On the development of multi-parametric controllers for the twin-column MCSGP

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Industrial processes are often characterized by complex configurations and periodic operation profiles. Mathematical models that describe such systems often comprise large sets of partial differential equations that introduce nonlinearities and lead to computationally expensive solutions. Such models also pose great challenges during the application of advanced optimization and control policies and they do not guarantee optimal solutions. In this work we focus on the design of multi-parametric controllers of the Multicolumn Counter-current Solvent Gradient Purification process (MCSGP).

MCSGP is a chromatographic process used for ternary separations (Aumann and Morbidelli, 2007, Krättli et al., 2013) run in either semi-continuous or continuous operation. One of its key advantages is that it recycles impure product fractions, thus maximizing the extraction of product. The process principle was first presented by Ströhlein et al. (2006) using a five-column system, while the latest development is the twin-column setup (Müller-Späth et al., 2013) (Figure 1). MCSGP is a cyclic process, where the columns operate in batch mode for some percentage of the cycle time, while during the rest of the cycle the operation is continuous and counter-current.

At the beginning of each cycle, column 2 is equilibrated and empty, while column 1 starts the cycle by eluting the overlapping region of W and P. During the I1 phase the outlet stream of column 1 is mixed with adsorbing eluent (E) and enters column 2. In the B1 phase, the columns operate independently and fresh feed is introduced to column 2. The columns are then connected again (I2 phase) and the overlapping regions of P and S that exit column 1, enter column 2. The outlet stream of column 1 is mixed with E before reaching the entrance of column 2. The B2 phase starts with the columns operating in batch mode and column 2 elutes W by starting the gradient. The afore-described phases (I1 to B2) form a switch. Once the switch is completed, the columns swap places and the procedure is repeated. The cycle is completed once the two columns have passed through all the possible configurations and return to the initial configuration.

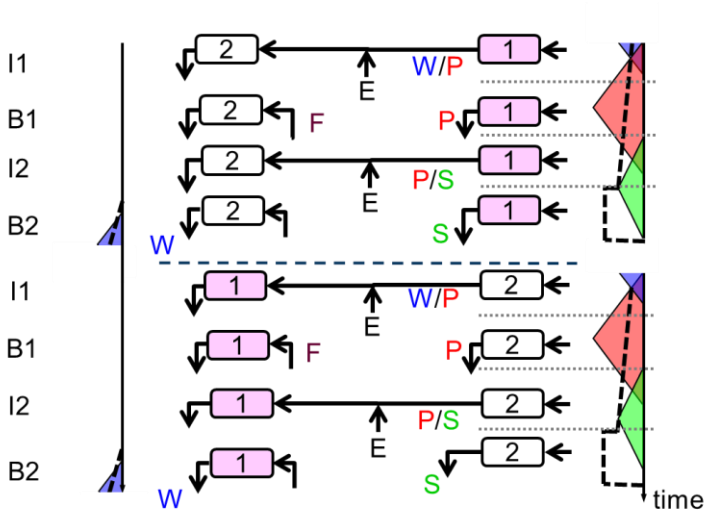


Figure 1 The twin-column MCSGP

The above system is described by a mathematical model, comprising partial differential and algebraic equations (PDAE). The model is based on lumped kinetics and is governed by the principal equations of chromatography. To describe the events during separation, the model uses a competitive bi-Langmuir isotherm. The model was simulated in gPROMS® (PSE, Ltd.) and the system dynamics were tested. Figure 2 indicatively shows the extraction profiles for the separation of a three-component mixture.

