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PROPYLENE DISTILLATION COLUMN COMPOSITION CONTROL

ŘÍZENÍ PROPYLENOVÉ DESTILAČNÍ KOLONY

Abstract

In petrochemical industry, distillation columns are great energy consumers, their consumption usually representing more than 40% of total plant consumption. Therefore, the investigation of these columns is an important tool in finding solutions to this problem. This paper presents the results of simulating the propylene separation process when best control configuration is used. First a simplified model of the propylene/propane distillation column (PPDC) is proposed. A decoupler is designed for the chosen configuration. Also, a multivariable internal model control (IMC) system is designed and applied to ideal PPDC. Simulation results prove that IMC controller can deal with the interactive nature of ideal PPDC more effectively than PI controllers, indicating that the IMC controller could provide a better solution for ideal PPDC if high control performance is required.

Abstrakt

V petrochemickém průmyslu destilační kolony jsou velkými spotřebiteli energie, jejich spotřeba představuje obvykle více než 40 % celkové spotřeby podniku. Výzkum těchto kolon je tedy důležitým nástrojem pro nalezení řešení tohoto problému. Tento příspěvek presentuje výsledky simulace procesu separace propylenu, kdy je používána nejlepší konfigurace řízení. Nejdříve je navržen jednoduchý model propylenové/propanové destilační kolony (PPDC). Pro danou konfiguraci je navržen kompenzátor (korekční člen) zajišťující autonomnost. Pro ideální PPDC je také navrženo mnohorozměrové řízení s vnitřním modelem (IMC). Výsledky simulace potvrdily, že regulátory IMC jsou schopny poradit si se vzájemnými interakcemi ideálních PPDC efektivněji než PI regulátory a ukazují, že IMC regulátory mohou zajistit lepší řešení, pokud je vyžadován vysoký výkon.

1 INTRODUCTION

The propylene-propane distillation column is part of catalytic cracking unit, from hydrocarbon distillation plant. The goal of the plant is to recover as much $C_3 - C_4$ fractions as possible from FCCU rich gas and gasoline. The PPDC is one of the final columns with valuable products and 0.90-mole fraction purity is required in distillate product.

The control structure for PPDC can be chosen following steady state and dynamic criteria. The steady state RGA criterion leads to the results presented in Table 1. The best configurations from RGA point of view are DL/B, DV/B and SV/B. LV configuration leads to a gain greater than 20 which makes this structure not suitable for controlling PPDC [2], [3].

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Tab. 1 Steady state RGA

Λ_{DV}	$\Lambda_{DL/B}$	$\Lambda_{DV/B}$	Λ_{LD}
0.841	1.019	1.042	0.165
Λ_{LV}	$\Lambda_{LL/B}$	$\Lambda_{LV/B}$	Λ_{SD}
20.831	0.910	0.828	0.241
Λ_{SV}	$\Lambda_{SL/B}$	$\Lambda_{SV/B}$	Λ_{DS}
2.435	0.942	1.010	0.758

The dynamic criteria must be used, as well. In PPDC case, dynamic behavior was the best criterion for this selection. The selected structure was SV/B (see Figure 1); it has the smallest effect on products composition for changes in feed rate, which is the most frequent disturbance for PPDC [3].

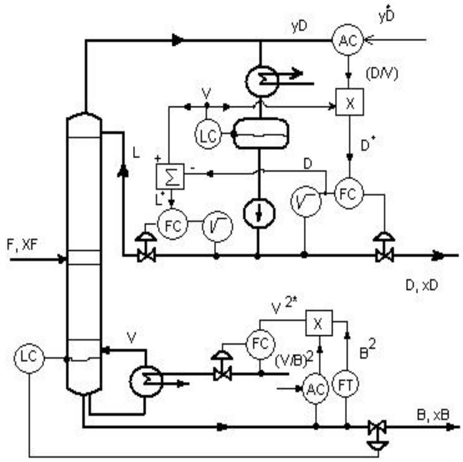

Fig. 1 SV/B structure

The structure has the advantage of a faster dynamic response of bottom composition control and $\Lambda_{SV/B}$ is smallest within larger than 1 relative gains. From accuracy point of view, the best manipulated variable for distillate composition control is D/V .

