STUDY ON OPEN-CYCLE DESICCANT DEHUMIDIFICATION AND AIR CONDITIONING FOR DRYING OF AGRICULTURAL PRODUCTS

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（農産物の乾燥のためのオープンサイクル除湿空調に関する研究）

Title

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論 文 内 容 の 要 旨

Thesis Summary

High growth rate in world population has doubled the liability on agriculture sector to meet the challenges in food security. It is required to develop better genetics of the crop seeds as well as energy conservative drying system followed by safe storage. In drying process, air conditions, temperature and relative humidity affects the quality of the drying product. High temperature drying causes loss of nutrients and vitamin C, found in agricultural products. In addition to higher drying air temperature, higher humidity also affects the color and quality of the drying product. Due to the complex structure of biological product, convective drying mechanism complete in two phases, known as constant and falling-drying rate. During constant drying rate, water is removed from the surface of the product whereas during falling drying rate, water is removed from inside of the product. Usually, falling-drying rate is more energy intensive and sometime give rise to over dry or even burn the surface of the product. This problem is addressed with the development of drying system that creates more pressure deficit by dehumidification of air to increase the moisture carrying capacity of the air. In this regard desiccant drying system provides its best applicability for low temperature and quality drying. This study focuses on low-temperature drying of agricultural produce, steady state desiccant-drying, dynamics of adsorption-drying and comparison with conventional-drying system. In addition, to change in effective thermal conductivity at different relative humidity, attributed to change in heat transfer coefficient is also discussed. The key features of the study are highlighted as follows:

The need for drying agricultural produce, drying mechanism and the degradation factors are discussed in chapter one. While chapter two, accounts for the review of literature in detail about desiccant drying technologies including bed type, wheel type and liquid desiccant system. A brief review about some other drying technologies including; convective drying, freeze drying, microwave and vacuum drying is also indicated. Out of these technologies; freeze drying, microwave and vacuum drying are regarded as best as they maintain the good quality of the products. It is due the fact that these technologies ensure volumetric heating and fast drying while limiting shrinkage of the product. However, their cost of energy is high, overall efficiency is low and it is difficult to control the product temperature in some cases. On the other hand, desiccant drying technology provides energy efficient system and also reduces thermal degradation. In addition, a brief review about hybrid drying with its potential to make significant progress in industrial drying is also mentioned. These systems (integration of desiccant and other drying technologies) give better solutions with special focus on the quality and quantity of drying product.

The chapter three illustrates the steady state investigation of desiccant drying system (DDS) for the drying of cereals grain at low temperature and lower humidity. The performance of two drying approaches with two desiccant materials i.e. silica gel and lithium chloride (LiCl) have been analyzed by a desiccant dehumidification model as presented in literature. Case-I deals with the drying of cereals grain without heating at various levels of humidity ratio of processed air. Whereas Case-II deals with the dehumidification of the ambient air at certain levels, then heating the processed air up to safe

temperature limit. Case I results showed that, by increasing the regeneration temperature moisture, the carrying capacity of the air increases, however at the expense of elevated energy. In Case-I, drying air conditions found effective for seed drying as drying air temperature does not exceed the recommended drying temperature limit of the seed. Case-II gives more economical and energy saving drying solution as compared to Case I, however, it is suitable for commercial purpose drying, because temperature rises little higher than the safe limit.

In contrary to steady state, chapter four characterizes the drying kinetic of freshly harvested wheat grains in order to reduce the moisture to an optimum level. A comparison of desiccant drying has been made with the conventional method in terms of drying kinetics, allowable time for safe storage, the total time for drying cycle, and overall energy consumption. It has been found that the proposed desiccant drying system provides high drying rate and allows higher time for the safe storage. As the desiccants possess water adsorbing ability by means of vapor pressure deficit, therefore, the desiccant system successfully provided low-temperature drying which ensures the quality of wheat grains. It could be useful not only for domestic drying applications but also for industrial applications. Upon comparison with conventional drying methods, it has been found that the proposed drying system is not only useful for providing quick and low-temperature drying but also helps in overall energy saving. The performance index of desiccant drying system is found higher than the conventional system at drying temperatures. Overall energy consumption required for desiccant system is less as compared to conventional drying energy at all drying temperatures. This Study has been very useful to develop a low-cost and sustainable drying technology for various agricultural products.

In chapter five, the effect of relative humidity on the effective thermal conductivity of the desiccant materials is demonstrated Change in effective thermal conductivity is attributed to the change in heat transfer coefficient, which influences the performance of the systems. Most of the adsorbents are porous in nature and therefore adsorption uptake is affected due to monolayer/multilayer configuration, that results into different ETC at different operating conditions i.e. temperature and relative humidity (RH). Consequently, present study, experimentally investigates the RH effect on the thermal conductivity of the commercially available zeolite-based adsorbents, which are commercially named as: AQSOA-Z02 (zeolite-1) and AQSOA-Z05 (zeolite-2). The study is useful for the researchers who are working in the field of adsorption cooling, air-conditioning and desalination. In this regard, an experimental setup was developed by which the ETC was measured at different levels of RH. According to the results, the ETC of oven dried zeolite-1 and zeolite-2 was 0.060 W m^{-1} K^{-1} and 0.066 W m^{-1} K^{-1}, respectively. With the increase in RH, the numerical value of ETC increases up to 0.090 W m^{-1} K^{-1} for zeolite-1 and 0.089 W m^{-1} K^{-1} zeolite-2. Moreover, the empirical relation is proposed which can estimate ETC at different levels of RH for both adsorbents.

The present work concludes that desiccant drying should considered on top priority for drying of agricultural produce as DDS not only provides low temperature drying for temperature sensitive products but also reduce the total drying time. The basic principle is to create vapor pressure deficit between the product and environment hence accelerate the moisture removal. Present study illustrates the energy consumption for two different desiccant drying approaches i.e. latent load control and both latent and sensible load control. The choice of approach depends on the purpose of end use e.g. seed or commercial use. It is also concluded that the performance of desiccant system is affected by the change in relative humidity (RH). As change in RH causes to change in effective thermal conductivity (ETC) of the desiccant material attributed to change in heat transfer coefficient.