Study on Adsorption Characteristics of Ethanol onto Activated Carbons : Effect of Surface Treatment

Uddin, MD Kutub

氏　　　名：　MD KUTUB UDDIN

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論　文　内　容　の　要　旨

Adsorption refrigeration and heat pump systems powered by waste heat sources utilizing environment friendly adsorbent and refrigerant pairs received great attention in the past few decades. The main feature of these systems are; the ability to operate by low temperature heat source typically below 100ºC that would be abundantly available from industrial waste heat or solar energy, almost no electricity usage, no movable parts and simple in operation.

For adsorption cooling and heat pump application, among the adsorbents studied so far, highly porous activated carbon powders have been proven to be efficient adsorbents. Due to higher surface area and pore volume, it exhibits higher uptake and faster kinetics compared to granular type of activated carbon when operates with environmental friendly alcohols such as ethanol. Ethanol is a non-toxic substance and it has relatively higher vapor pressure even at a low temperature levels. Despite the perceived suitability of activated carbon powder/ethanol pairs, there is a dearth of adsorption characteristics (e.g. adsorption isotherms, kinetics, isosteric heat), specific heat capacity and design data for cooling/heat pump systems hitherto in the literature. From the above perspective, the objectives of this thesis is to gather the adsorption characteristics and design data for parent and surface treated activated carbon/ethanol pairs considering the suitable working conditions for adsorption cooling and heat pump system.

This thesis consists of seven chapters which describe the experiments and theory to achieve the research objectives. Following are the brief description of the contents of each chapter.

Chapter 1 provides a scientific background about the adsorption phenomenon and the classifications of sorption systems. The theory of operation of the basic adsorption cooling cycle is also discussed in this chapter. A literature review on adsorbent/refrigerant pairs which are commonly used in adsorption cooling and heat pump systems are presented therein. The research objective and scope has also been enumerated in this chapter.

Chapter 2 describes the experimental methods, apparatus and procedures in determining the adsorption

equilibria of the parent and surface treated Maxsorb III and ethanol pair. The isotherm data are measured using a magnetic suspension balance adsorption measurement unit at temperatures and pressures ranges corresponding to the working conditions of adsorption cooling cycles. Experimental data have been analyzed and fitted using Dubinin Radushkevich (D-R) and Dubinin-Astakhov (D-A) equations.

Chapter 3 presents experimental and theoretical studies on the adsorption kinetics of ethanol onto parent and surface treated activated carbons. Experiments have been carried out at different adsorption temperatures ranging from 30 to 70ºC and relative pressure up to 0.9, which are suitable for adsorption chiller design. The mass of ethanol adsorbed onto parent and treated Maxsorb III is measured by a magnetic suspension balance unit under a controlled pressure and temperature environment. The measured uptake mass is logged with a time interval of 0.1 second making a continuous change of ethanol uptake with time. The experimental data are regressed with expression derived from the Fickian diffusion (FD) model. The particle size of adsorbents has been measured using a laser diffraction particle size analyzer.

In Chapter 4, a simplified method for isosteric heat of adoption has been proposed using the D-A isotherm model and the Van't Hoff equation. In the proposed correlation, isosteric heat is found to be a function of the refrigerant concentration and adsorbent temperature and it is expected that it will be useful for designing adsorption cooling and heat pump systems.

Chapter 5 deals with the heat capacity measurement of the parent and surface treated activated carbon along with other commonly used adsorbents for temperature ranging from 30 to 150 ºC. A differential scanning calorimeter is used to measure the specific heat capacity. These data are also essential for accurate system design.

Chapter 6 presents thermodynamic analysis of adsorption refrigeration cycles using parent and surface treated activated carbons/ethanol pairs employing a time-independent mathematical model. The study considers the refrigeration and air-conditioning application of adsorption systems.

The conclusions of the work are presented in Chapter 7 which highlights the practicality of choosing the pairs of surface treated activated carbon/ethanol for adsorption cooling and heat pump systems. A case study in this regard proved that 30% energy saving by adsorption-compression hybrid refrigeration systems as compared to the conventional mechanical compression system as presented in Appendix D. The experiment results show that the $KOH-H_2$ treated activated carbon has significantly higher adsorption kinetics than the other studied pairs. The use of $KOH-H_2$ treated activated carbon will enhance the energy saving potential of the waste heat driven adsorption cooling and heat pump system.