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主 論 文 の 要 旨

論文題目　**Study on high-quality food storage system for low carbon transport (低炭素型高品質食品貯蔵輸送システムに関する研究)**

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論 文 内 容 の 要 旨

In view of the fasting growing market for food storage and transportation, especially in developing countries, it is unavoidable to increase greenhouse gas emissions considerably in the future if no relevant action is taken. The development of a high-quality food storage system for low carbon transport is necessary. In order to reduce unnecessary energy consumption and CO_2 emissions in the food transportation system, it requires not only proper regulation of storage conditions and accurate and convenient food quality evaluation method but also technologies of efficient energy utilization. The contribution of food transport refrigeration to the energy aspect of efficiency improvement could be demonstrated through the vital role of thermally driven refrigeration technologies for maintaining high food quality by optimization of storage conditions. Recovering a large amount of energy contained in the waste heat is an attractive way to create a sustainable economic and environmentally friendly development in the transportation system. Adsorption technology appears to be an efficient and promising option for use in the food refrigeration system, mitigating CO_2 emissions and reducing system fuel consumption.

In Chapter 1, background information regarding world energy and environmental issues, agricultural products are briefly introduced. The motivations for studying on the development of a high-quality food storage system to realize long-term preservation and transportation of agricultural products are then summarized. Finally, the objectives and outline of this thesis are presented.

In chapter 2, the influences of storage conditions on three perishable agricultural products (spinach, komatsuna, and strawberry) were experimentally investigated. The results indicate that the storage temperature and the relative humidity dramatically influence the storage period of the products studied. Storage temperature higher than 5 °C and relative humidity lower than 85% would accelerate leaf senescence, facilitate plant transpiration and induce thermal stress those contribute to a considerable decrease in the qualities of the three products. The products could maintain a high-quality level during 14 day storage at the storage temperature of 0 °C and the relative humidity of 90 %.

The management and inspection of agricultural product qualities are of critical importance throughout the whole chain. In order to develop an objective, fast and efficient quality evaluation method for the agricultural products storage, a laboratory-based hyperspectral imaging system profiling the chlorophyll distribution was established. The results indicate that hyperspectral imaging is capable of identifying and mapping chlorophyll pigments and their changes in samples non-destructively. The hyperspectral images provided the effective spatially-detailed information of chlorophyll distribution in different parts of the samples. After the acquisition of hyperspectral images and data processing, average spectral reflectance extracted from the interested region of sample leaves and calyxes were applied to develop the quality prediction model. Normalized different vegetation index (NDVI) as a function of the spectral reflectance at the regions of red (670 nm) and red edge (705 nm) was used to evaluate the visual quality change in samples. The changes in sample visual quality at different storage conditions were reasonably well evaluated by both the two indices. In contrast, there was a stronger correlation between $NDVI_{705}$ and visual quality rating than that between $NDVI_{670}$ and visual quality rating, indicating the superiority of spectral reflectance in red edge region for visual quality evaluation.

In order to effectively utilize the exhaust heat from the food storage system, an activated carbon–NH_3 adsorption refrigeration system was proposed in Chapter 3. The application of adsorption refrigeration systems is constrained by their low coefficient of performance (COP), specific cooling power (SCP) and volumetric cooling power (VCP). To achieve high system performance, the selection of appropriate adsorbent–adsorbate pair is critical. In comparison with other natural refrigerants, NH_3 has a high latent heat of evaporation, high vapor pressure, and can be applied to produce sub-zero temperatures. Due to the high ability of mass transfer and stable adsorption capacity, activated carbon was chosen as the adsorbent for NH_3 in this research. The specific surface area, pore size distribution and morphological structure of the several activated carbons have been characterized by N_2 adsorption, SEM, and XRD. The adsorption capacities of activated carbons were compared based on adsorption isotherms at 30 °C. The results indicate that MSC30 had an excellent adsorption capacity of NH_3 due to both higher specific surface area and higher pore volume than the other activated carbons tested. The adsorption isotherms of NH_3 on MSC30 at 20 °C, 30 °C, and 40 °C could be described by the modified Dubinin–Astakhov equation successfully. Isosteric heat of adsorption of MSC30-NH_3 was evaluated by using the Clausius–Clapeyron equation and was found in the range of 1552 to 2317 kJ/kg (with an average value of 1922 kJ/kg) depending on the amount adsorbed.

