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CONTROL STRUCTURE DESIGN FOR PARALLEL PROCESSES
Application to Heat-integrated Distillation

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Parallel process units are often encountered in chemical process systems for different considerations, e.g., parallel reactors from reactor network synthesis, parallel columns for heat integration. One notable example is the feed split configuration of heat-integrated distillation columns. In this work, the control of parallel processes is illustrated with the heat-integrated distillation column example. Results show that more consistent control performance can be achieved using the proposed control structure for both feed composition and feed flow disturbances. More importantly, the improvement is obtained using simpler instrumentation and much less engineering effort.

Keywords: heat-integration; distillation configuration; parallel process; control structure design.

INTRODUCTION

Parallel process units are often encountered in chemical process systems for different considerations, e.g., parallel reactors from reactor network synthesis, parallel columns for heat integration. On the production plant level, we have seen parallel production lines for the same product. On the unit operation level, one notable example is the feed split configuration of heat-integrated distillation column (King, 1980; Chiang and Luyben, 1983; Andrecovich and Westerberg, 1985) where the feed is splitted into two streams and are fed separately to two columns which are heat-integrated, theoretically 50% energy can be saved by parallelizing the process. This unique process configuration, in theory, will lead to somewhat different control structure design, because we are interested in the global product quality measure (instead of the local one). In other words, one should take advantage of the process configuration to devise simpler and yet effective control structure.

We have seen extensive literature on the design and control of heat-integrated distillation systems. Tyreus and Luyben (1976) examine the control issue of double-effect distillation and an auxiliary reboiler is suggested for improved control performance. Chiang and Luyben (1988) study the control for three different heat-integration configurations: feed-split, light-split forward (integration), and light-split reverse. They concluded that the light-split reverse is the most controllable scheme. Weitz and Lewin (1996) study the same system using the disturbance cost as a controllability measure and a similar conclusion is drawn. Wang and Lee (2002) explore nonlinear PI control for binary high-purity heat-integrated columns with light split/reverse configuration. Yang *et al.* (2000) use a simplified model derived from state space equations to evaluate disturbance propagation for double-effect column under feed-split configuration.

Interaction between design and control for heat-integrated and/or thermally coupled distillation systems are studied by Rix and Gelbe (2000) and Bildea and Dimian (1999) using dynamic RGA as a controllability measure. Lin and Yu (2004) explore the interaction between design and control for heat-integrated columns. However, few of these works take advantage of the parallel characteristic of the processes into account. That is, in control structure design, one should emphasize on the output of the entire system instead of the output of individual (parallel) unit. The objective of this work is to explore the design and control of parallel processes and it is illustrated using heat-integrated distillation columns with feed split (FS) configuration. The remainder of this paper is organized as follows. The Steady-State Design section describes the advantage of the heat-integrated configurations via quantitative analysis. The control structure design and controller design are presented in the Control section followed by rigorous nonlinear simulations for performance comparison. The conclusion is drawn in the final section.

STEADY-STATE DESIGN

Process Configuration and Design Procedure

At the steady-state design, a systematic procedure is employed to find the number of trays and feed tray location. For the single column configuration, initially the reflux

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ratio is set to 1.2 times of the minimum reflux ratio (RR_{min}), then the number of trays and feed tray location are found by tray-by-tray calculation until the specification is reached, followed by refining the reflux ratio to meet the exact product specifications. For the heat-integrated systems, three configurations are considered: (1) feed split (FS), (2) light-split reserve (LSR), and light-split forward (LSF). Figure 1 shows these three configurations where one column is pressurized and the high pressure column provides the heat to boilup the vapour in the low pressure column via condensation. Theses three configurations differ in the direction of material flow versus the direction of the heat-integration. Again, the '1.2 RR_{min}' criterion is used for the design of the heat-integrated column and 5% heat loss in the high pressure column is assume. That is heat transfer to the low pressure column via the heat exchange is limited to 95% of the heat of condensation in the high pressure column. Fifteen degrees of temperature driving force is assumed for heat transfer in all cases.

