Investigation of Desiccant Air-Conditioning and Evaporative Cooling Systems for Agricultural Storage Applications

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論 文 内 容 の 要 旨

Thesis Summary

Energy efficient and low cost agricultural storage is a burning issue of 21st century where postharvest losses (PHL) are ranging from 25-50% of net agricultural produce. Lots of storage techniques have been adopted worldwide in this regard but these are either expensive or inefficient. Therefore, Desiccant Air-Conditioning (DAC) and Evaporative Cooling (EC) systems are investigated in this study in order to establish low-cost, energy-efficient and environmentally benign system. The study focuses on theory of agricultural storage and consequently performs series of experiments for the performance evaluation of desiccant unit. Simplified mathematical models of evaporative cooling are employed in order to opt-in these technologies into the proposed cooling system. The key features of the study are highlighted as follows:

Theory of agricultural storage as well as insights of storage are explained in the very first chapter keeping in view the complex mechanism of respiration, transpiration and fermentation. The PHL in existing agricultural/food production system are elaborated. Factors affecting the PHL in terms of products quality, quantity, storage life and mal/nutrition are correlated. Studied technologies are motivated vis-à-vis typical HVAC systems, and thermodynamics limitations are discussed. In the second chapter extensive literature has been reviewed for existing and advanced storage practices. In addition to the proposed storage, following storage techniques are reviewed: drying, ice, ventilation, refrigeration, HVAC, hypobaric, hyperbaric, heat treatment, ultraviolet irradiation, and controlled and modified atmosphere.

The chapter three is devoted for evaporative cooling technologies. Direct and indirect evaporative cooling (DEC / IEC) technologies are explained and compared. As all the conventional evaporative cooling is based on wet-bulb cooling conception therefore the present study emphasis on dew-point based advanced indirect evaporative cooling (named as Maisotsenko cycle or M-cycle cooling) for agricultural storage application. In addition to subjected application, the applicability of M-Cycle has also been studied and analyzed for various applications which include cooling tower, condenser, heat recovery from turbines using various cycles (see appendices). It has been found that direct evaporative cooling is only applicable for dry regions or climates where the prime objective is to control the temperature irrespective of air enthalpy. On the other hand indirect evaporative cooling including M-Cycle cooling (MEC) can be utilized sensibly in order to reduce the air enthalpy and dry-bulb temperature simultaneously. It is worth mentioning that the benefits of M-Cycle integration are obvious due to its dew-point cooling approach.

In contrary to evaporative cooling systems, desiccant air-conditioning (DAC) is investigated in chapter four for humid climates/regions where the prime objective is to reduce the humidity. An open-cycle experimental apparatus was setup for the performance evaluation of hydrophilic polymer based desiccant blocks. Series of experiments are conducted for various: ambient air conditions, regeneration conditions, cycle time, and switching time. Generalized root sum of squares method is used to calculate the experimental uncertainty, and experimental data can be reproduced within 2-3% error. It is examined that when humid ambient air passes through the desiccant unit deep dehumidification occurs. It shows huge potential of air dehumidification at low regeneration temperature (60ºC). It is determined that under the relatively dry ambient

air conditions equivalent heat of adsorption (q_{eq}) profile approaches to net value equals zero. The average effective dehumidification slightly increases under humid ambient air conditions by changing the switching time ratio from 1:1 to 2:3 due to higher process air relative humidity. However, it keeps decreasing with increase in switching time ratio for relatively dry ambient conditions. It has been found that the switching time depends on dehumidification amount, nature of application and operating conditions. From the bunch of experiments, it has been concluded that the switching time ratio of 1:2, 2:3 and 1:1 can be selected for the operation of DAC system for high, medium and low humidity operating conditions, respectively. The desiccant dehumidification process should follow isenthalpic line on psychrometric chart in an ideal scenario when there is no adsorption heat. The slope of dehumidification line on psychrometric chart is therefore modified for the realization of real desiccant dehumidification process based on experimental data. Consequently a simplified correlation is developed by which real desiccant dehumidification process can be predicted on psychrometric chart for polymeric desiccant. In addition the study also highlights the applicability of few polymer- and carbon- based nano and micro sorbents for agricultural storage (see appendices). The correlation leads toward the stead-state analysis of DAC systems.

In chapter five, six kinds of desiccant air-conditioning systems are proposed and analyzed for the summer conditions of Fukuoka (Japan). In each system latent load of AC was accomplished by desiccant unit whereas sensible load of AC was accomplished by M-cycle evaporative cooling. Storage compatibility of agricultural products is crucial to maintain the quantitative and qualitative attributes. In this regard, three different compatible groups of postharvest agricultural products (fruits and vegetables) according to their temperature and relative humidity (RH) are established for the psychrometric presentation of ideal storage zones. In case of dried fruits the ideal temperature and RH zones are established using Guggenheim, Anderson and De-Boer adsorption model. The effects of temperature on the storage life of dried fruits are realized by which it is found that shelf life reduces 50% by increase of 10ºC temperature. It has been found that the system without pre-evaporative cooling on regeneration side, require less regeneration heat due to the provision of regeneration air stream to the heat exchanger (HX) at higher dry-bulb and lower dew-point temperature. It also provides higher dehumidification and wet-bulb/dew-point effectiveness. Similarly system pre-cooling does not give positive outcomes even when HX is not integrated in to the systems. On the other hand, system with pre-evaporative cooling on regeneration side in the absence of MEC enables higher cooling capacity, supply air relative humidity and COP.

The study concludes that the evaporative cooling (preferably M-Cycle) systems should be considered on top priority for agricultural storage applications wherever these are thermodynamically and meteorologically applicable. When these are not applicable, thermally driven DAC systems could yield advance agricultural storage system which can control temperature and humidity distinctly irrespective to conventional compressor based AC systems. Therefore, integration of evaporative cooling unit(s) into DAC system will lead towards energy-efficient and reliable low-cost AC systems for various applications. However optimum operational conditions will need to be determined and regulated for particular application. Herein it has been concluded that one or other DAC system could be efficiently utilized for the storage of agricultural products.