The Potential of Economic Model Predictive Control for Spray Drying Plants

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In 2015 the milk quota system in the EU will be completely liberalized, causing powder production to increase while its price will drop. Efficient control and optimization of the multi-stage spray drying process has thus become increasingly important.

Motivation
Multi-stage spray drying (MSD) is a very energy consuming and widely used unit operation in the production of dairy powders. Conventional control of MSDs keeps inlet and outlet temperatures constant during operation. This approach is simple, but known to be insufficient for controlling the product quality (residual moisture and particle size) and energy inefficient, increasing the total energy consumption.

Multi-stage spray dryer model
We have developed a first-principle engineering model for simulation purposes. As illustrated in Fig. 1, spray drying is a continuous process which produces a dry powder from a liquid feed. Three stages (SD, SFB and VFB) are used to enhance drying efficiency and powder quality. We model each stage as ideally mixed and describe these by mass- and energy balances.

The stage equations are
\[
\frac{dm}{dt} = F_{in} X_{in} - F_{out} X_{out} - R_w m_w
\]
\[
\frac{dm}{dt} = F_{vap} - F_{vap} - R_w m_w
\]
\[
\frac{dU}{dt} = H_{in} - H_{out} + H_{vap} - Q_{loss} + Q_{exc}
\]

With the rate of evaporation
\[
R_w = k_1 (\rho_{vap} - \rho_e) \exp \left( \frac{k_2 (X_{out} - X_{eq})}{RT_{out}} \right)
\]

\(R_w\) is based on the Arrhenius' equation

Simulation
The two most dominant disturbances are the inlet air humidity and the feed concentration. The effect of these on the residual moisture is shown in Fig. 2. The inlet air humidity (top figure) is altered in steps of 5, 15, 25 g/kg and back. The residual moisture content increases due to the decreased force of evaporation between the air in the dryer and the drying particles. The feed concentration (bottom figure) is altered from 50% to 40% and then to 60% and back. As seen the residual moisture increases in both cases. The nozzle spray collapses for 60% feed concentration and this state should be avoided by all means. The particle size is also of importance, as it affects the tap density and solubility.

An increase of 0.6% in mean residual moisture, will result in savings of 2.19M DKK/year and 88 tons CO₂/year for a medium size dryer

Economic MPC
Conventional control systems are not able to reject the presented disturbances, leading to excess drying most of the time to satisfy powder quality restrictions. We will formulate an Economic MPC with the objective to optimize the cost of operation, while rejecting disturbances and satisfy stickiness constraints of the process.