Steady-State Economics

Three systems are studied, they are: methanol–water, benzene–toluene, and isobutane–n–butane systems which correspond to high ($\alpha = 2.45–7.58$), medium ($\alpha = 2.35–2.65$), and low ($\alpha = 1.29–1.30$) relative volatilities, respectively. Table 1 compares the absolute energy consumption for these three chemical systems with three different feed compositions (of light component). The results show that percent energy saving ranges from 32–41% for the feed-split configuration, from 3–36% for the light-split forward configuration, and from 14–43% for the light-split reverse configuration. The percent of energy saving clearly reveals that the feed split configuration consistently provides economical incentives over the conventional single column configuration. However, the FS configuration show four product streams and, in the context of process control, this implies that we have a system with four controlled variables, quite possibly a 4×4 multivariable system. A possible tradeoff between steady-state economics and dynamical controllability may result as compared to the 2×2 multivariable system in the conventional configuration.

Table 1. Percentages of energy consumption (compared with the single column case as 100%) of various heat-integration configurations for different chemical systems with different feed compositions.

x_F	0.3	0.5	0.8
Methanol–water			
FS	68%	64%	62%
LSF	75%	67%	64%
LSR	70%	61%	57%
Benzene–toluene			
FS	66%	64%	61%
LSF	97%	81%	66%
LSR	86%	71%	59%
Isobutane–n–butane			
FS	60%	59%	59%
LSF	80%	75%	67%
LSR	77%	70%	60%

Figure 2 shows that the FS configuration is a typical parallel process where the products come from two parallel units and what we really care is the resultant composition after blending the product streams. That is, from a system perspective, we only need to control two product compositions, as opposed to the 4×4 control problem from the unit-wide perspective.

CONTROL

Nominal Operating Condition

A methanol–ethanol system is used to illustrate the control of heat-integrated system. The separation process separates 50/50 mixture of methanol and ethanol with top and bottom product specification of 99% methanol and 99% ethanol. All simulations were carried out using

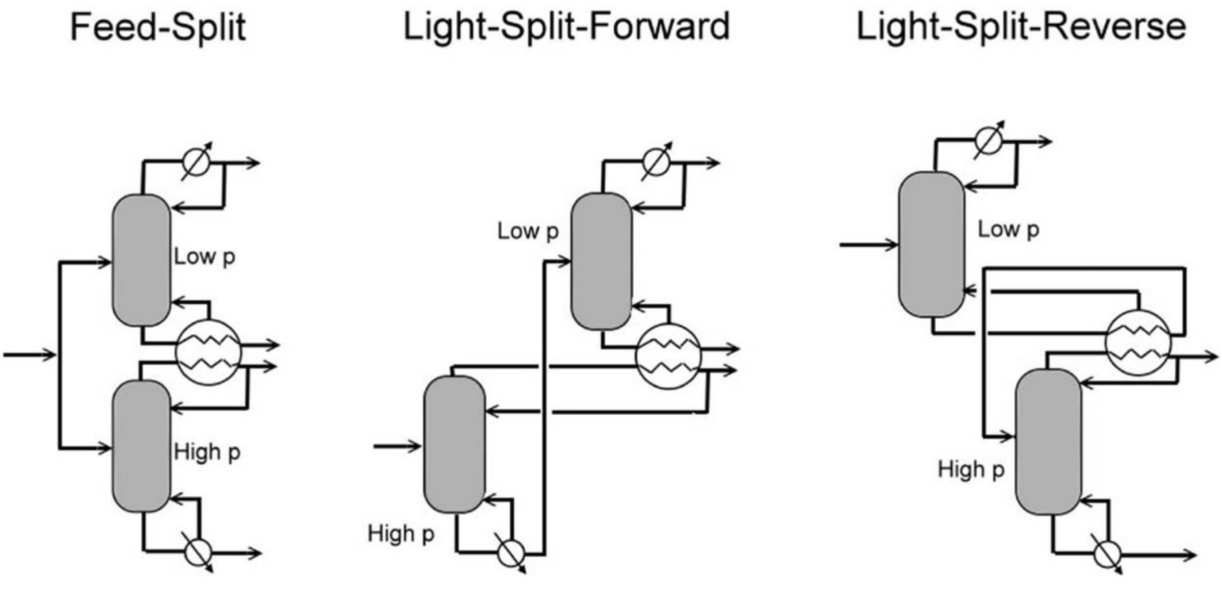

Figure 1. Three different heat-integration configurations.