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Multivariable linearizing control of an industrial sugar crystallization process

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ABSTRACT

This paper illustrates the benefits of a multivariable linearizing control approach applied to an industrial crystallization process. This relevant approach proposes a setpoint tracking for the crystal mass/concentration couple. In this purpose, a model dedicated to last stage crystallization is designed, without consideration of crystal size distribution. The controlled variables, unavailable, are obtained using an extended Luenberger observer. The observer is validated on industrial data and shows good performance in both convergence rate and accuracy. The performance of the proposed linearizing strategy, which application to cane sugar crystallization constitutes a real novelty, is tested via simulation. The good performance in setpoint tracking, even in presence of noise, disturbances and modeling error, allows to consider a significant improvement of the global productivity.

1. Introduction

Crystallization is a unit operation widely developed in pharmaceutical, chemical and food industries, which aims at extracting a solute from a saturated solution. The presence of a continuous phase and a dispersed phase gives rise to physicochemical phenomena such as nucleation, growth, agglomeration and dissolution. Crystallization results mainly from the difference of potential between the supersaturated solution and the solid crystal face [1,2]. Commonly, growth and nucleation kinetics are represented in terms of the supersaturation, i.e. the difference between the solution and the saturation concentrations. The state of supersaturation can be reached by mean of cooling, evaporation or use of a solvent.

Usually, a fine control of the crystallization process is mandatory, and this stage is particularly critical for one main reason: crystallization processes are modeled by nonlinear algebraic integro-partial differential equations, whose kinetics parameters are most of the time uncertain. The complexity of the models is due to the necessity to describe the crystals in terms of shape and size, leading to a crystal size distribution (CSD). This CSD is particularly difficult and expensive to apprehend from a measurement point of view, but some relevant solutions are described in the literature [3]. Nevertheless, even if advanced control algorithms have been proposed (nonlinear model-based predictive control, generic model control, H_∞-control, etc.) for both continuous and batch crystallization processes [4–10], the lack of sensors remains a significant slowdown in the implementation of relevant control strategies.

In cane sugar industry, in order to improve exhaustion, crystallization is achieved grade wise through multiple stages, with a decrease in purity from the first to the last stage. In the first stage, the objectives are similar to those mentioned above, that is, a good product quality, such as a good CSD. Control tools mentioned in the previous sections can thus be applied, with less or more success. Indeed, the concentration of impurities being relatively small, a wide variety of mathematical models can be found in the scientific literature to describe the sugar crystallization phenomena, both steady state and dynamic models [11–14]. The most widely used methodology to estimate the crystallization rate involves the population balance [15,16] that gives information about CSD such as the mean particle size and deviation, or the number of particles. Consequently, the widely used dynamic model for first stage is based on nine ordinary differential equations.

The problem addressed in this contribution is significantly different and the control objectives are much less restrictive, since the case mentioned here concerns the last step of cane sugar extraction. At this stage, the control objective is limited to a maximal sucrose exhaustion of the solution, regardless of the quality of the CSD. The mass of crystals is then sufficient and relevant information to properly follow the evolution of the crystallization. Moreover, the large concentration of impurities in the solution keeps out to identify the usual momentum model parameters.

In all stages the process control is designed to maintain the solution in a supersaturated state [17]. In practice, industrialists consider the electrical conductivity of the solution as an indicator of the supersaturation. Consequently, the electrical conductivity

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