Computers and Chemical Engineering 81 (2015) 138–146

Contents lists available at ScienceDirect

Computers and Chemical Engineering

journal homepage: www.elsevier.com/locate/compchemeng

Challenges and opportunities in integration of design and control

Jakob Kjøbsted Huusom *

CAPEC-PROCESS, Department of Chemical and Biochemical Engineering, Technical University of Denmark, Building 229, DK-2800 Kgs. Lyngby, Denmark

ARTICLE INFO

Article history:
Received 16 December 2014
Received in revised form 20 March 2015
Accepted 24 March 2015
Available online 4 April 2015

Keywords:
Process design
Process synthesis
Process control
Process integration

ABSTRACT

Process synthesis and design of plant operation are related topics but current industrial practice solves these problems sequentially. The implication of this sequential strategy may result in design of processing systems which are very hard to control. This paper presents a discussion on drivers for an integrated approach and outlines the challenges in formulation of such a multi-objective synthesis problem. This discussion is viewed in relation to some of the changing trends in the industry. Significant results have been published which in different ways seek to handle the integrated problem. Further, advancements in control algorithms and software have widened the range of feasible operation and control for strongly interconnected production systems. In light of these advances in different areas of the field, recommendations for further research and initiatives for development of an integrated approach are given with focus on how new results on the short term can improve industrial practice.

1. Introduction

Traditionally the process synthesis problem and the design of a strategy for process operation are performed subsequently in the development of a new production process. There are a number of valid reasons for this solution strategy, but as will be discussed here, there are advantages but also significant challenges in promoting an integrated approach. Fig. 1 depicts a processing plant that consists of a number of physical unit operations interconnected through flow of material and energy. Each of these units communicates through measurement of process variables with a local control system, which in return sends commands to the actuators on the units such as pumps, valves, etc. Interconnections between local controllers are facilitated by shared information in the control network through the DCS software (Distributed Control System). As the performance of each unit will influence any unit, either downstream or upstream through recycles and energy integration, there is a benefit for the control system to consider the production line as a whole.

The synthesis of the design for a new production facility is a comprehensive undertaking, and even the conceptual design phase is often decomposed into a number of tasks including, but not limited to collecting information, generation of alternatives, analysis, evaluation and optimization, which are repeated and refined as the level of understanding and precision requirement is increased (Siirola, 1996). Alternatively the problem can be solved through one large mathematical optimization problem by generation and evaluation of process options through a superstructure (Grossmann, 1996; Friedman et al., 2013). This approach typically leads to a mixed integer nonlinear optimization problem (MINLP) which can be solved directly or by a mathematical decomposition strategy. The nonlinearity usually comes from the model, the constraints or the objective function itself, while the integer variables reflect structural decisions which can include or exclude different alternatives. There are a number of sources that provide a thorough introduction to defining and solving the process synthesis problem, including but not limited to the following excellent books: Douglas (1988), Biegler et al. (1997), Peters et al. (2003), Turton et al. (2008) and Towler and Sinnott (2013). The reasoning for applying a decomposition strategy for the overall problem is partly to reduce the complexity of a large open problem. The decomposition into a number of tasks also introduces gates for managerial decisions and allows allocation of expert resources at each step of the design process to recognize the overall complexity is significant and a team consisting of diverse competences is needed. In this decomposition approach, issues of operation and controllability of the processing plant/network are typically considered in the detailed engineering of the individual units and in the overall process performance evaluation in the task based synthesis process. This results in development of the piping and instrumentation diagram (P&ID) from the process flow sheet as well as a design for the individual regulatory control loops and the plant wide control design. Hence, these tasks are related to safety and dynamic performance. They are often considered relatively late in the overall design process and usually by a different team. This implies that the control problem is solved subject to constraints set by the design decisions, i.e. in a fixed flow sheet, rather than solving both in an integrated approach. This