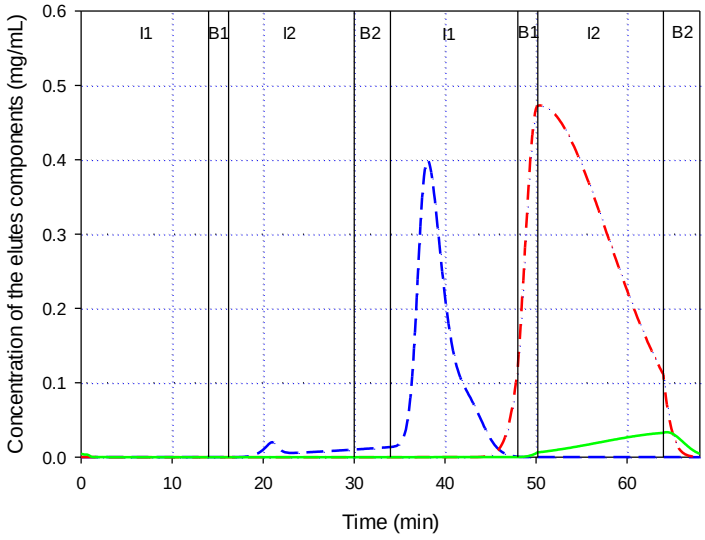


Figure 2 Elution profiles of weak impurities (– –), product (– · –) and strong impurities (—)

The model complexity and the periodicity of MCSGP pose great challenges in the application of the existing control strategies. The trade-off between purity and productivity, however, render the optimal solution even more challenging to be found, as it has to meet two antagonistic goals. At the same time, this trade-off is one of the main reasons that constitute the existence of a successful controller essential. Additionally, an advanced controller can increase the system stability and compensate for any variations in the feed stream. This work presents a methodology for the development of multi-parametric Model Predictive Controllers (mp-MPC) for the MCSGP process. The aim is to develop advanced multi-

parametric controllers that will (a) successfully maintain the system under optimal operation profile, while (b) satisfying the purity constraints and (c) effectively rejecting disturbances. For the purposes of this work the switching time is set a priori and the control strategies are developed based on the rest of the process parameters. The controllers are developed following the framework suggested by Pistikopoulos (2009).

Starting from a relatively complex process, the first step is to understand the system dynamics and be able to identify the effect of each input to the targeted outputs. Therefore, the system is decreased to a single-column system that provides all the information and required for preliminary experimentation. First, a Single Input Single Output (SISO) controller is developed. The system is exercised under random input profile, aiming to identify the most significant input. Computationally, this is realized utilizing the gO:MATLAB interface of gPROMS® that allows communication between gPROMS® and MATLAB® (MathWorks, Inc.). Following that, an approximate model (in state-space form) is obtained and tested in MATLAB®. It should be underlined that at this stage, instead of directly monitoring purity and productivity, the outlet concentrations of the three components are tracked. Effectively, there are three state-space models developed, using one input and one of the concentrations as output. The above models are used for the design of three SISO mp-MPCs that are developed in MATLAB® using the POP (Parametric Optimization Programming (ParOS) Ltd.) toolbox. The controllers are tested, inependently, in silico (‘closed-loop’ validation) against the original PDAE model. The validation is performed using the gO:MATLAB interface of gPROMS®, where the controllers provide the control actions to gPROMS® and gPROMS® returns the output profile to MATLAB®.The explicit/multi-parametric controllers manage to efficiently control the outlet concentrations of the outputs, on a SISO basis.

Following the procedure described above, the second step is to design a Single Input Multiple Output (SIMO) controller. A SIMO controller allows simultaneous control of the three outputs mentioned above with the application of a common control law for the input. The combination of the three outputs, however, is not a trivial task. The approximate model is being thoroughly designed in order to efficiently capture the dynamics of the system and has the ability to describe not only the relations between the input and the outputs but also any possible interactions between the three outputs. Additionally, in the SIMO case the problem becomes significantly larger and therefore requires greater computational effort. Subsequently, this renders the derivation of the control law a challenging problem.

Aiming to the development of a control strategy for continuous operation, this work suggests a methodology expanding the framework presented by Pistikopoulos (2009) to nonlinear, periodic systems. Apart from the application of the existing control strategies, systems similar to MCSGP offer fertile ground for further developments in the theory of control.

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