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Adsorption characteristics of ethanol onto functional activated carbons with controlled oxygen content

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HIGHLIGHTS

- Presents adsorption characteristics of ethanol onto parent and surface treated Maxsorb III.
- Measurements have been conducted for adsorption temperatures from 20 to 80 °C.
- The isosteric heat of adsorption data extracted using popular equations.
- These data are essential for designing adsorption cooling and heat pump systems.

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ABSTRACT

The present study aims to investigate adsorption characteristics of ethanol onto activated carbon powders namely; parent Maxsorb III and surface treated Maxsorb III with controlled oxygen content. Experiments have been conducted gravimetrically using a magnetic suspension adsorption measurement unit. The measurements have been conducted within evaporator temperatures range from −14 to 77 °C and adsorption temperatures between 20 and 80 °C. The Dubinin–Astakhov (D–A) adsorption model is found to be suitable to correlate the adsorption isotherm data. The isosteric heat of adsorption of the assorted adsorbent/refrigerant pairs has been estimated using Clausius–Clapeyron and the D–A equations. Effect of the refrigerant purity on the adsorption characteristics of the adsorbent/refrigerant pair is also discussed. The data extracted from this study are useful for the design of adsorption cooling, refrigeration and heat pump systems.

1. Introduction

The thermally powered adsorption cooling and heat pump systems got considerable attention in the past few decades due to the awareness of global warming and ozone depletion problems. The main advantages of adsorption systems over the conventional cooling systems are: (i) the ability to use refrigerants having zero ozone depletion potential (ODP) and low global warming potential (GWP), (ii) these systems can be driven by low grade thermal energy, (iii) almost no electricity usage, and (iv) the simplicity of operation. Extensive studies have been conducted to investigate the performance of adsorption cooling/heat pump systems considering various adsorbent/refrigerant pairs, such as silica gel/water, zeolite/water, carbon/ammonia, activated carbon/methanol, activated carbon/ethanol and other working pairs [1–11]. The high adsorption capacity of ethanol and methanol onto highly porous activated carbons and low regeneration temperature (below 100 °C) makes it possible to use these working pairs in solar adsorption cooling application [8,11].

Adsorption characteristics of adsorbent/refrigerant pairs in terms of adsorption isotherms, kinetics and isosteric heat of adsorption are essential for the optimum design and development of adsorption cooling and heat pump systems. Adsorption isotherms describe the equilibrium uptake at a given equilibrium

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Nomenclature

A	adsorption potential, kJ/kmol
E	adsorption characteristic parameter, J/mol
n	exponent fitting parameter used in the D–A equation
P	equilibrium pressure of refrigerant, kPa
P_S	saturation pressure of refrigerant at adsorption temperature, kPa
Q_{st}	isosteric heat of adsorption, kJ/kg
R	universal gas constant, J/mol K
T	temperature, K
W	equilibrium uptake, kg/kg
W_0	maximum adsorption capacity, kg/kg

pressure and adsorption temperature. The most common techniques used for measuring adsorption isotherms are; (i) gravimetric method using thermogravimetric analyzer (TGA) unit [12–16] or magnetic suspension balance (MSB) [17,18], (ii) chromatographic method [19], (iii) constant volume variable pressure (CVVP) method [20,21], (iv) measuring the liquid refrigerant level at evaporator side [8,10], and (v) desorption method [22]. It is proven that the gravimetric method employing TGA or the magnetic suspension balance provides high accuracy of adsorption equilibrium and kinetic measurements. El-Sharkawy et al. [11] measured the adsorption equilibrium of ethanol onto activated carbon powder, namely parent Maxsorb III, for solar powered adsorption cooling applications using a TGA unit of type Chan-2121coupled with a controlled temperature evaporator. Hornbostel et al. [16] studied the characteristics of carbon sorbent for CO_2 capture using a temperature programmed TGA. Saha et al. [17] studied the adsorption characteristics of R134a onto activated carbons using Rubotherm ISOSORP 2000 within evaporation temperatures between −20 and 40 °C and adsorption temperatures ranges from 30 to 80 °C for refrigeration and cooling applications.

