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Adsorption of ethanol onto parent and surface treated activated carbon powders

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ABSTRACT

In this paper, adsorption isotherms and kinetics of ethanol onto highly porous activated carbon powders have been investigated. Adsorbents used in the present study are (i) parent Maxsorb III, (ii) KOH-H_2 treated Maxsorb III, and (iii) H_2 treated Maxsorb III. Adsorption isotherms and kinetics of the assorted pairs have been measured using magnetic suspension adsorption measurement unit (MSB-VG-S2). Experiments have been conducted across assorted adsorption temperatures that are useful for the operation of adsorption chillers. The Dubinin–Astakhov equation is used to fit adsorption isotherms of parent Maxsorb III/ethanol and KOH-H_2 treated Maxsorb III pairs whilst the Dubinin–Radushkevich isotherm model is found to be more suitable for fitting of adsorption uptake of H_2-treated Maxsorb III/ethanol pair. Adsorption kinetics of assorted pairs are presented by the Fickian diffusion model. Experimental results show that, among the assorted pairs, H_2 treated Maxsorb III/ethanol pair possesses the highest adsorption equilibrium uptake. However, the diffusion time constant of KOH-H_2 treated Maxsorb III is found to be higher than that of other two studied pairs.

1. Introduction

The decade of 1930s witnessed a revolution in cooling technology with the development of Freon type synthesis refrigerants, which greatly increased the coefficient of performance of vapor compression based systems. However, synthetic refrigerant based vapor compression systems have two major concerns. The substances such as CFCs, HCFCs, etc. which are used as the working fluid in most vapor compression systems have been found to be responsible for Ozone layer depletion as well as contributing to global warming. Moreover, vapor compression systems use compressors that consume huge amount of electrical energy. The need for a switch over to green and sustainable alternatives is, thus, evermore pressing. Thermally powered adsorption cooling system is considered one of the most promising alternatives of electricity powered vapor compression system. Design of efficient adsorption cooling systems requires accurate information about adsorption characteristics of adsorbent/refrigerant pairs. Among these characteristics, adsorption isotherms and kinetics play essential rules on the system design and performance optimization. Extensive research efforts have been conducted to investigate adsorption isotherms of various adsorbent/refrigerant pairs [1–7]. Adsorption kinetics has also been addressed by a notable number of researchers, following are some representative examples. Aristov et al. [8] measured adsorption kinetics of water vapor on loose grains of Fuji Davison RD silica gel using TG differential method. Experiments have conducted within a temperature range of 29–64 °C and a pressure range from 6.5 to 34 mbar. Adsorption kinetics of water onto composite material ($CaCl_2$ confined to mesoporous silica named SWS-1L) has also been investigated using a CAHN microbalance under isothermal conditions at constant pressure [9]. Three different grain sizes of SWS-1L have been tested and results showed a remarkable enhancement in adsorption rate with the decrease in particle size. El-Sharkawy et al. [10] investigated adsorption kinetics of activated carbon fiber/ethanol pair by gravimetric method using TGA (CAHN TG 2121) unit. The authors proposed a new concentration profile that removes the restrictions between

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Nomenclature

A	adsorption potential (kJ kg^{-1})	R_p	particle radius (μm)
D	diffusivity (m^2 s^{-1})	T	temperature (K)
D_{so}	pre-exponential constant (m^2 s^{-1})	t	time (s)
E	adsorption characteristics parameter (kJ kg^{-1})	W	equilibrium adsorption uptake (kg kg^{-1})
E_a	activation energy (kJ kg^{-1})	w	instantaneous adsorption uptake (kg kg^{-1})
F	fractional uptake (-)	w_{in}	initial uptake (kg kg^{-1})
P	equilibrium pressure (kPa)	W_o	maximum adsorption capacity (kg kg^{-1})
P_s	saturated pressure (kPa)		
R_g	gas constant (kJ kg^{-1} K^{-1})		

