Pilot Plant for Testing Control Configurations of Binary Distillation Columns

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Control structure design deals with the structural decisions of the control system, including what to control and how to pair the variables to form control loops. Although these are very important issues, these decisions are in most cases made based on experience and engineering insight, without considering the details of each problem. The paper addresses the problem of testing various control configurations for binary distillation columns (BDC). In this case the first thing to do is to select the best control configuration from plantwide control criteria. The proposed application Test BCC is a very useful tool to evaluate the resulted control configuration for distillation columns. This works within a pilot plant that can test simulated or real distillation column through DAQ modules. Other issues, discussed in the paper, include two-point composition control problem with a multivariable controller composed by a parametric decoupler and two monovariabile PI controllers. A practical example is used to demonstrate the pilot plant efficiency, identifying the best control configurations from potential structures. The limits of this approach for control configuration selection are also analyzed. The results in studying distillation column dynamics show the improved efficiency of proposed pilot plant over the previous schemes.

Keywords: plantwide control, integrated design and control of chemical processes

For the last 20 years, the problem of plant-wide industrial process control represents a main concern of the engineering process scientists and among these researches it is emphasized a new research direction in chemical process control field the so called integrated design and control of chemical processes [1-4]). The increasing use of multiple materials recycles along with complex energy management networks led to more integrated chemical plants. The complexity increase had the following results: increased difficulties in isolating the effects of each unit control and the increase of the conflicts among the individual control structures [5-8]. The goal of plantwide control studies is to design a control system that can achieve the operating requirements of the complete plant optimal conditions [9]. The problem focuses on the whole plant and not only on process units. The main problem in plantwide control study is the presence of recycle streams that provide interactions between different equipments. Disturbances that enter a process can propagate not only downstream from one unit operation to the next, but upstream through material and energy recycle loops [10, 11].

Plantwide control does not mean the tuning and studying the behavior of each of these loops; it corresponds to the control philosophy of the overall plant with emphasis on the structural decisions [5, 12]. The use of an effective plantwide control structure may lead to a significant reduction in the size of these intermediate inventories or possibly their elimination from plant design [13, 14]. Luyben and his coworkers [6] have provided a set of guidelines that enable the user to develop a plantwide structure that provides tight and effective control for some chemical processes. Arkun and Stephanopoulos have dealt with the problem of how one can systematically synthesize plantwide control architectures from steady-state process models with use of optimization. Results for the application of the synthesis procedure to the Tennessee Eastman process are presented [8, 11, 14].

Stephanopoulos and Ng [8] provided a comparative analysis of various approaches emphasizing some practical issues associated with the design of plantwide control.

Vasbinder and Hoo [9] described a modular decomposition of plant flowsheets that is assessed according to a decision-based approach to plantwide control structure synthesis.

Many works in the open literature present studies on modeling and control of the separation task from process unit approach [15-20]), but relatively few publications are found out concerning the plantwide control approach for a complex separation unit (formed by interconnected distillation columns). The objectives of this paper are the presentation of the proposed pilot plant that allows the testing and generating the best control structure for binary distillation columns and simulating it on the separation part of the FCCU (also called GPU – Gas Processing Unit).

By its topics, this paper is situated in the framework of general effort to develop modern techniques of plantwide control design for distillation plants.

Pilot plant

The proposed pilot plant must take into account the possibility of studying binary distillation column from plantwide control criterion and also of finding the best control configuration from its control dynamics.

One of the solutions proposed in order to find the best control configuration was the unit-based approach: the plant is decomposed into individual operation units, it is generated a best control structure for each unit, all these structures are combined in order to form a complete one for the entire plant and the conflicts among the individual control structures are eliminated by means of mutual adjustments. In plantwide based methods, the entire plant is the object of study at every step of the synthesis

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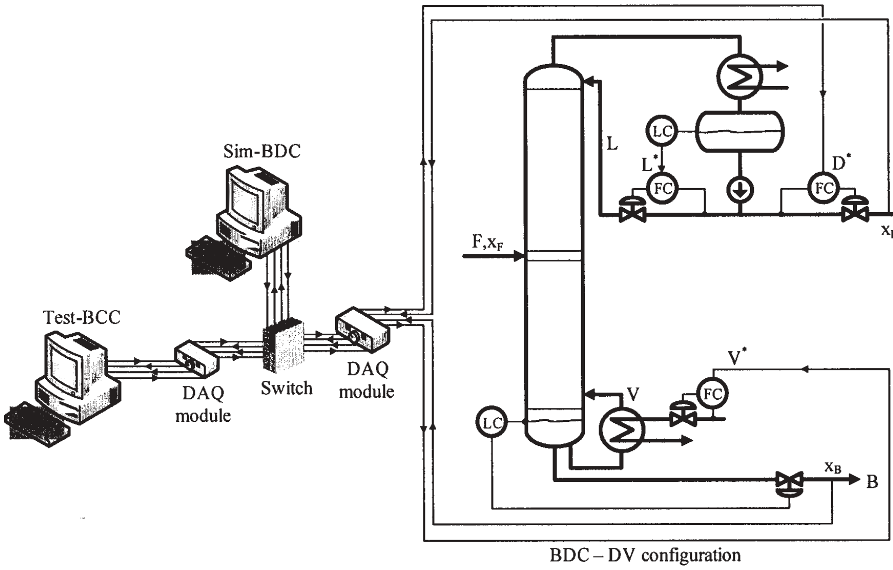

Fig. 1. Pilot plant structure

procedure. After establishing the best control configuration structure, it is necessary to test this configuration among many others [21-24].

