Synthesis of Plantwide Control Structures Using a Decision-Based Methodology

by

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September 14, 2003

1 Introduction

Increased competitiveness in the chemical process industry has lead to the design of highly complex processes. The increased complexity has been justified on the bases of (i) improving energy recovery and unused raw materials, and (ii) reducing the environmental impact of the process. These tasks may be accomplished by additional and new equipment, or the incorporation of novel techniques. Inclusion of novel techniques, although very beneficial with regard to environmental, safety, and economic perspectives, may result in undesirable effects on the overall operation of the chemical process due to increased interactions among process variables. Consequently, the motivation to develop a control structure for the entire plant, rather than on a unit by unit basis, is justified.

Another driving force for a plantwide approach to control structure synthesis is the possibility of operating at states different from the original design conditions, for instance, when there are economic incentives. Thus, a unit-by-unit control structure developed for only the design (nominal) operating state may deter other operations and ultimately reduce profit. Research conducted over the last two decades has not resulted in a consensus on how best to address the plantwide control structure synthesis problem. This is in contrast to the design of a chemical plant where the acceptable methodologies are variations of the hierarchical structure developed by Douglas [1]. There are numerous contributions on the design of different control structures for a variety of unit operations. Thus, there is much to be garnered from these single unit operation control studies to address the larger issue of plantwide control, but they must be coordinated with the goals of the entire plant, and not just the control objectives of the individual units.

The chapter is organized as follows. Section 2 presents brief reviews of the hierarchical steady-state design structure and a particular plantwide control synthesis structure. Both have relevance to this work. The former because some of the plantwide control methods rely on this hierarchy, and the latter to complement the proposed approach. Section 3 begins with preliminaries that define the state of the process design flowsheet, the modified Analytical Hierarchical Process (mAHP) method used for assessment, and the process flowsheet decomposition approach. A description of a multivariable, nonlinear, process that produces benzene by hydro-dealkylation (HDA) of toluene [1] is provided in Section 4. The HDA process is used as the demonstration system because (i) it is

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well studied in the literature and (ii) there are published plantwide control structures to which the solution obtained here can be compared. Section 5 demonstrates the modular plantwide control structure development for the HDA process. Section 6 presents the results of the proposed procedures and methods to arrive at the plantwide control structure. A discussion that compares and contrasts this control structure to existing solutions is also provided. Lastly, Section 7 summarizes the findings and provides some recommendations.

2 Background

A traditional process design approach follows the hierarchical structure of Douglas [1], shown in column 2 of Table 1.

Table 1: A steady-state chemical process design hierarchy.

Layer	Task (Douglas) [1]	Task (Mann & Hoo [2])
1.	Batch/Continuous operation	Batch/Continuous operation
2.	Definition of input/output structure	Definition of input/output structure
3.	Design of recycle subsystem	Design of the chemical reactor subsystem
4.	Design of separator subsystem	Design of separator subsystem
5.	Energy Integration	Unit Integration a. recycle b. heat integration

The development of the process flowsheet begins with the determination of the type of process to be designed. Successive layers are then added to provide more details, leading to the final flowsheet that consists of all of the necessary process units and their connectionsto meet the steady-state design objectives. It is important to note that (i) design is a steady-state concept while control issues are dynamic in nature, and (ii) steps three and five are based solely on economics (maximize profits, minimize waste of raw material and energy, etc.) and not on operational or design considerations.

Also worth noting is that for chemical processes involving chemical reactions, the chemical reactor is the *heart* of the process and its operation affects the operation of other units (separation units, utility requirements, etc.) [3]. Therefore, the design of the chemical reactor should be a distinct step in the hierarchical design structure of chemical processes with chemical reactions. Recently, Mann and Hoo [2] have proposed a modified hierarchical structure, shown in colum 3 of Table 1.

The goal of plantwide control structure synthesis is to develop feasible control structures that address the objectives of the entire chemical plant and account for the interactions associated with complex recycle and heat integration schemes, and the expected multivariate nature of the plant. Many strategies have been proposed for accomplishing this task, and the majority of them have been demonstrated using dynamic process simulations. However, none have been accepted as the universal approach, in a manner similar to the steady-state process design synthesis hierarchy of Douglas [1].

The study of plantwide control dates back to 1964 when Buckley proposed that the control structure should be addressed on a plantwide basis, considering inventory first and than product quality [4]. Foss [5, 6] later followed by proposing that