2 THE PROPOSED CONTROL SYSTEM

The simulations for ideal PPDC were made using a simplified model from [6]. The model has 140 states, but it can be reduced to about 20 states without any noticeable difference in the response. Small changes in operating conditions allow the use of a linearized model.

Although the SV/B configuration has the biggest decoupling feature, a decoupler must be designed in order to improve control performances. The decoupling problem is solved by compensating the effects of two parallel-opposite channels, with the same gain, deadtime and almost equal transient time, expressed by relations [4]:

$$\begin{aligned} 4T_{11} + T_{t21} &= 4T_{21} + T_{t22} \\ 4T_{22} + T_{t12} &= 4T_{12} + T_{t11} \end{aligned}, \qquad (1)$$

where: T_{ij} – decoupler time constants.

After identification, the following parameters (gain c_{ij}, deadtime τ_{dij}, transient time T_{tij}) for each input output channel will be used to design the associated decoupler:

$$\begin{bmatrix} (0.9,\,7\,\text{min},120\,\text{min}) & (-0.76,\,8\,\text{min},\,400\,\text{min}) \\ (0.2,\,9\,\text{min},\,300\,\text{min}) & (-0.83,\,7\,\text{min},\,400\,\text{min}) \end{bmatrix} \quad (2)$$

with $[L/D \quad V/B]'$ as inputs, $[x_D \; x_B]'$ as outputs.

The resulted decoupler has the following structure

$$D(s)=\begin{bmatrix} \dfrac{1}{T_{11}s+1} & \dfrac{k_{12}e^{-\tau_{12}s}}{T_{12}s+1} \\ k_{21}e^{-\tau_{21}s} & 1 \end{bmatrix}, \quad (3)$$

where decoupler gains are calculated with

$$\begin{aligned} k_{12} &= -c_{12}/c_{11} = 0.76/0.9 \\ k_{21} &= -c_{21}/c_{22} = 0.2/0.83 \end{aligned}. \quad (4)$$

The new decoupled process will have the following steady state gains:

$$\begin{cases} K_{pm1} = c_{11} + k_{12}c_{21} = c_{11} - \dfrac{c_{12}c_{21}}{c_{22}} \cong 0.72 \\ K_{pm2} = c_{22} + k_{21}c_{12} = c_{22} - \dfrac{c_{12}c_{21}}{c_{11}} \cong -0.66 \end{cases}. \quad (5)$$

This leads to a simpler design of multivariable IMC controller that consists of the decoupler and two monovariable IMC controllers (for the two distinct product composition control loops). The decoupled process contains the PPDC, the decoupler, all valves and composition transducers. The transfer matrix of decoupled process is:

$$HD(s)=\begin{bmatrix} \dfrac{K_{pm1}e^{-T_{d1}s}}{(T_{2m1}s+1)^2} & \cong 0 \\ \cong 0 & \dfrac{K_{pm2}e^{-T_{d2}s}}{(T_{2m2}s+1)^2} \end{bmatrix}. \quad (6)$$

The model (6) will be used to design the IMC controllers. If the model describes perfectly the real process dynamics, the command has a step evolution, and the variation form of controlled variable is similar to the step response of the process [1]. An IMC controller has the transfer function:

$$H_{RS}(z) = \frac{K_R}{K_{pm}} \frac{1-2pz^{-1}+p^2z^{-2}}{1-2pz^{-1}+p^2z^{-2}-(1-p)^2 z^{-l_m-1}} \quad (7)$$

where: $p = e^{\frac{-T}{T_{2mi}}}, i=\overline{1,2}$, $\tau_{pi} = l_{mi}T$, T – sample time.