The starting point is implementing at a minimum functional level the working framework to develop the application of generating the best structure. This means the design of these basic components: simulation module of binary distillation columns Sim BDC, the simulation module of decoupling control composition loops, and the composition control modules.

Next, the hardware implementation requires the use of data acquisition modules. In this case, the proposed application Test BCC works with two KUSB 3100 serial interface from Keithley Instruments. One interface is used to acquire/generate the data from/to the real BDC (on line mode) and the other to do the same with the simulated column (off line mode).

The off line mode is very useful for testing the behavior of the binary distillation column, because the results are obtained much faster than from real column. The resulted pilot plant configuration that runs Test BCC application is presented in figure 1. The PI monovariable controllers modules contains a user interface that allow tuning the K_p and T_i parameters. First the decoupler parameters are tuned, after that the task of tuning the multivariable controller is much simpler, the 2 monovariable controllers being tuned as for two separate SISO control loops.

After a thoroughgoing study on mathematical formalism used for distillation columns the result is a distillation model suited for control purposes. This model is resulted after studying the dynamic behavior of distillation columns with different control configuration using Dynsim® and Aspen Hysys® environments and it is used in Sim BDC module.

The proposed method takes into account the place of the studied distillation column. Distillation columns usually take part into a large complex formed by other process unit. From this point of view we can characterize a distillation column as the first process unit, intermediate or final distillation column. An intermediate column influences downstream units if there are no recycle streams; otherwise it has effects on both downstream and upstream unit.

Final columns do not disturb any upstream or downstream unit. From plantwide control strategy, there is no restriction imposed to this final column, the best control structure for it being generated by steady state criteria (e.g. RGA) usually combined with dynamic simulations with rigorous simulation tools.

The first distillation column is usually forced to refine the main flux formed by a mixture from which the final products of the unit will be recovered. The throughput manipulator place also influences the control decisions to be taken. The control structure chosen must have good features regarding the effect of the main disturbances that affect a distillation column, namely feed flowrate F and its composition x_F.

The simulation module of decoupling control composition loops, and the composition control modules have the structure from figure 2.

In order to design the decoupler, each input-output channel of the process must be characterized by three parameters, which are determined experimentally: the proportional gain $(K_p)_{ij}$, deadtime $(\tau_p)_{ij}$ and transient time $(T_t)_{ij}$:

$$\text{Process}: \begin{bmatrix} (K_{p11}, \tau_{p11}, T_{pt11}) & (K_{p12}\ \tau_{p12}, T_{pt12}) \\ (K_{p21}, \tau_{p21}, T_{pt21}) & (K_{p22}, \tau_{p22}, T_{pt22}) \end{bmatrix}. \qquad (1)$$

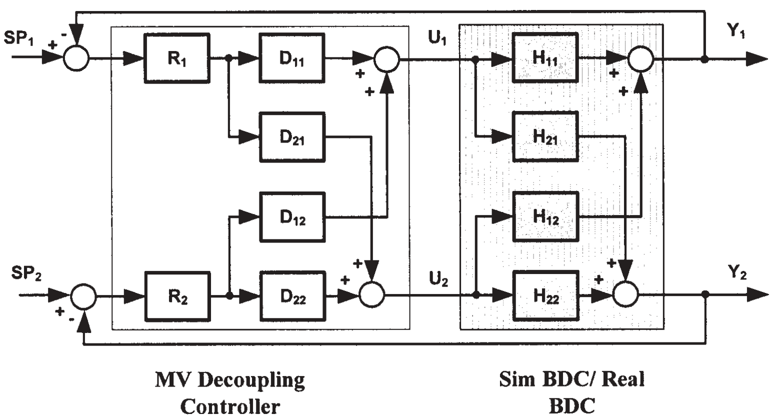

Fig. 2. The multivariable control structure

The decoupler has the following structure:

$$D = \begin{bmatrix} \dfrac{e^{-\tau_{11}s}}{T_{11}s+1} & \dfrac{k_{12}e^{-\tau_{12}s}}{T_{12}s+1} \\ \dfrac{k_{21}e^{-\tau_{21}s}}{T_{21}s+1} & \dfrac{e^{-\tau_{22}s}}{T_{22}s+1} \end{bmatrix}, \qquad (2)$$

where

$$k_{12} = -K_{p12} / K_{p11},\ k_{21} = -K_{p21} / K_{p22}. \qquad (3)$$

These features simplify the decoupler structure and lead to a decoupled process with faster dynamics. The decoupling problem is solved based on the idea of compensating the effects of two parallel opposite input-output channels, with almost the same proportional gains, deadtimes and transient times.

