Study on sorption characteristics of water adsorbents for agricultural air-conditioning systems

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論 文 名：　Study on sorption characteristics of water adsorbents for agricultural air-conditioning systems
(農業用空調システムに向けた水蒸気吸着材料の特性に関する研究)

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論 文 内 容 の 要 旨

Agricultural greenhouses possess a complicated scheme of sensible and latent load of air-conditioning (AC) in order to maintain the ideal vapor pressure deficit, photosynthesis, and evapo-transpiration. The desiccant air-conditioning (DAC) system in comparison with conventional AC system enables the progressive ability to deal these loads distinctly. It is an environmentally friendly technology which can utilize low temperature waste heat and renewable energy sources.

In comparison with conventional hydrophilic ad/sorbents, the carbon and polymer based ad/sorbents enable higher water vapor adsorption uptake and possess different kinds of adsorption trend which could be interesting for greenhouse DAC application. Unlike conventional AC, the greenhouse AC requires high relative humidity and ventilation rate. The adsorption characteristics (e.g. adsorption isotherms, adsorption kinetics, isosteric heat of adsorption etc.) and system design data for high humidity based adsorbent/water pairs are limited in the literature in order to establish the advance DAC system for greenhouses. Furthermore, there is a lack of thermodynamic analysis and heat/mass transfer understanding of greenhouse DAC.

From the above perspective, the present study emphases the optimization of adsorbents for greenhouse DAC by means of experiments, thermodynamic analysis, and numerical simulation. Apart from the fundamental adsorption characteristics, the dissertation provides steady-state and dynamic approaches to analyze the adsorbent/water pairs for long and short cycle based greenhouse DAC application. Due to adsorption kinetics variability, the studied carbon based (CBAs) and novel polymer based (PBAs) ad/sorbents are investigated for long and short cycle time applications, respectively.

Water vapor adsorption data by two CBAs and two PBAs have been obtained using volumetric and gravimetric method based experimental units, respectively. The measured data are modelled for various water vapor adsorption isotherm and adsorption kinetics models for comparative analysis. The adsorption models' parameters are optimized and their sensitivity is addressed accordingly. Experimental adsorption rate by PBAs couldn't fit with most commonly used adsorption kinetic approximations because of particle swelling and/or adsorption/absorption phenomena. Hence, a novel adsorption kinetics model is introduced which successfully addresses these issues and gives best regression of the experimental data. The numerical values of diffusion time constant are determined, and their sensitive with operating parameters is explored. Moreover, the isosteric heat of water vapor adsorption is determined as a function of adsorption uptake using Clausius–Clapeyron relationship for all the studied ad/sorbents.

Ideal greenhouse growth zones are determined on the basis of VPD for various agricultural products. The performance of CBAs in steady-state DAC cycle has been evaluated for long-cycle based greenhouse DAC application. Effect of regeneration temperature on the dehumidification performance is investigated. Steady-state cycled moisture and adsorbent to air mass fraction is determined for three kinds of demand categories. The analyses are directed to make use of low temperature regeneration with long-cycle time in order to utilize the solar thermal energy.

Dynamic simulation of greenhouse DAC has been conducted on behalf of different climatic cities which include: Fukuoka, Multan, Kuala Lumpur, and Bangkok. Honeycomb like desiccant blocks composed of PBAs are assumed for analysis. A dynamic simulation model is programmed into MATLAB which utilizes the scientific relationships developed for adsorption isotherms, adsorption kinetics, isosteric heat of adsorption, and thermo-physical properties. A novel correlation is developed by which the open-cycle adsorption rates are optimized from close-cycle adsorption kinetics data. Parametric analyses are performed in order to comprehend the sensitivity of the operating parameters. Finally the effects of operating parameters on system coefficient of performance (COP) have been investigated.

The present work concludes that the polymer sorbent PS-I is the promising sorbent for greenhouse DAC application, though its performance depends on ambient conditions. On the other hand, CBAs can be used for greenhouse DAC economically only if considered for long cycle time with solar regeneration.