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Location Effect of Temperature Control on the Fund in a CPD

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Abstract

In this work the effect of the location of the secondary loop temperature control on the performance of a structure to control product composition background of a dividing wall column (DWC) is studied. The results show that the location has a significant effect in the control and in proper positions is possible to maintain product purity background close to the desired value in the presence of disturbances in the feed composition. The backstepping methodology shows the nature of the design temperature-temperature cascade control, in addition to extensions multicascada obtained control. Based on these initial results it will be possible to obtain control structures based on multiple temperature measurements for controlling the composition of the products in dividing wall columns making a contribution to the research of control in this type of separation structure.

Column, distillation, control, disturbances

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Introduction

Distillation is the separation process more common in the chemical process industry. Usually a ternary mixture can be separated by a direct, indirect or a distributed sequence comprising two or three distillation columns. It has made a significant effort in developing new methods of design, optimization and control of thermally coupled distillation columns, which provide savings of up to 30% of the annual cost in the separation compared to conventional distillation sequences (Schultz et al., 2002). To reduce the number of columns and avoid remixing in such sequences, a thermally coupled arrangement that is now known as Petlyuk distillation column (Figure 1a) and in it the vapor streams and liquid exiting from the prefractionator introduced They are directly connected with a second column directly eliminating a column, a reboiler and a condenser. An alternative configuration for the prefractionator thermally coupled using a single housing with a vertical partition dividing the central section of the housing into two parts is known as dividing wall column (CPD) (Figure 1b).

Despite the potential benefits of the dividing wall column, it was not until in recent years the industry chosen by them (Kaibel, 2002). The main reason for the slow acceptance is attributed to lack of knowledge on the dynamics of the process and its controllability (Abdul Muttalib et al, 1998a;. Abdul Muttalib et al, 1998b;. Serra et al., 2003). Recently there has been more effort on these issues and have been published more articles on the dynamics, control and operation of dividing wall columns (Rodriguez and Chinea, 2012).

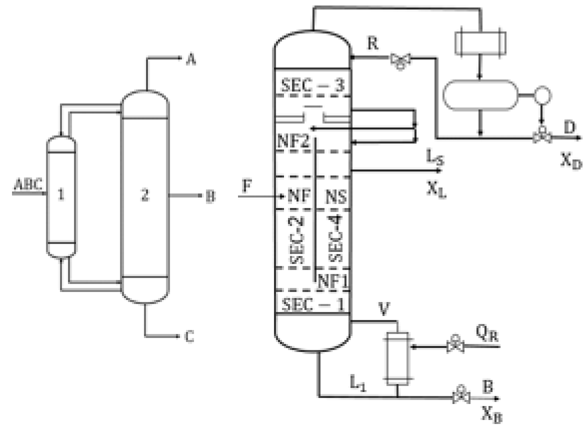

Figure 1 Column Petlyuk (a) Dividing Wall Column (b)

Because the temperature measurements are usually more sensitive and cheaper than compositional schemes have been proposed inferential control these measurements. Luyben 1969 proposes a technique to control the product composition of a distillation column by controlling the difference between two temperature differences (DT) column. Raised as an effective control scheme for a variety of disturbances in different operating conditions such as disturbances in the feed rate and feed compositions, achieving better performance on the grounds that the changes are canceled in the pressure drop if two (DT) are taken in the same section of the column where the same changes are in the vapor and liquid loads. In 1996, Wolff Skogestad and present examples of the application of cascade control for distillation columns to quantify improvements focusing on the interaction and the rejection of disturbances and provide some analytical expressions for the gain of the secondary controller. Shin et al. (2000) proposed an observer using temperature measurements of plates instead of the composition. Ling and Luyben (2010) made attempts to control the composition indirectly to the operation of the DWC and these include structures for temperature control (TC) and control of temperature difference (TDC).

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Luan et al. (2013) proposed a control structure simple temperature difference (STDC), consisting of two temperatures and two control loops temperature difference.

