (thirteen) equilibrium stages (sieve trays). The feed was introduced into tray 4 (four), the reboiler being the 0 (zero) stage. Each module had a point for temperature measurement, one for sample collection and a third one for the distributed heating adaptation. For the latter, the measurement was performed by means of electrical resistances with a power of up to 3.5 kW each.

The local control configuration for the distillation column was defined based on classical studies (Nooraii et al, 1999). The following control loops were defined: (1) bottom level control through the bottom product flow rate adjustment; (2) accumulator level control manipulating the top product flow rate; (3) feed flow rate control as a function of the adjustment of the same stream flow rate; (4) feed temperature control through the fluid flow rate adjustment in the heat exchanger of this stage; (5) last tray temperature control by means of the manipulation of the reflux flow rate; (6) reboiler temperature control through the vapor flow rate in the heat exchanger of this stage and (7) control of temperature of pre-defined stages of the column through the adjustment of the dissipated power in the electrical resistance of the tray.

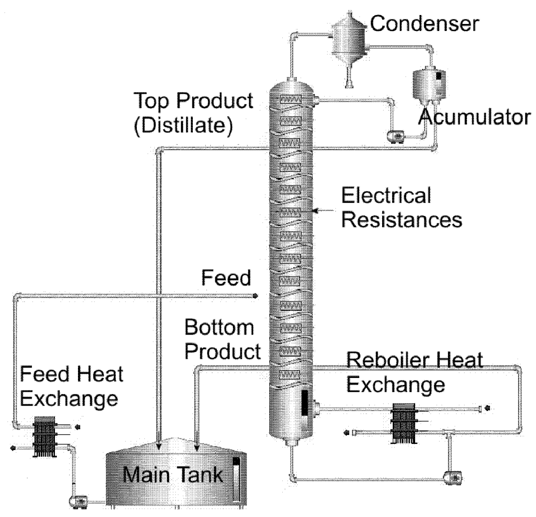

Figure 2. Schematic illustration of the experimental unity equipments.

The first, second and third loops represent mass balance (inventory) control. The fifth and sixth loops comprise the quality control – in this case represented by temperature. When only these two loops were used we called this conventional control. When these two loops were combined with the seventh one described above, we considered this as the distributed strategy.

3. Results and Discussion

To implement the new control strategy, the definition of the tray used is required, which was performed through a sensitivity analysis by classical methods (Luyben, 2006). Tests were carried out with different feed compositions and results indicated plates 1, 3, 5 and 7 as sensible ones. As is common to obtain more than one tray as a result, we decided to work only with trays 2 and 3 since they were in the stripping section. Tray 1 was discarded because only one method demonstrated its importance, and trays 5 and 7 were not used since they are in the rectifying section. Figure 3 shows the position of these stages on the column.
The feed response of the reboiler face to a temperature feed disturbance is illustrated in Figure 4a**.** Pointed line is this and in all other figures, indicates the disturbance moment. It can be observed that there is a lower oscillation around the steady state when the distributed approach is applied. The oscillation is also observed in the control action, which is lower for the distributed approach, resulting in a lower wear of the valve. Also, as was expected, on account of the heat distribution, the vapor valve operated with smaller openings during the first 30 minutes after the disturbance. This result indicated that the distribution of the heat supplied to the distillation unit had occurred. This same behavior is observed in Figure 4b where the effect of the disturbance of the temperature control of tray 13 is shown. The distributed approach rejects the temperature decrease of the feed more quickly, and with a lower oscillation, than the conventional approach. Also, the distributed strategy remained closer to the reference than the conventional one.

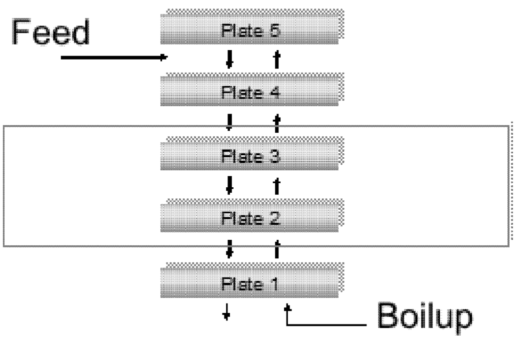

Figure 3. Selected plates according its column position: Results of sensitive tests.

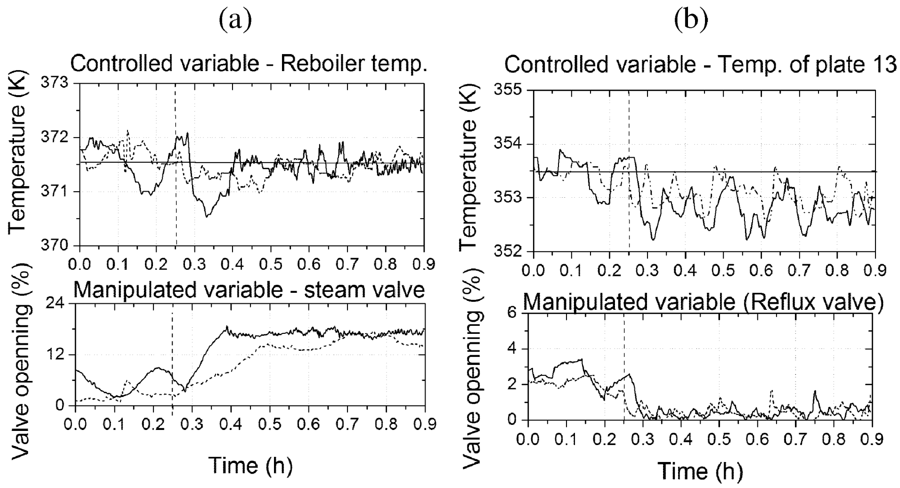

Figure 4. Comparison between the conventional (—) and distributed control (- - -). (a) Reboiler temperature control (b) tray 13 temperature control.