In the present study an automated controlled magnetic suspension adsorption measurement unit of type MSB-VG-S2 has been used to investigate the adsorption characteristics of environment friendly refrigerant ethanol onto activated carbons, namely parent Maxsorb III, KOH–H_2 treated Maxsorb III and H_2 treated Maxsorb III within evaporation temperature ranges between −14 and 77 °C and adsorption temperature from 20 to 80 °C. This paper emphasizes the evaluation of adsorption equilibrium and isosteric heat of adsorption of the assorted pair. Effect of the refrigerant purity on the isotherms parameters of adsorbent/refrigerant pairs derived from popular models have also been discussed.

2. Experiments

2.1. Materials

Adsorbents used in the present study are parent Maxsorb III, KOH–H_2 treated Maxsorb III and H_2 treated Maxsorb III. The sample, H_2 treated Maxsorb III is prepared by placing parent Maxsorb III in a reduction environmental condition (Ar/H_2 = 8/2 (v/v)) at a temperature of 600 °C for 24 h. To prepare the KOH–H_2 treated Maxsorb III, potassium hydroxide (KOH) treatment was applied to H_2 treated Maxsorb III at different weight ratios and the mixture is heat treated at temperature between 600 and 750 °C for 1 h under nitrogen flow and finally washed with HCl to adjust the pH value of about 7 [23]. Fig. 1 shows the SEM pictures of the studied adsorbents whilst their elemental compositions are summarized in Table 1. The particle size distributions of the assorted adsorbents have been measured by El-Sharkawy et al. [24]. It can be seen from Table 1 that the parent Maxsorb III contains 0.13% of ash and 4.35% of oxygen whilst the H_2 treated Maxsorb III and KOH–H_2 treated Maxsorb III having no ash and the oxygen contents varies between 1.75 and 10.46%, respectively. It is worthy to mention that, for polar molecules such as ethanol, surface functional groups should have a strong influence on the adsorption behaviors. Therefore, the main intention for the treatment is to clarify such influence by changing oxygen contents of activated carbon maintaining very similar thermophysical properties (specific surface area, pore volume, and pore size). The refrigerant used in the present study is ethanol with a purity of 95%. A sample of ethanol is tested and its compositions are furnished in Table 2. As ethanol has few percentages of other

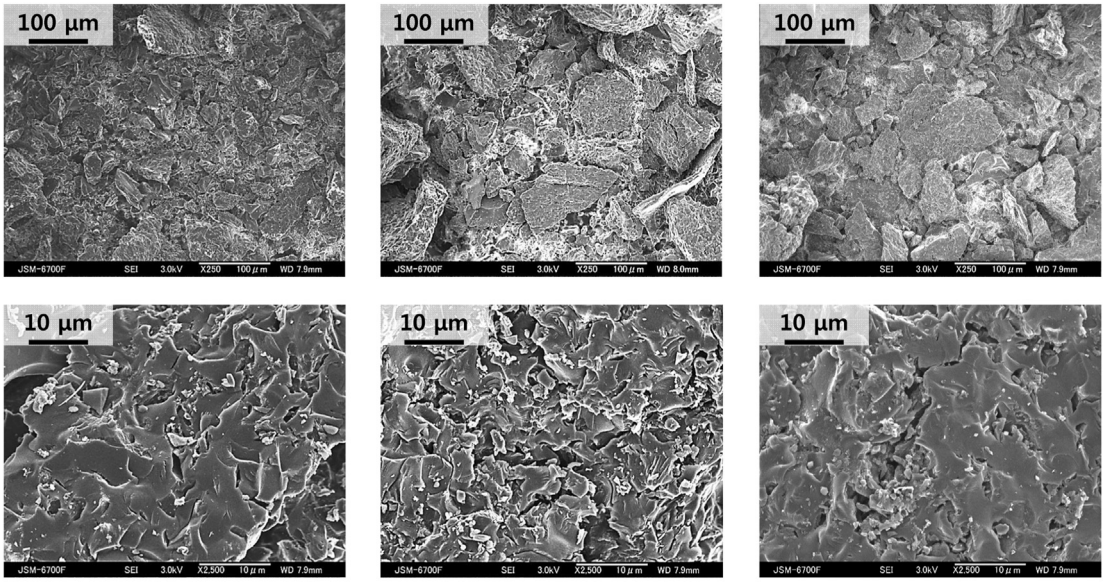

Fig. 1. SEM pictures of the studied adsorbents (a) parent Maxsorb III, (b) H_2 treated Maxsorb III and (c) KOH–H_2 treated Maxsorb III.