the overall mass transfer coefficient and the diffusion time constant and the model has been validated experimentally. Adsorption kinetics of ammonia onto composite adsorbent material ($BaCl_2$ impregnated into a vermiculite matrix) has been investigated under isothermal conditions and in a laboratory scale system [11]. Veselovskaya et al. [12] measured adsorption kinetics of the same pairs under conditions more close to the real conditions of adsorption chillers. The authors reported that this material can provide a COP as high as 0.54 ± 0.01 and SCP ranging from 300 to 680 W/kg using heat source temperatures between 80–90 °C. Dawoud and Aristov [13] measured adsorption kinetics of water vapor sorption on mesoporous silica gel, alumina, microporous silica gel and two composites, namely SWS-1L and SWS-1A. These composite materials are formed by impregnating $CaCl_2$ into mesoporous silica gel and alumina, respectively. The authors reported that there is an increase of about two to three times in the differential water loading on the SWS-composites compared to the host materials. However, the kinetics of water sorption into the host matrices is faster than that into the studied two SWS-composites. Aristov [14] discussed principles of creating database of adsorbents promising for adsorptive transformation of heat. The proposed database considered the main adsorbent properties and addresses the issues of their measurement and calculation. The study also presented a tentative list of promising adsorbent-adsorbate pairs. Other studies dealing with adsorption kinetics can be found elsewhere [15–19].

The present study deals with experimental investigation of adsorption isotherms and kinetics of ethanol onto three types of adsorbents namely; parent Maxsorb III, KOH-H_2 treated Maxsorb III and H_2 treated Maxsorb III. Experimental measurements have been conducted using a magnetic suspension balance. Experiments have been conducted across assorted adsorption temperatures that are useful for the operation of adsorption chillers. The Dubinin–Astakhov and the Dubinin–Radushkevich equations are used to fit the equilibrium uptake whilst adsorption kinetics are correlated using the Fickian diffusion model.

2. Experimental section

2.1. Materials

The adsorbents used in the present study are: (i) Parent Maxsorb III which is a highly porous activated carbon powder provided by Kansai Coke & Chemicals Co. Ltd., Japan (ii) a surface treated Maxsorb III (KOH-H_2 Maxsorb III), and (iii) H_2-surafce treated Maxsorb III. The treatment procedure has been described in reference [20]. Thermo-physical properties and elemental composition of assorted adsorbents are given in Tables 1 and 2, respectively. It can be seen from Table 1 that, there is no significant change in both surface area and average pore width. However, H_2-traeted Maxsorb III possesses the highest micropore volume followed by parent

Table 1
Thermo-physical properties of parent and surface treated Maxsorb III [20].

Sample	Total surface area [m^2 g^{-1}]	Micropore volume [cm^3 g^{-1}]	Average pore width [nm]
Parent Maxsorb III	3045	1.70	1.12
KOH-H_2-Maxsorb III	2992	1.65	1.11
H_2-Maxsorb III	3029	1.73	1.15

Table 2
Elemental composition of parent, KOH-H_2 and H_2 treated Maxsorb III [20].

Sample	C [%]	H [%]	N [%]	O(diff.) [%]	O/C	Ash [%]
Parent Maxsorb III	95.13	0.14	0.25	4.35	0.034	0.13
KOH-H_2-Maxsorb III	89.15	0.27	0.08	10.46	0.088	–
H_2-Maxsorb III	97.91	0.22	0.12	1.75	0.013	–

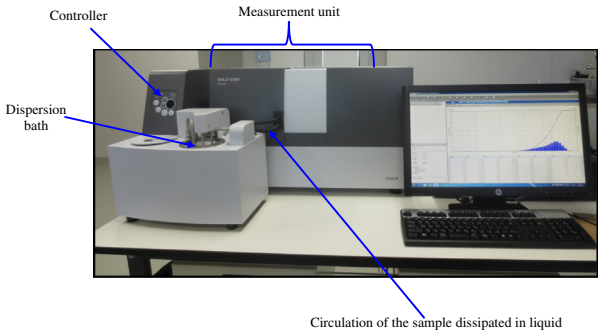

Fig. 1(a). A pictorial view of laser diffraction particle size analyzer.

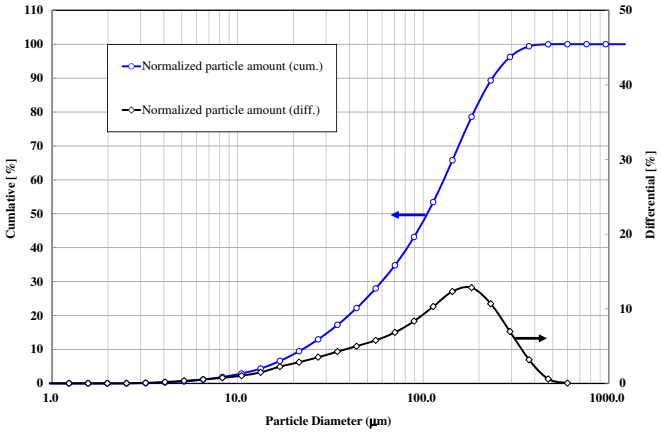

Fig. 1(b). Particle size distribution for a sample of parent Maxsorb III.