This result is corroborated by the temperature deviation in both stages in relation to time, as shown in Figure 5. This illustration (5a) shows an amplification of the immediate control system response, where it is can be observed that the conventional strategy has a deviation 2.5 times higher than that of the distributed one, for the reboiler temperature control. The deviation of tray 13 in relation to time, for the first 30 minutes after feed disturbance, is shown in Figure 5b. On analyzing this figure, can be seen that even with an accentuated oscillatory behavior around the set point, this is reduced when distributed actions are used.

For the reboiler temperature control loop, it was observed 1.98 min (118 seconds) of delay in the control action, in relation to the moment of the disturbance, with conventional approach and only 1.02 min (61 seconds) with the distributed test. For plate 13 these values were 0.9 min (54 s) for conventional and 0.24 min (14s) for distributed approach.

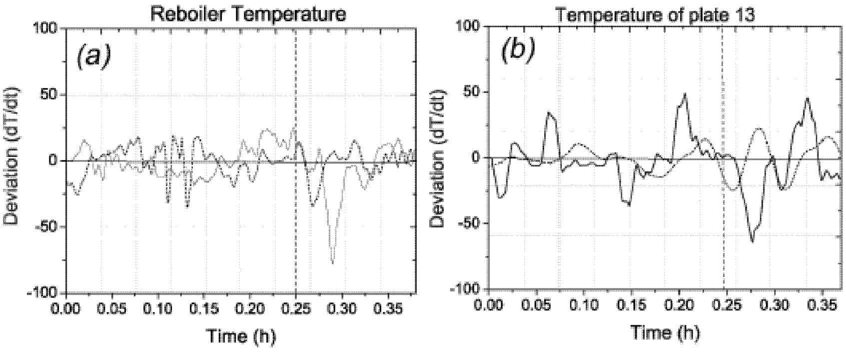

Figure 5. Deviation of the reboiler temperature (5a) and tray 13 temperature (5b) in relation to time when applied to the conventional (—) and distributed control (- - -).

This indicates that the distributed action is 47% faster at minimizing the temperature feed disturbance in relation to the reboiler control loop, and 375% faster for the tray 13 control loop. Since the last stage of the column is tray 13, which has the greatest response time to feed disturbances, to minimize the time necessary for the control action in this stage means to reduce transition period of the column.

In a general way, the temperature responses at the column extremities show that the introduction of the distributed control contributed to the disturbance rejection. The control became less oscillatory and, in some cases, it was possible to maintain the control variable within the reference value using only the distributed approach. The application of the control to the tower stages kept the variables within the desired values and thereby, allowed the minimization of the transients caused by the disturbance of the variables at the column extremities. This behavior can also be observed in Figure 6..

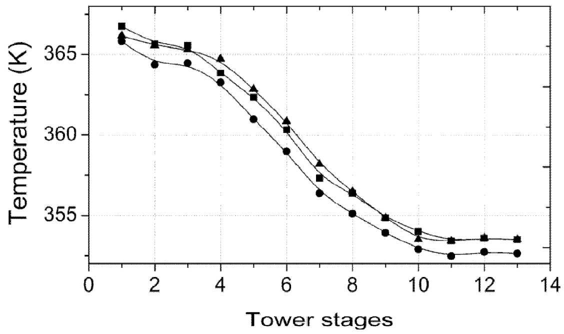

Figure 6. Temperature profile along the column trays in the steady state (--■--)after the disturbance using conventional control (--●--) and distributed control (--▲--).

It is desirable that the curves remain close to the steady state, for in this case the disturbance should be completely rejected and the transient should be minimized, as observed in the curve represented by the distributed control. This behavior was not observed with the conventional approach, where the temperatures inside the column decreased as expected following the disturbance applied.

The conventional approach allows the temperature alterations inside the column to take place, and the control is applied at the equipment extremities. The distributed strategy keeps the temperatures at trays 2 and 3 (where the control loops are applied) in a steady state. We may observe that the temperatures of the other trays in the column are also closer to the desired value. Therefore, the entire temperature profile of the column is barely changed when the distributed control is applied.

4. Conclusions

The evaluation of the conventional and distributed approaches, for a disturbance in the feed temperature enabled us to verify reductions in the transition time of the column and the oscillations of the controlled variable when the proposed approach was used. The distributed strategy kept the tray temperatures where the control loops were applied within the desired value, rejecting the disturbance. Thus, the distributed heating introduction throughout the column was shown to be a valid option for transient reduction, resulting in faster dynamics with lower volumes of the processed product out being of the pre-defined quality parameters.

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