3 SIMULATION RESULTS

The decoupler with the structure from (3) and the parameters from (4) improves decoupling features of $L/D - x_D$ and $V/B - x_B$ channels as shown in Figure 2. The PPDC model without decoupler has the coupling coefficient CC:

$$CC = \frac{c_{12}c_{21}}{c_{11}c_{22}} \cdot 100 = 20.34\%\,, \quad (8)$$

where c_{ij} are process gains. The decoupler will reduce these coupling features to the value:

$$CC' = \frac{K_{pm12} K_{pm21}}{K_{pm1} K_{pm2}} \cdot 100 = 1.03\% . \quad (9)$$

The decoupled process is sensitive to very large input changes, but it performs well for medium input changes.

Decoupling operation quality can be experimentally validated through the suitable tuning of decoupler parameters, especially of the two lag time constant.

Tuning multivariable IMC controller is reduced to tuning two distinct monovariable composition control loops. The composition analyzer imposes sample time of the system (5 min) (Figures 3 and 4).

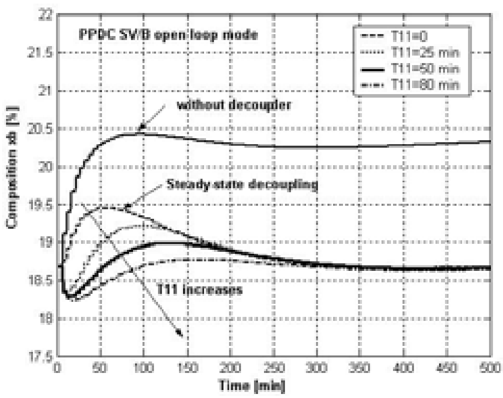

Fig. 2 SV/B open loop mode: the x_B composition changes to 5% increase of manipulated variable for x_D (c_1, L/D)

The IMC controller has three model parameters (the gain K_{pm}, the deadtime τ_d and the time constant T_{2m}) and one tuning parameter (the gain K_R). The increase/decrease of model gain leads to the decrease/increase of the command intensity that is made by the increase/decrease of gain K_R.

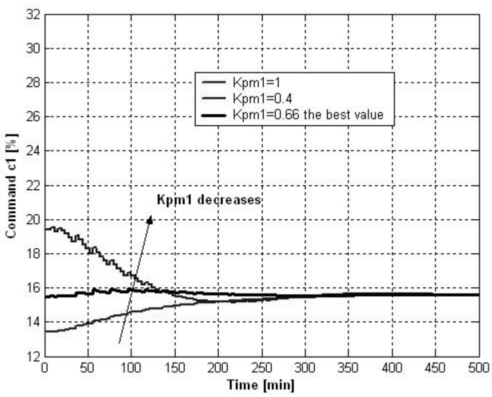

Fig. 3 K_{pm1} tuning of IMC1: c_1 response to a 0.02 mole fr. step increase of x_D setpoint

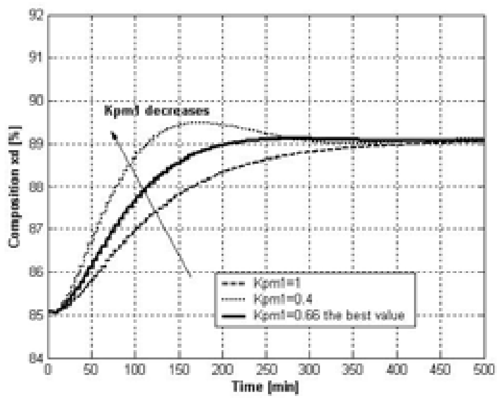

Fig. 4 K_{pm1} tuning of IMC1: x_D response to a 0.02 mole fr. step increase of x_D setpoint

The standard value $K_R = 1$ of IMC algorithm does not provide special dynamic performance, but a relatively simple and robust control ($K_{R1} = K_{R2} = 1$ were used). As stated before, if the model perfectly describes the real process dynamics, the command has a step evolution, and the variation form of controlled variable is similar to the step response of the process (Figures 3 and 4). This is the main idea in tuning this controller.