Cascade control applied to distillation columns possesses robustness properties is still not entirely clear, however, Alvarez-Ramirez et al. (2002) used the backstepping approach where passivation show that the nature of the design of cascade control of the composition in a distillation column is rinsed under these terms, plus systematic extensions for configuration control is obtained as multicascada a natural consequence of this same design. These researchers used a cascade control composition-temperature, however in controlling the composition by measuring the composition often presents certain practical difficulties.

Preliminary work such as Matla-González et al. (2013) and Castellanos-Sahagun and Alvarez (2013) used temperature-cascade control temperature to indirectly control the purity of the products. Early investigators apply them to a Petlyuk column consisted of linear models showing interesting input-output stability properties and performance during periods of time to disturbances in the feed composition. The second researchers applied to a binary distillation column using a combination of the theory of nonlinear constructive passivation control and observability notions.

In a previous study Medina-Rodriguez et al. (2015) designed controllers cascade temperature-temperature under the backstepping principle for rectifying section (SEC-3) of a dividing wall column evaluating the effect of the location of the temperature measurement on the performance of the controller using as manipulated variable reflux rate.

These paper controllers are designed under the same principle backstepping to the stripping section (SEC-1) of a CPD, evaluating the effect of the location of the temperature measurement on the controller performance using the rate of heat as manipulated variable.

Dynamic Simulation System

The dynamic behavior of the dividing wall column (CPD) is based on a dynamic model solution obtained by mass and energy balances for each component in each dish and, in thermodynamic relations. The model consists of the following set of ordinary differential equations (ODE) and algebraic equations for each stage of the column: NC-1 continuity equations for component 1 equation total continuity, one equation of energy balance, 1 Hydraulic connection for flow rates of liquid on each tray, one equation for the density of the liquid, two equations to obtain the enthalpy (liquid and vapor); NC relations vapor-liquid equilibrium. For PCD considered in this work consisted of a total of 70 stages (in the prefractionator 24 and 44 in the main column), a condenser and a reboiler, the resulting pattern was formed with a total of 280 490 ODEs and algebraic equations. The set of ordinary differential equations are solved using the Runge-Kutta algorithm 4th order.

System Overview

As case study considering the separation of a mixture of benzene (B), toluene (T) and o-xylene (X) which has a feed composition of 30/30/40% mol respectively and to be separated reaching individual purity of 99 mol% in the currents of distillate, intermediate and bottom. Table 1 shows the operating conditions and design specifications required for the model solution. The detailed description of the model to the case of the column Petlyuk presented in the previous work (Matla-González et al., 2013).

The same can be applied to the CPD model, considering the decrease in size of the intermediate stages (sections 2 and 4) column, which are smaller than the sections 1 and 3, as shown in Figure 1b.

Parameters	Value
Number of components	3
Return the liquid fraction (β)	0.322
Return the liquid fraction (α)	0.631
Prefactionator (SEC-2)	
Number of stages	24
Feeding step	13
Feed flow kmol / s	1
Diameter, m	5.63
Main column	
Number Plates	44
Liquid feed step	12
Stage steam feed	37
Output stage sidestream	25
Diameter SEC 1 and 3 m	7.23
Diameter SEC 4, m	4.53
Reflux ratio, kmol / s	0.6672
Bottom pressure, kPa	67.89
Pressure in the dome, kPa	37.49
Heat input to the reboiler, 106	127.24
Stage efficiency,%	100

Table 1 Parameters of the column

Considerations in the design of the control

This paper considers the temperature of step 1 (T1) as the controlled variable, and the heat rate (QR) as the manipulated variable. (Ts) Is the temperature of any stage of the section corresponding to section 1 of Figure 1b exhaustion. Assume that Ts is measured without delay and temperature of step 1 (T1) is measured with θ> 0 delay, so T1 and Ts are the primary and secondary measuring respectively the temperature-cascade control temperature.

For control design, we consider input-output models of first order plus delay, calculated from the response to a step change in the rate of heat:

$$\frac{T_1(s)}{QR(s)} = G_{QRT_1}(s) = \frac{K_{QRT_1}}{\tau_{QRT_1}s+1}\exp\left(-\theta_{QRT_1}s\right) \quad (1)$$

$$\frac{T_s(s)}{QR(s)} = G_{QRT_s}(s) = \frac{K_{QRT_s}}{\tau_{QRT_1}s+1} \quad (2)$$

where s = d / dt is the Laplace variable, K is the gain, τ is the time constant and θ> 0 is the delay due to the measurements and internal transport.

