On the dynamic operability of adsorption dryers

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Introduction and background

Drying is an energy intensive process. Theoretically, about 2.5MJ of heat energy is required to drive away 1kg of water from a product if the dryer is 100% efficient. Yet, for conventional convective dryers, efficiencies could be as low as 20%, particularly for low drying temperatures required for heat-sensitive products like food and pharmaceuticals. Adsorption drying using zeolite has been identified as a promising method for energy efficient drying at low temperatures [1]. In these systems (Fig. 1), ambient air is dehumidified by passing through a zeolite adsorbent bed such that drying capacity is increased for low temperature drying. Although energy is spent on regenerating the used adsorbent, it has been shown [2] that the overall energy efficiency compared to a conventional dryer is improved by optimizing the flowrates of drying air, regeneration air, zeolite and the regeneration air temperature. Energy efficiency is further improved by heat recovery from the regenerator high temperature exhausts.

The introduction of the adsorber/regenerator subsystem with its recycle loop and the heat recovery loop however increase the complexity of the system so that controllability becomes an important issue. The purpose of this work is to analyse the controllability of the system with a view to determining how robust the energy and quality performance is to disturbances and changes in operating conditions.

Methodology

The system is represented in state space [2] as

$$\frac{dx}{dt} = \boldsymbol{f}\left(\boldsymbol{x},\boldsymbol{u},\boldsymbol{d}\right) \qquad (1)$$

where the state vector $\boldsymbol{x}$ consists of the temperatures and moisture contents of the air, product and zeolite in the dryer, adsorber and regenerator. The control input variable $\boldsymbol{u}$ consists of the drying air flowrate, regeneration air flowrate, zeolite flow speed and heat inputs to the regenerator air and the drying air, while ambient air and feed conditions constitute disturbance variable $\boldsymbol{d}$. The most important output variables are the product outlet moisture content $\boldsymbol{X}_{\boldsymbol{p}}$ and temperature $\boldsymbol{T}_{\boldsymbol{p}}$ with a constraint

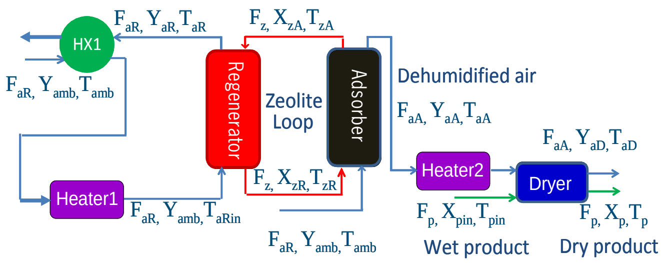

Fig. 1. Adsorption drying system

that the energy efficiency of the system is robust to disturbances and changes in operating conditions. Energy consumption is also taken as a controlled variable.

For analysis, first, the nonlinear plant is linearized about the optimal operating point as determined in [2]. Thereafter, using various controllability indices, the right choice of input-output pairings for optimal performance is examined. Also, sensitivity to disturbances and set point transitions are analysed.

With heat recovery, the degrees of freedom are reduced. The effect of this is examined and finally, comparisons are made with conventional dryers with and without heat recovery.

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References

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