Reducing energy consumption in food drying: opportunities in desiccant adsorption and other dehumidification strategies

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INTRODUCTION

Drying is one of the most popular methods for preserving foods. Due to the latent heat of evaporation required, drying is energy intensive, accounting for about 15% of industrial energy consumption. In addition, achieving desired quality levels is of importance in food drying. For a given dryer design, drying at high temperatures is the standard way of improving efficiency, but at the expense of product quality. By dehumidifying the drying air, the moisture removal capacity and hence, energy efficiency can be increased while drying at low temperatures. In refrigerant based systems, dehumidification would lead to drying air sensible heat loss on the evaporator side coupled with the need to pump the refrigerant from the evaporator to the condenser sides. In desiccant based systems, regeneration is required. Both processes involve energy expenditure. In this work, an assessment is made of the dehumidification drying techniques, vis-à-vis conventional convective drying in terms of energy efficiency. An additional aspect of drying with dehumidified air is the lower dryer exhaust air and product temperature. Drying with dehumidified air has therefore a positive impact on the retention of heat sensitive products, like vitamin C. In this work this positive impact is demonstrated.

MATERIALS & METHODS

The results presented in this work are based on mathematical models derived from first principles using mass and energy balances. The efficiency of the dryer is defined as:

$$\eta = \frac{Q_{evap}}{Q_{in}} \qquad (1)$$

where, Q_{evap} is the energy used for water evaporation from product and Q_{in} is the total input energy. Where heat Q_{rec} is recovered in the system, the definition becomes,

$$\eta = \frac{Q_{evap}}{Q_{in} - Q_{rec}} \qquad (2)$$

The efficiency is evaluated for a conventional dryer and the following dehumidification dryers: dryer with inlet air condensation, heat pump dryer and desiccant adsorption dryer.

RESULTS & DISCUSSION

The derived energy efficiency expressions show that the key factor to efficiency improvement lies in dehumidification-induced dryer outlet temperature drop (it is known that a drop in dryer outlet temperature raises efficiency). The derived results indicate that the efficiency of each type of dehumidification dryer can be expressed in terms of the efficiency of the conventional dryer with additional terms included.

For the adsorption dryer, the extra variables are the regeneration air inlet temperature, flowrate for the adsorbent and the drying air flowrate. This is consistent with previous results [1] where by degree of freedom analysis, the same conclusion was arrived at. These variables affect the extent of dehumidification and the corresponding dryer outlet temperature drop as well as the magnitude of adsorption heat release which aids drying and hence, efficiency. They also affect the amount of energy spent on regeneration which tends to reduce efficiency.

For the heat pump dryer, the determining factors are the degree of cooling to dewpoint and then below as well as the compressor power applied and the efficiency of compression and also, the efficiency of electrical power generation and transmission (assuming an electrically-powered compressor).

For the condensation dryer, the degree of cooling and hence, dehumidification affect efficiency. In all cases, these extra terms are seen to affect the dehumidification and at the same time, the extra energy spent. Optimization of the variables contained in these extra terms within constraints thus holds the key to fully utilizing the benefits of dehumidification.

Fig. 1(a) shows the energy efficiency of the different dehumidification dryers at a dryer inlet air of 5g/kg compared to a conventional dryer at 10g/kg. The heat pump and adsorption dryers perform better than conventional dryers. To achieve the same efficiency, conventional dryers must be operated at higher temperatures which lead to product quality degradation. Fig. 1(b) shows a comparison of vitamin C degradation in drying pumpkins. For the same energy consumption, the use of adsorption dryers leads to less degradation than conventional dryers.

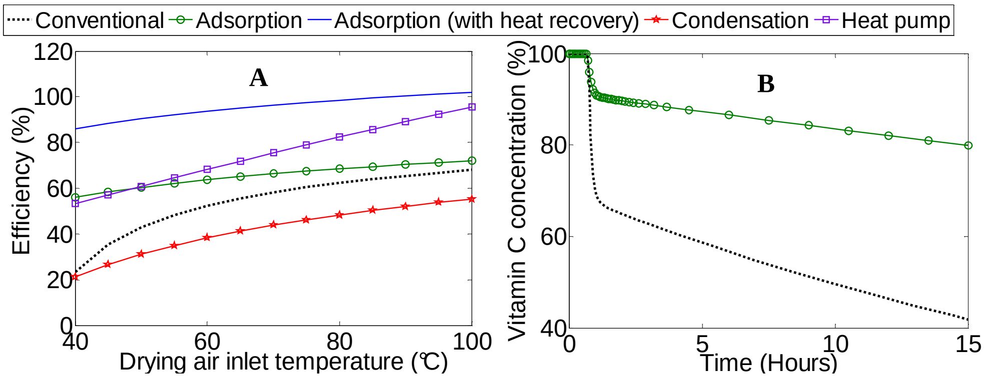

Fig. 1. A) Energy efficiency for different dryer types (see top of figure), B). Vitamin C degradation for drying with and without air dehumidification both with energy efficiency at 60%

CONCLUSION

The efficiency of dehumidification dryers can be expressed in terms of that of the conventional dryer permitting the isolation of important design and operational parameters specific to each dryer type which when optimized will improve energy efficiency and product quality.

REFERENCES

[1] Atuonwu J.C., Straten G. van., Deventer H.C. van & Boxtel A.J.B. van. 2010. Modeling and energy efficiency optimization of low temperature adsorption based food dryer. International Drying Symposium Magdeburg, Germany, 423-431.