Cascade control design

This section backstepping approach to design cascade controller temperature-temperature applies (see Figure 2) in order to counteract the non-linearities. This is accomplished through the use of virtual or passive inputs. Once the design is applied to a stage, this is recursive with the other steps until the actual control input. The cascade control structure is composed of two controllers with feedback where the output of the primary control or master changes the reference point of the slave or control. The output of the secondary control directly affects the final control action. The primary controller is governed by temperature measurement in stage 1 of the column, T1, and calculates the required temperature in the stripping section Ts considered as a virtual controller. In the secondary controller the primary controller provides the reference temperature, Ts, ref, where the manipulated input is the rate of heat, QR.

For the design of the controller is used the method steps tuned Internal Model Control (Skogestad, 2003). For a PI controller, these parameters are the gain Kc controller, and integral time constant τI. These tuning steps are relatively simple analytical rules used to calculate the parameters of the controller in accordance with the following equations:

$$K_c = \frac{1}{K}\frac{\tau_1}{2\theta} \qquad y \qquad \tau_I = \min(\tau_1, 8\theta) \tag{3}$$

Where K, τ_I and θ are the process gain, time constant and downtime respectively, obtained in the characterization of the dynamic behavior.

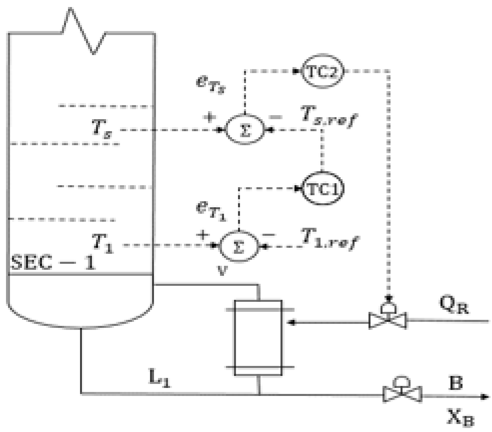

Figure 2 Structure of backstepping control the stripping section

Design of the primary controller

The function of the primary loop is to regulate the temperature of step 1, T1, through manipulation of the temperature of the stripping section Ts. For the model input (Ts) -output (T1) combining Eqs. 1 and 2 thus have:

$$G_{T_s,T_1}(s) = \frac{G_{QR,T_1}(s)}{G_{QR,T_s}(s)} = K_{T_s,T_1}\left(\frac{\tau_{QR,T_s}s+1}{\tau_{QR,T_1}s+1}\right)\exp(-\theta_{T_s,T_1}s) \tag{4}$$

Where $T_{Ts,T1} = K_{QRT1}/\ K_{QRTS}$. For close to steady state conditions:

$$G_{T_s,T_1}(s) \approx K_{T_s,T_1}\exp(-\theta_{T_s,T_1}s) \tag{5}$$

$T_{s,ref}$ is taken instead of the deviation temperature Ts, so that the model for calculating the primary controller is:

$$G_{T_{sref},T_1}(s) \approx K_{T_{sref},T_1}\exp(-\theta_{T_{sref},T_1}s) \tag{6}$$

From Eq. 6 shows the tuning parameters for the primary controller which is kind Proportional-Integral (PI) and operates under the expression described are calculated in Eq. 7

$$T_{s,ref} = T_{s,nom} + K_c\left(\left(T_{1,ref} - T_1(t)\right) + \frac{1}{\tau_I}\int_0^t\left(T_{1,ref} - T_1(t)\right)dt\right) \tag{7}$$

Where $T_{1,ref} - T_1(t) = e_{T1}$ is the error of temperature on dish 1 (bottom).