The best tuning parameters obtained for composition controllers were:

$$\begin{aligned} &IMC1: K_{R1} = 1, K_{pm1} = 0.66, T_{2m1} = 45 \text{ min}, T_{m1} = 7 \text{ min} \\ &IMC2: K_{R2} = 1, K_{pm2} = -0.9, T_{2m2} = 35 \text{ min}, T_{m2} = 7 \text{ min} \end{aligned} . \quad (8)$$

IMC performance is compared to PI one as shown in Figures 5 and 6. Composition control loops usually use PI algorithm; the output signal generated by composition analyzer is step type (if PID algorithm is used this signal should first be filtered with a second order lag element).

The best tuning parameters for PI controllers are $k_P = 1, T_i = 50 \text{min}$.

As shown in Figure 5, IMC responds better than PI to a x_D setpoint change (any product composition bellow setpoint specification means loss).

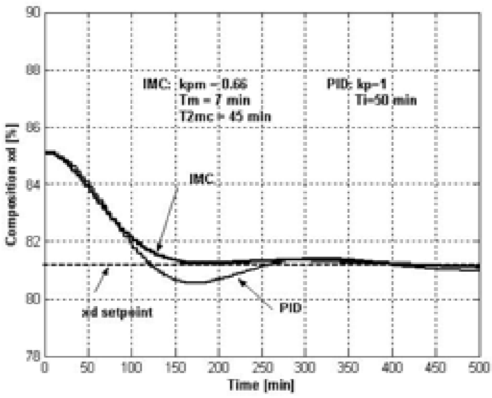

Fig. 5 IMC/PI: x_D response to a 0.02 mole fr. step decrease of x_D setpoint

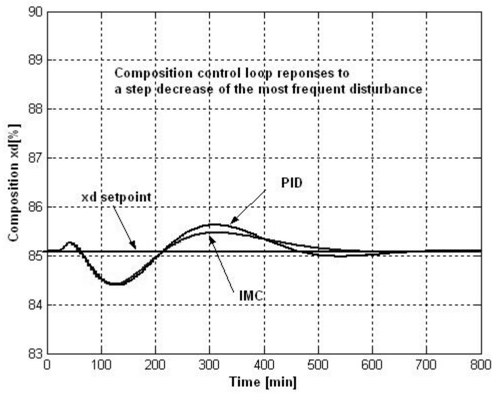

Fig. 6 IMC/PI: x_D response to a step decrease of F feed flowrate

As for x_D response to a change of the main disturbance, the feed flowrate F it can be stated that IMC has a better response than PI (the gain response for IMC is slightly smaller than PI one).

4 CONCLUSIONS

An appropriate structure for a reduced-order model of transfer function type is first proposed for an ideal propylene/propane distillation column (PPDC) based on the process dynamics. The reduced-order model could well represent the process not only in steady state but in dynamic state as well.

A multivariable internal model control (IMC) system is designed and applied to the ideal PPDC. The multivariable IMC controller consists of a decoupler and two monovariable IMC controllers. One of the important advantages of using decoupler is that tuning multivariable IMC controller is reduced to tuning two distinct IMC monovariable composition control loops. The decoupler improves decoupling features of SV/B configuration for PPDC, which is the best control configuration (from RGA and CLDG criteria).

The simulation results demonstrates that the IMC controller can deal with the interactive nature of the ideal PPDC more effectively than PI controllers, indicating the IMC controller could be a better solution for the ideal PPDC operation in cases where high system performance is required. However, the ideal PPDC is extremely sensitive to great changes in operating conditions and this makes it necessary to adopt an online model adaptation mechanism.

An appropriate approach for highly non-linear distillation columns is the use of logarithmic compositions, which makes the response of distillation columns more linear [5].

Nevertheless, for medium changes in operating conditions IMC controllers perform better than PI controllers.

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