* Tel.: ++45 45252801.
E-mail address: jkh@kt.dtu.dk

http://dx.doi.org/10.1016/j.compchemeng.2015.03.019
0098-1354/

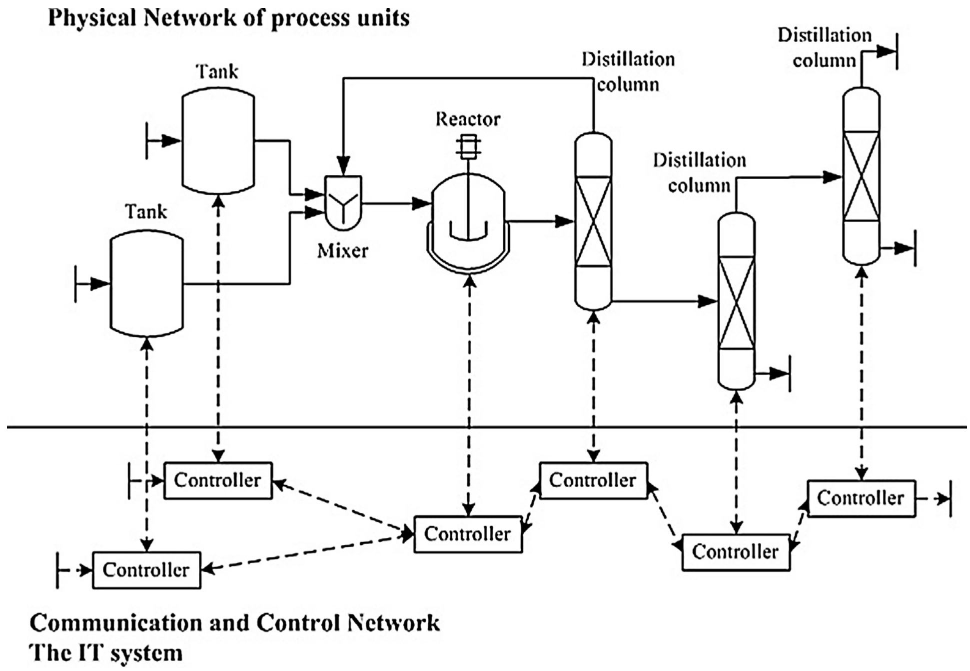

Fig. 1. Schematic representation of the physical networks of unit operation and their connections to the communication and control network of the process.

practice has roots in the historical development process synthesis and synthesis of control structures as separate fields of research for entire processing plants. This is excellently described in the early review paper on process synthesis by Nishida et al. (1981) where the obviously connections between design and control is also discussed in relation to the plant wide control synthesis problem.

In this contribution, the conceptual problem of process design and control design will be discussed and compared in terms of common and conflicting objectives. This will be followed by a discussion of drivers for an integrated design approach and the inherent difficulties in such a solution strategy. Some thoughts of simple means for design of processes which are easy to control and how advanced process control may help operate more complex processing plants will be given before the discussion is summarized and the need for improved methods and new research is identified.

Recent reviews have been published on these subjects in e.g. Ricardez-Sandoval et al. (2009), Yuan et al. (2012) and Sharifzadeh (2013). These reviews are very focused on the mathematical formulation and solution strategies for the resulting problems and list a vast number of scholarly contributions within the subject. However, the focus in this paper is to a higher degree process oriented compared to the previous works, and discusses different drivers for an integrated approach. Furthermore, it focuses on how advances in model based control have moved the criteria for controllability requirements for the process design and which requirements that will never change regardless of how advanced feedback algorithms can be developed. New drivers for an integrated approach are discussed as the development of novel hybrid and intensified processes.

2. The process design and control design problems

The general synthesis problem in process design can be formulated as:

> Chemical process design is about finding a **sustainable** process that can convert the raw materials to the desired chemical products.

Where the term sustainable may refers to economics, low environmental impact, low waste generation, correct use of raw materials, low utility requirements, etc., as well as safe and efficient operation (Douglas, 1988; Biegler et al., 1997).

Most of these metrics for a feasible and sustainable process are quantities which are evaluated in average over the process life time. That is, these can be evaluated from the steady state design model of the plant consisting of balance equations in combination with the constitutive equations e.g. reaction rates, transport mechanisms and thermodynamic equilibrium. Efficient operation of the plant and safety is on the other hand a dynamic phenomenon which to a large extent quantifies if the process can be regulated satisfactory in case of abnormal events. These can be regarded as small or large disruptions to the nominal process operation through disturbances or as scheduled changes to the operation such as start-ups, shut down or production rate changes. The solution to the design problem, whether solved by a superstructure, through a decomposition-based method or by heuristics, is through evaluation of a steady state model. Solution of such static flow sheet models can be performed using short cut or rigorous process models. This can be performed efficiently in a number of commercial simulation tools such as: Aspen Plus, CHEMCAD, gPROMS and PROII to name a few of the larger and more general packages which cover a wide application range in chemical engineering.

Analogous to the synthesis problem, an objective for the design of a control structure can be formulated as:

> Process control is about achieving the **desired performance** subject to the **actual process disturbances**.

In this objective the desired performance is normally coinciding with the performance of the designed process form the synthesis problem solution, but the disturbances are dynamic deviations in the design specifications to the process. These can come from e.g. changes in raw materials or disruptions in the utilities as well as slowly changing performance parameters for catalyst activity or increased resistance to heat transfer due to fouling. For any process, it is important to establish: what is the dominating disturbance structure for the production system? The dominating