Design of the secondary controller

Once built the primary to regulate the bottom temperature by manipulating the trajectory $T_{s,ref}$ plate measured temperature, the controller design objective is to obtain a secondary controller driver manipulates the heat rate so that the temperature fit the set-point variation in the time $T_{s,ref}$ provided by the primary controller. The controller design is based on Eq. 2. The corresponding PI controller is given by Eq. 8, wherein the error calculated by the temperature difference described in Eq. 9

$$QR = \overline{QR}_{nom} + K_c\left(e_{T_s} + \frac{1}{\tau_I}\int_0^t e_{T_s}\,dt\right) \tag{8}$$

$$e_{T_s} = T_{s,ref} - T(t) \tag{9}$$

Integral Performance Criterions

To evaluate the performance of the proposed control structure is introduced to the system a disturbance in the feed composition in order to observe the response of the controller in the temperature control selected plate SEC-1 which indirectly controls the compositions of the final products.

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The dynamic behavior of the error control system is commonly used as a design criterion for tuning PI controllers. The criteria used in this study to measure the performance of the controller was integral absolute error criterion IAE and thus the absolute error of temperature (IAET) and composition (IAEC) (Eq. 10 is obtained and 11).

$$\mathrm{IAET} = \int_0^t [\mathrm{T}_{1,\mathrm{ref}} - \mathrm{T}_1(\mathrm{t})]\mathrm{dt} = \int_0^t \mathrm{e}_{\mathrm{T}_1}\,\mathrm{dt} \quad (10)$$

$$\mathrm{IAEC} = \int_0^t [0.99 - \mathrm{X}_B(\mathrm{t})]\mathrm{dt} = \int_0^t \mathrm{e}_{\mathrm{X}_B}\,\mathrm{dt} \quad (11)$$

Results

In this section the results of the effect of the location of the secondary controller of temperature on the performance of the temperature control back of a CPD and regulating the composition of the bottom product are presented. And parameters characterizing the dynamic behavior of the dividing wall column by a step change in the rate of heat are present, the effect thereof on the temperature of the dishes and on the composition of o-xylene was evaluated. In addition the effect of the location of the temperature measurement on the ability of regulating a cascade control structure in the presence of disturbances in the feed composition is studied.

The step changes ± 1% in heat rate (QR) transfer functions presented in equation (12) were obtained - (19).

$$\frac{\mathrm{T}_1}{\mathrm{QR}} = \mathrm{G}_{\mathrm{T}_1,\mathrm{QR}}(\mathrm{s}) = \frac{(1.19413)\mathrm{e}^{0.17711\mathrm{s}}}{3.55441\mathrm{s}+1} \quad (12)$$

$$\frac{\mathrm{T}_2}{\mathrm{QR}} = \mathrm{G}_{\mathrm{T}_2,\mathrm{QR}}(\mathrm{s}) = \frac{(2.16622)\mathrm{e}^{0.14963\mathrm{s}}}{3.56565\mathrm{s}+1} \quad (13)$$

$$\frac{\mathrm{T}_3}{\mathrm{QR}} = \mathrm{G}_{\mathrm{T}_3,\mathrm{QR}}(\mathrm{s}) = \frac{(3.56539)\mathrm{e}^{0.11713\mathrm{s}}}{3.5619\mathrm{s}+1} \quad (14)$$

$$\frac{\mathrm{T}_4}{\mathrm{QR}} = \mathrm{G}_{\mathrm{T}_4,\mathrm{QR}}(\mathrm{s}) = \frac{(5.29313)\mathrm{e}^{0.07963\mathrm{s}}}{3.66313\mathrm{s}+1} \quad (15)$$

$$\frac{\mathrm{T}_5}{\mathrm{QR}} = \mathrm{G}_{\mathrm{T}_5,\mathrm{QR}}(\mathrm{s}) = \frac{(6.89026)\mathrm{e}^{0.04214\mathrm{s}}}{3.80186\mathrm{s}+1} \quad (16)$$

$$\frac{\mathrm{T}_7}{\mathrm{QR}} = \mathrm{G}_{\mathrm{T}_7,\mathrm{QR}}(\mathrm{s}) = \frac{(7.53903)\mathrm{e}^{0.4308\mathrm{s}}}{4.3080\mathrm{s}+1} \quad (17)$$