The coefficient of performance (COP), specific cooling power (SCP) and volumetric cooling power (VCP) of MSC30–NH_3 refrigeration system at various evaporating temperatures (5 °C, 10 °C, and 15 °C) and cycle times (300 s ~ 600 s) were experimentally investigated. The COP, VCP, and SCP increased as the evaporating temperature decreased. However, it is hard to satisfy both COP and VCP/SCP at the same cycle time. The COP, VCP, and SCP obtained were 0.35, 109 $W/L_{\text{-heat exchanger}}$, and 520 $W/kg_{\text{-absorbent}}$, respectively, at the condition of 15 °C and 600s. The results indicated that the system needed improvement on the heat transfer performance in the adsorbent packed bed and the heat exchanger. A long-term operation without degradation for MSC30-NH_3 adsorption/desorption process was experimentally demonstrated from the repetition operations, showing the MSC30-NH_3 is a promising pair for the adsorption refrigeration system.

In Chapter 4, a lab-scale FAM-Z05/H_2O type adsorption chiller cycle with or without mechanical booster pump (MBP) was analyzed. The objective of this chapter is to investigate the possibility to apply an MBP–assisted adsorption chiller cycle to improve the cooling power and generate cooling power at a wider operational temperature range, such as operation at a waste heat temperature below 60 °C or a lower evaporating temperature. The MBP was set either between the evaporator and the adsorber to increase the vapor pressure in the adsorber or between the adsorber and the condenser to decrease the vapor pressure in the adsorber. The results indicate that the increase of adsorber vapor pressure in the adsorption process contributed to a higher equilibrium adsorbed amount, and the decrease of adsorber vapor pressure in the desorption process resulted in a lower equilibrium adsorbed amount. The cooling heat output and the amount of cooling heat were improved and increased with the input electrical power of MBP. Moreover, the adsorption chiller could be operated at the evaporating temperature of 10 °C which is not available in thermal driven adsorption system when the adsorption temperature and desorption temperature are set at 30 °C and 60 °C or lower, respectively.

COPs based on electricity input, heat input and total energy input (the sum of electricity and heat) were investigated. The $COP_{electricity}$ decreased with increasing the input electrical power of the MBP. When the evaporating temperature was 15 °C, the $COP_{electricity}$ for the input electrical power of 20 W, 60 W, and 120 W was 7.0, 5.0, and 3.0 respectively, which were approximately the same as mechanical chiller cycle. In addition, the $COP_{electricity}$ at the evaporating temperature of 10 °C exhibited the same tendency as the results of 15 °C. On the other hand, COP_{heat} increased with the increase of input electrical power and obtained COP_{heat} values of 0.69 and 0.68 at 1500 s that is 1.2 times and 1.1 times higher than that of without MBP (0.62) at 15 °C when the input electrical power was 60 W and 120 W, respectively. At 10 °C, COP_{heat} of about 0.67, 0.66, and 0.55 could be obtained at 1500 s when the input electrical power was 20 W, 80 W, and 120 W, respectively. COP_{total} decreased with the increase of operation time when the input electrical power at 60 W and 120 W due to the adsorption capacity of adsorbent nearly reached the saturation state, indicating that there is an optimum input electrical power and operation time for acquiring the maximum cooling power and COP_{total} at different conditions. The desorption heat input and the amount of heat input were improved and increased with the input electrical power of MBP. Desorption cycle could be effectively driven by a relatively low desorption temperature such as 45 °C, in comparison with the cycle without MBP.

Chapter 5 summaries the conclusions of this study and suggestions in the future work about the high-quality food system for low carbon transport system.