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Hybrid modelling and self-learning system for dextrose crystallization process

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ABSTRACT

This paper deals with the modelling of a continuous cooling column crystallizer. An accurate model of this system is needed for complex process control. The investigated system consists on dextrose monohydrate in aqueous solution. An adaptive hybrid model is presented. The model consists of two parts: the phenomenological model, expressed by a set of differential algebraic equations, and a neural network, based on historical data, developed by the fuzzy ARMAP technique. The empirical part of the hybrid model is aimed at eliminating the deviations of the prediction of the phenomenological model caused mainly by incrustations over the surface of the cooling coils located along the column crystallizer. The model is adaptive since neural network parameters are updated by a self-learning system (SLS) based on the acquired process data storage of the DCS of an industrial plant. Firstly, the hybrid model was implemented by using the data of a three-month campaign of the crystallizer, then the self-learning technique was checked on site in a subsequent campaign.

Keywords: Hybrid modelling; Self-learning system; Dextrose monohydrate

1. Introduction

Dextrose monohydrate ("DX") represents one of the major source of energy in human metabolism: for this reason it is mainly used in food processing and in pharmaceutical industries. Despise its importance, few information on its crystal growth and nucleation kinetics are available in the literature (Perelygin et al., 1990; Srisa-nga et al., 2006).

DX is mainly produced by crystallization of the syrup obtained from the hydrolysis of cornstarch. Since its solubility is strongly dependent on the temperature, cooling crystallization is generally adopted. The mother liquor is quite concentrated in sugar, i.e. more than 60% b.w., and is very viscous. The crystallization process can be performed either in batch or in continuous mode, always by seeding: in both cases the mixing is very poor, in order to avoid the breakage of the fragile crystals, and a big incrustation over the surface of the cooling devices takes place. Incrustation, also called scaling, is often present in industrial crystallizers. It leads to a progressive worsening of the crystallizer performances due to lowering of the active volume and modifications of fluid dynamics. Then, after weeks or some months incrustation thickness is so increased that the process has to be stopped and the crystallizer is shut down.

Rigorous modelling of crystallization processes has received much attention in the last decades: the conventional approach is based on the balance equations of mass, energy and crystal population (Mullin, 1992). It must be considered that modelling a crystallizer is a hard task for both continuous and batch processes, since it is affected by several factors: nucleation by several mechanisms, crystal growth rates, hydrodynamic of the suspension and the effective residence time in the apparatus,. When seeds are added, their amount and characteristics also influence the final crystal size distribution.

Recently Parisi et al. (2007) suggested a two-step procedure to implement a model of a dextrose cooling crystallizer, based on experiments carried out both at lab and pilot scale. In this work, firstly, the relationship between the crystal growth and nucleation rates and supersaturation were determined from specific lab experiments, then the kinetic coefficients were evaluated from an experimentation performed by a pilot plant

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Nomenclature

B	secondary nucleation rate (#/m^3 s)
F	mass flow rate (kg/s)
E_a	energy of activation (J/mol)
G	linear crystal growth rate with respect to the second dimension (m/s)
k_G	growth rate coefficient (m/s)
k_{pure}	growth rate coefficient for pure dextrose (m/s)
k_n	nucleation rate coefficient (#/m^3 s)
k_{nd}	crystal growth rate parameter
k_v	volume shape factor with respect to the second dimension
L	crystal second dimension (m)
M_T	magma density (kg of solid/kg of slurry)
n	population density function (#/(m^3 of slurry m))
T	temperature (K)
V	volume of the compartments (m^3)
w	weight fraction
ρ_{cryst}	crystals density (kg/m^3)
ρ_{slurry}	density of slurry (kg/m^3)
σ	relative supersaturation

Superscripts

DX	dextrose
i	impurities

Subscripts

eq	equilibrium condition
i	compartment number

located at the industrial crystallizer site. The model did not consider scaling, since the incrustation phenomenon did not affect too much the batch crystallizer, since it was cleaned between two subsequent runs. DX industrial crystallizers are, on the contrary, largely prone to scaling. The presence of scaling gets hard to predict the performances of an industrial crystallizer, in particular because it is not possible to foresee when and where the starting of incrustation, due to nucleation over the cooling surface, occurs. Moreover, since it is not possible to measure the extension of scaling throughout the crystallization operation the only monitoring way of the scaling extend is to provide a prediction model, which acts as soft sensor.