$$\frac{\mathrm{T}_8}{\mathrm{QR}} = \mathrm{G}_{\mathrm{T}_8,\mathrm{QR}}(\mathrm{s}) = \frac{(6.30117)\mathrm{e}^{0.45667\mathrm{s}}}{4.56672\mathrm{s}+1} \quad (18)$$

$$\frac{\mathrm{T}_9}{\mathrm{QR}} = \mathrm{G}_{\mathrm{T}_9,\mathrm{QR}}(\mathrm{s}) = \frac{(4.57376)\mathrm{e}^{0.47617\mathrm{s}}}{4.76171\mathrm{s}+1} \quad (19)$$

When designing the seven control loops that regulate the temperature of the dishes, according to the procedure described in Section 4 parameters that characterize it obtained. The results of this characterization are shown in Table 2.

In Table 3 the three disturbances introduced to the system and consisted of changing the feed composition to analyze the behavior of each of the control structures shown in closed loop.

In Table 4 the results of the integral of absolute error of temperature (IAET) and composition (CDAI) are shown, along with the values of settling times each controller. Table shows that the ECC ECC T1-T2 and T1-T3 were the presetaron better performance, however, the settling time is greater in these two structures, diminishing as the secondary controller is located at higher stages.

In Figure 3 the response of the three structures having the best performance in the temperature control plate 1, it is observed that despite the disruption the composition is maintained above 99% purity is shown.

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Cascade control structure	Primary controller	
	K_c(°F/(Btu/h)$^{-1}$)	τ_I(h)
T_1-T_2	0.55125	2.66861
T_1-T_3	0.33492	1.06707
T_1-T_4	0.33157	0.53353
T_1-T_5	0.32487	0.44817
T_1-T_7	0.32153	0.40546
T_1-T_8	0.31818	0.37348
T_1-T_9	0.30478	0.41082
	Secondary controller	
	K_c(°F/(Btu/h)$^{-1}$)	τ_I(h)
T_1-T_2	5.50011	1.19708
T_1-T_3	4.26438	0.93708
T_1-T_4	3.83795	0.91833
T_1-T_5	2.98507	0.89866
T_1-T_7	3.71001	0.89584
T_1-T_8	4.05117	0.81525
T_1-T_9	3.28358	0.89491

Table 2 Parameters of the cascade controller

	P 1	P 2	P 3
Time, h	20	60	100
composition% mol	30/35/35	30/30/40	35/30/35

Table 3 Disturbances in the system for each cascade control structure

Cascade control	IAET	IAEC	Settling Time (hr)
ECC $T_1 - T_2$	2.212	0.17667	114.323
ECC $T_1 - T_3$	3.162	0.10776	111.542
ECC $T_1 - T_4$	3.772	0.12599	89.023
ECC $T_1 - T_5$	5.925	0.16901	93.884
ECC $T_1 - T_7$	10.47	0.23618	93.646
ECC $T_1 - T_8$	10.48	0.26196	79.817
ECC $T_1 - T_9$	11.71	0.27630	70.374

Table 4 Comprehensive error and settling time

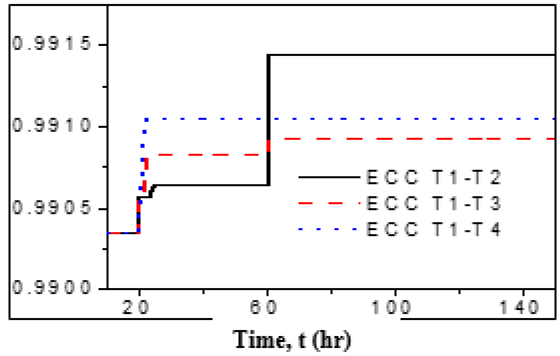

Figure 3 Performance of the composition of o-xylene to disturbances in the feed composition

