Control of ice cream crystallization

Keywords : Ice cream; Crystallization; Control.

Céline Casenave, Denis Dochain

Abstract – This research activity deals with the control of ice cream crystallization. More precisely, a controller for the viscocity has been designed and implemented on a pilot-scale ice cream crystallizer.

In crystallization processes, an important challenge is to control the quality and/or the properties of the product. In the case of ice creams, it is well known that the quality, that is the hardness and the texture of the ice cream, depends on the ice crystal size distribution (CSD). For example, depending on the mean crystal size, or more precisely on the dispersion of crystal sizes (that is on the shape of the CSD), the obtained texture of the ice cream is more or less grainy. Indeed, an ice cream with a narrow ice CSD and a small mean ice crystals size is smoother and more palatable. But it can also be interesting, in a production point of view, to control other properties of the ice cream, as its viscosity. Indeed, the ice cream market is characterized by a variety of products that can be classified in particular in term of their final packaging. Each type of final product is characterized by a specified viscosity: for instance a lower viscosity is required for large carton packaging than for cones. One of the objectives of ice cream crystallization processes is therefore to produce an ice cream of specified viscosity.

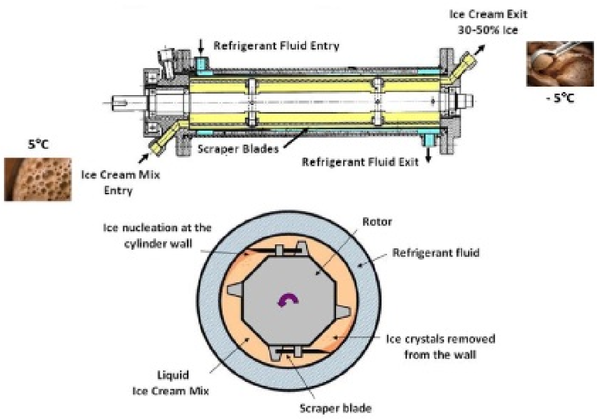

Figure 1: Schematic view of the ice cream crystallizer.

The dynamics of a crystallisation process can be given from mass and energy balances in the form of a population balance model in which one of the independent variable is the size of the crystals. The resulting model is a distributed parameter model, also known in mathematics as an infinite-dimensional system. For the purpose of the control design and implementation, the model has been reduced by considering the method of moments.

The study of the crystallization system shows that the viscosity of the ice cream can be expressed as a function of the ice temperature and the third moment of the ice CSD. As a consequence, it is not necessary to control the shape of the CSD itself: only the control of the third moment is needed. A careful analysis shows the saturation temperature (measured on-line) can be efficiently used to appropriately describe the dynamics of the third moment

The control design couples a linearizing control (to account for the nonlinearities of the system dynamics) with a Smith predictor (to compensate the time delay in the on-line measurement of the saturation temperature at the outlet of the crystallizer). It finally takes the form of a cascade controller with an inner loop with the saturation temperature as the controlled variable and the evaporation temperature, and an outer loop where the compressor rotation speed controls the evaporation temperature. The controller has been successfully implemented on the pilot-scale ice cream crystallizer of the IRSTEA in Antony (Paris).

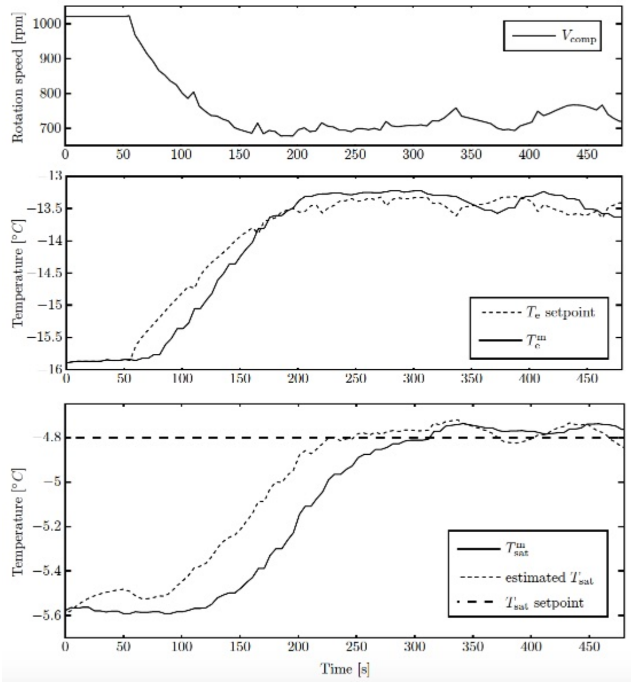

Figure 2: Equivalence Batch - Plug Flow.

References

[1] C. Casenave, D. Dochain, G. Alvarez, M. Arellano, H. Benkhelifa A and D. Leducq (2014). Model identification and reduction for the control of an ice cream crystallization process. Chemical Engineering Science, 119, 274-287.

[2] C. Casenave, D. Dochain, G. Alvarez, M. Arellano, H. Benkhelifa and D. Leducq (2013). Control of a nonlinear ice cream crystallization process. Proc. NOLCOS 2013, 717-722.

[3] C. Casenave, D. Dochain, G. Alvarez, H. Benkhelifa, D. Flick and D. Leducq (2012). Steady-state and stability analysis of a population balance based nonlinear ice cream crystallization model. Proc. ACC, 6461-6466.