Model Predictive Control for Improved Yield and Throughput of Spray Drying Plants

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Abstract

Spray dryers are widely used in the chemical, pharmaceutical and food industries to turn liquid products into free flowing powder. To increase the energy efficiency and improve the product quality, the dryer in question combines drying in four stages, instead of single stage drying.

In this paper, we present our latest developments within advanced process control for the four-stage spray dryer. We present our linear model predictive controller with real-time optimization (MPC-RTO) and industrial application of the controller to a four-stage spray dryer that produces milk powder. By closed-loop operation of the MPC-RTO and the proportional-integral (PI) control strategy, we compare and present the key performance indicators of the MPC-RTO to the PI control strategy.

Controlling a four-stages dryer is complex as the inputs and outputs of this type of spray dryer are highly cross-coupled and long process delays may be present. Furthermore, the residual moisture of the powder must be controlled below a maximum limit, and deposits due to sticky powder inside the dryer must be avoided.

Traditionally, spray dryers are operated using a PI control strategy with fixed targets that are independent of disturbances such as the ambient humidity and the feed composition to the spray dryer. The concerns of adjusting the operation to the conditions is left to the process operator. The PI controller must avoid violation of the stickiness constraint and the powder moisture limit by the application of a considerably back-off from the process constraints, as the PI-control strategy can only partially and indirectly mitigate the effect of the disturbances on the outputs. Due to the applied back-off, the PI control strategy makes the dryer dry the powder more than necessary. This more extensive drying decreases the energy efficiency, the throughput and the yield, i.e. the residual moisture content sold as product, of the production.

The MPC-RTO is a two-layer optimization based controller. Using the measured disturbances, the estimated integrating disturbance states, the operating profit function, the constraints, and a steady-state linear model, the RTO layer computes the optimal target, for the controlled outputs by solving a steady-state optimization problem. The MPC layer in the MPC-RTO solves a weighted and regularized least-squares problem with constraints using a dynamic linear model. The MPC is based on feedback from the measurements and feed-forward from the measured disturbances. The MPC brings the controlled outputs to the target by manipulating the inputs. The RTO frequently adjusts the target including the corresponding back-off to the variations in the disturbances.
The resulting back-off of the MPC-RTO is smaller than the back-off of the PI control strategy due to better regulation by the MPC. The economic value of the MPC-RTO compared to the PI control strategy stems from the adjustment of the target to the actual disturbances. Less back-off can thus be applied as a consequence of better regulation with less output variance. The reduced back-off results in an increased profit of operation. Compared to the PI control strategy, the MPC-RTO increases the average product yield and throughput considerably.

Keywords: Spray drying, Multi-Stage dryer, Model Predictive Control, Real-Time Optimization