Case study

GPU consists of three distillation columns A, C, D and dehydrating column B that works out only if the raw material has important changes. The simulations of the separation unit were done using Dynsim® simulator. The transient times associated to these columns are about 600-700 min. For A (depropanizer), C (butane-butylene distillation column, BBDC) and D (propylene-propane distillation column, PPDC) the best control configurations were established taking into account their influences in the plant (plantwide control criteria).

The serial branch sequence of gas separation unit lead to the following control structures:

-for depropanizer column – LV structure with one point bottom composition control;

-for BBDC - SV/B structure;

-for PPDC - SV/B structure.

The BBDC and PPDC are final distillation columns that processes the most important products of FCCU. The SV/B structures associated to these columns do not influence any downstream units. The depropanizer column has as ends the distillate D that represents the feed for PPDC, and the bottom product B, that represents the feed for BBDC. Consequently, these two streams cannot vary too much in order not to upset downstream columns BB splitter and PP splitter that proved to be very sensitive to feed changes (in flowrate and composition, fig. 4). The external flows D and B will be used to inventory control loops. D is manipulated variable for depropanizer reflux drum level control and B is the manipulated variable for the depropanizer bottom level control. The level control loops uses PI controllers with weak integral component (k_p =1 and T_i =200 min), in order to minimize the effect on downstream units.

Test BCC offers the opportunity of studying the behaviuor of the column with several control configurations in offline mode (no composition control, one point control, two point control) and in online mode to the real distillation column. In figure 4 it is presented the behaviour of propane-propylene splitter in offline mode, two point control with 8 potential control configurations, to a step increase in feed flowrate (main disturbance).

Another important feature of Test BCC is the possibility to use a parametric decoupler in two point control mode (for the real or simulated distillation column).

For the studied column with SV/B structure the resulted decoupler has the structure

$$D_{C-a} = \begin{bmatrix} \dfrac{1}{T_{11}s+1} & \dfrac{k_{12}e^{-\tau_{12}s}}{T_{12}s+1} \\ k_{21}e^{-\tau_{21}s} & 1 \end{bmatrix}, \qquad (4)$$

with static parameters k_{12} = 0.84, k_{21} = 0.24, time constants T_{11} = T_{12} = 50 min and deadtimes τ_{12} = 1 min and τ_{21} = 2 min. The decoupling features of the process are improved about 20 times. The limit of this approach is the need of two composition analyzers that usually are expensive and

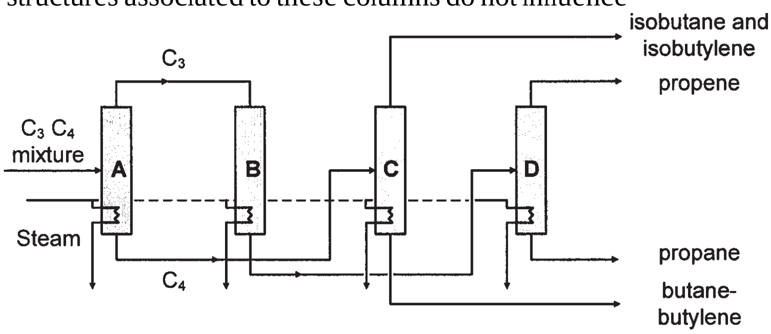

Fig. 3. Gas Separation subsystem

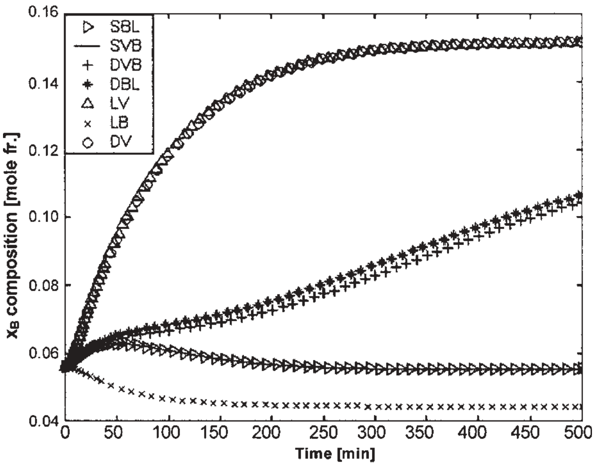

Fig. 4. The bottom composition response to a step increase in feed, open loop mode, PPDC case

used only on very important products (the case of propane propylene splitter). The future work will try to find an adequate inferential composition measurement from available tray temperature transducers and extending the use area of Test BCC to BDC without online composition measurement.

Conclusions

The paper addresses the problem of testing various control configurations for binary *distillation columns*. The proposed application works with two modes (on line and off line) each of them with the possibility to choose no composition control, one point composition control, two point composition control. In this case the first thing to do is to select the best control configuration from plantwide control criteria. The proposed application Test BCC is a very useful tool to evaluate the resulted control configuration for *distillation columns*. This works within a pilot plant that can test simulated or real distillation column through DAQ modules. The associated multivariable controller consisted of two PI feedback components and a parametric decoupler with 6 tuning parameters dependent on process features. The proposed application was tested within the GPU representative columns (e.g. propane-propylene splitter) matching or improving the behavior obtained with previous schemes.

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