Optimization of the adsorption drying process for energy efficiency and product quality

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The sustainability of industrial processes depends largely on the energy consumption and the quality of the products. Sustaining economic prosperity while satisfying stringent environmental requirements demands energy efficient process design. Drying is an energy intensive process accounting for about 15% of industrial energy consumption. In food processing, drying at low temperatures is desired to ensure nutrient retention. Conventional convective drying at these temperatures is however highly inefficient at low temperatures (typically below 50% for temperatures below 50℃).

Adsorption dryers, utilizing adsorbents for air dehumidification, show great promise for energy efficient low temperature drying. In these dryers, the drying air is dehumidified by passing it through an adsorber such that the humidity is reduced while the temperature rises as a result of the release of adsorption heat. The combined effect brings about increased drying forces. The main energy input is for regenerating the spent adsorbent by the use of hot air. This regeneration process on the other hand gives opportunities for heat recovery and energy integration. The determination of optimal operating conditions with respect to energy efficiency, coupled with heat integration is expected to yield significant improvements in efficiency. To achieve this, rigorous models capable of reliable energy sensitivity analysis must be available.

In this work, a simulation model for the steady-state operation of an adsorption dryer is developed. The model is used for energy efficiency optimization subject to constraints on product temperature. Decision variables identified as being useful for the optimization are the regeneration air inlet temperature, ratios of adsorbent to drying air flowrates and regeneration air to adsorbent flowrates. Sensible and latent heat recovery is also considered, and for this purpose, two optimization approaches are employed, namely, the sequential and the simultaneous optimization. In the sequential approach, the drying system is optimized with respect to the stated decision variables, and then, the outlet streams from the optimized process are analysed for maximum heat recovery using pinch analysis, but with latent heat recovery also considered. In the simultaneous approach, sensible and latent heat recovery are considered an integral part of the overall process design and the drying system and heat recovery network simultaneously optimized using a variable pinch location method.

It is shown that by proper selection of the decision variables and effective sensible and latent heat integration, the energy performance of the drying system for low drying temperatures is improved considerably while drying at 50℃. Without heat recovery, an adsorption dryer achieves an efficiency of 68% under optimal conditions. By taking sensible and latent heat recovery into consideration in the sequential approach, an overall efficiency of 125% is realized. When heat recovery is taken as an integral part of the process design and the process and heat recovery simultaneously optimized, an efficiency of 134% is achieved. (Remark: note efficiencies above 100% are possible at intensive latent heat recovery).

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