In this work a hybrid model is proposed to predict the behaviour of a DX cooling column crystallizer. An innovative model of an industrial crystallizer that allows the control of dextrose crystallization is presented. Adequate process control of such a system returns in reduced operational costs. The overall model consists of a phenomenological model which describes the mass, heat and population balances of the process and an empirical algorithm which provides the adaptiveness to the unforeseen internal conditions of the crystallizer caused by scaling. The empirical model was continuously adapted to account for the actual crystallizer operating conditions by updating its coefficients through a self-learning procedure.

2. The examined crystallizer

The industrial crystallizer has a big residence time (higher than a day) and a big volume (higher than 100 m^3). It is operated using a seeded feed stream. Five heat exchangers along the column crystallizer may be operated to determine the required temperature profile. Each heat exchanger consists of several rows of coils horizontally located over the whole crystallizer section. Under each coil layer there is an impeller rotating at a very low rate in order to improve the heat transfer, avoiding a significant crystal breakage, as shown in Fig. 1. More detailed information on the apparatus cannot be disclaimed for sake of confidentiality.

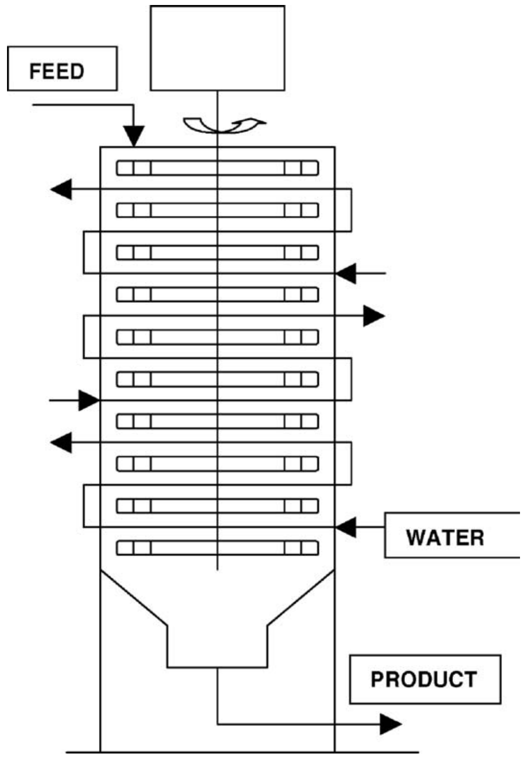

Fig. 1 – The examined column crystallizer.

Flow rate, input and output temperatures of the cooling water stream entering each coil are measured. Several temperature sensors located inside the column and at the column entrance and exit measure the temperatures of the slurry along the crystallizer. The other measured variables are the input flow rate and the solution Brix in the outlet slurry stream, by means of a K-patent instrument. The Brix in the output stream is the variable of interest. It is proportional to the final DX concentration, which determines the process productivity. This Brix value is strictly related to the amount of heat removed by each cooling coil. A few days after the operation start, incrustation takes place over the coils surface. This phenomenon decreases the heat removed by the heat exchangers, at constant temperature driving force and, as a consequence, the temperature of the outlet slurry is decreased and the process productivity as well. In order to restore the required productivity it is necessary to increase the flow rate of the cooling water feed stream until, after some months, the heat transfer efficiency has reached its lower acceptable limit and the crystallizer is shut down and cleaned.

3. The hybrid model

The hybrid model used in the present work is composed by two parts. A phenomenological (or physical) model that describes the process using differential equations and phenomenological parameters, and an empirical model that