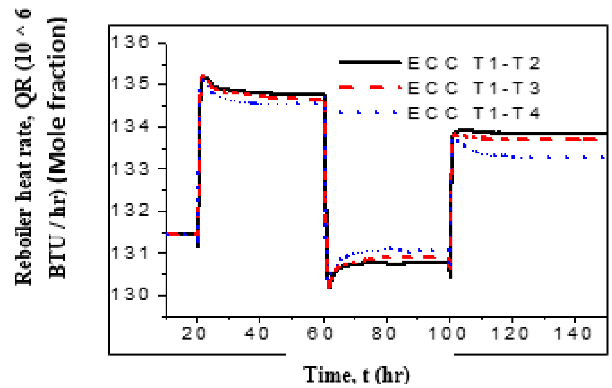

Figure 4 Response of heat rate to disturbances in the feed composition

In Figure 4 the response of the rate of heat showing the response to reach the steady state occurs, this agrees with the results presented in Table 4, and that the more rapid the rate response time heat settling the temperature of step 1 decrease.

In Figures 5 and 6 the temperature response on the plate 1 of the structures of ECC T1-T2 and ECC T1-T3 control performed better shown, therein it is seen that by introducing our controller proposed in the presence of disturbances, you come to regulate the temperature of the plate 1 by deleting mistakes and reaching the setpoint again. It is also noted that the oscillations decrease when the secondary controller is positioned in upper stages of the stripping section.

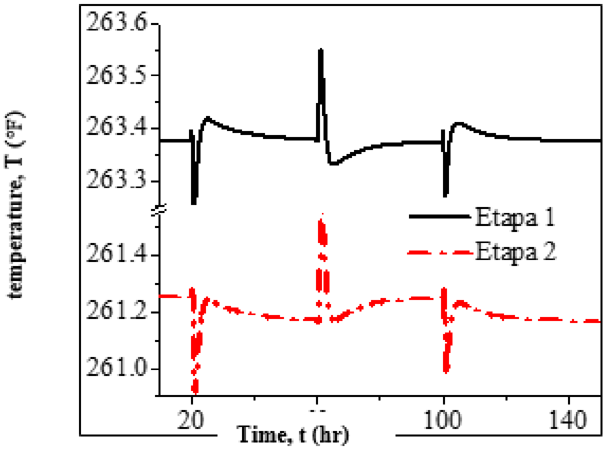

Figure 5 Response ECC temperature T1-T2

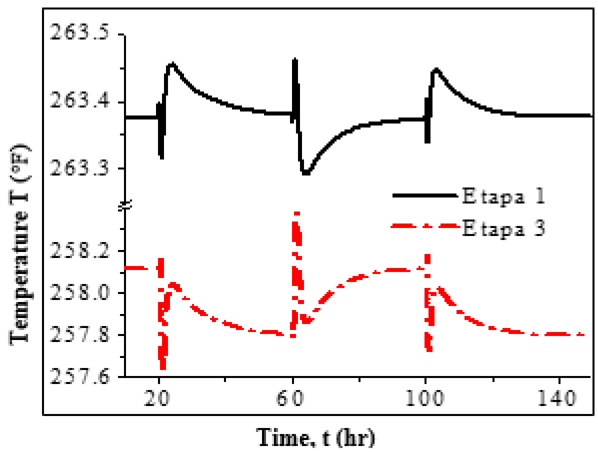

Figure 6 Response of the temperature of the ECC T1-T3

Conclusions

Using the Backstepping principle in cascade, which was taken as reference temperature of step 1 (background) corresponding to the primary controller and selecting different than the latter (step 2, 3, 4, 5, 7, 8, 9) stages wherein the secondary controllers for measuring corresponding temperatures, as an indirect measure of the composition regulated by the rate of heat was observed were located that its location has a significant effect in controlling the composition of o-xylene. The use of these controllers in different stages of the grinding part allows to keep the composition of o-xylene above 99.0% purity, from disruption in the feed composition.

From the results it can be seen that the performance will improve as the secondary controller is close to Stage 1 where it aims to keep its temperature setpoint, however, the settling time is greater. This drawback can be reached to improve with the help of a controller designed under the same backstepping approach in the rectifying section, reaching steady state and getting shorter settlement.

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