STOCHASTIC OPTIMIZATION FOR THE SIMULTANEOUS SYNTHESIS AND CONTROL SYSTEM DESIGN OF AN ACTIVATED SLUDGE PROCESS

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***Abstract*—This work presents two stochastic optimization methods to perform the integrated synthesis and design of an activated sludge process. The process synthesis and design are carried out simultaneously with the control system design to obtain the most economical plant which satisfies the desired control system performance. The mathematical formulation of this objective translates the process superstructure into a mixed-integer optimization problem with non-linear constraints and dynamical-performance-indices evaluations. The proposed stochastic optimization algorithms, namely simulated annealing and a real-coded genetic algorithm, are valid alternatives to classical optimization techniques for the solution of such complex problems. The results are encouraging for future applications, because the easy implementation and the quality of the solutions obtained make not only possible but practical the solution of the integrated synthesis and design problem.**

***Keywords*—Process synthesis, integrated design, genetic algorithms, simulated annealing, controllability.**

I. INTRODUCTION

The advantage of considering controllability issues in the early stage of process design has been broadly recognized in the literature (Ziegler and Nichols, 1942; Luyben, 1993; Luyben and Floudas, 1994). Based on this idea, several authors have proposed different methodologies for the simultaneous design and control of chemical processes (Sakizlis *et al*., 2004), addressing the systematic study of the influence of the process design on the controllability and dynamic behavior of the plant. Several authors perform the integrated design considering an economic objective and a dynamic measure of performance, for instance the integral-square-error, for a more systematic analysis of the interactions of design and control (Schweiger and Floudas, 1997; Gutiérrez and Vega, 2002; Kookos and Perkins, 2001; Revollar *et al*., 2005; Francisco and Vega, 2006; Revollar *et al*, 2006).

Thus, *the integrated design and control methodology*, leads to a non-linear optimization problem where economic objectives, operability specifications and control performance are considered. The most comprehensive applications also contemplate the process synthesis or the control structure selection, Tlacuahuac-Flores and Biegler (2008), resulting into a mixed-integer-non-linear optimization problem (MINLP). The controllability analysis may require the evaluation of dynamic performance indices, which translates the problem into a mixed-integer-dynamical optimization (MIDO). Therefore, this approach involves the use of advanced algorithms that handle both continuous and discrete decisions, to lead the design to economically optimal processes operating in an efficient dynamic mode around the nominal working point.

Several deterministic mathematical programming optimization techniques have been applied successfully to solve mixed integer non-linear optimization problems in different process engineering problems. However, in complex problems these algorithms, at times, fail to give any solution and their effectiveness decreases when discontinuities and non convexities are present (Tsai and Chang, 2001; Costa and Oliveira, 2001).

Some works addressing the MINLP or MIDO that arise from *integrated design and control* of chemical processes are found in the literature. Narraway and Perkins (1994) studied the problem of selecting an economically optimal multi-loop proportional-integral control structure using non-linear models. The solution was found using dynamic optimization and the OA/ER/ AP (Viswanatan and Grossman, 1990) technique for the MINLP, however, they reported a poor performance of the method due to the non-convexity of the problem.

On the other hand, Schweiger and Floudas (1997) presented a methodology for analyzing the interaction of design and control that resulted in a multi-objective Mixed Integer Optimal Control Problem. A control parameterization technique was used to transform the MIOCP into a MINLP with Differential and Algebraic Constraints problem, which was then decomposed in a NLP/DAE primal and MILP master problem to provide upper and lower bounds of the solution. Three chemical engineering examples were effectively solved using this procedure.

More recently, Kookos and Perkins (2001) proposed a decomposition algorithm for the simultaneous design of structure and parameters of the process and the control system, based on the generation of lower and upper bounds on the optimal economical performance of the