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Experimental investigation on activated carbon–ethanol pair for solar powered adsorption cooling applications

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ABSTRACT

Adsorption equilibrium uptake of ethanol onto a highly porous activated carbon based adsorbent, namely Maxsorb III, has been experimentally investigated using a thermogravimetric analyzer (TGA) unit over adsorption temperatures ranging from 20 to 60 °C. The Dubinin–Astakhov (D–A) equation has been used to correlate the experimental data. Isosteric heat of adsorption is also estimated by using the Clausius–Clapeyron equation. Employing a thermodynamically equilibrium model, the performance of the ideal adsorption cooling cycle has also been studied and compared to that of activated carbon fiber (ACF)–ethanol pair. Experimental results show that Maxsorb III can adsorb up to 1.2 kg of ethanol per kilogram of adsorbent. Theoretical calculations show that, the Maxsorb III–ethanol adsorption cycle can achieve a specific cooling effect of about 420 kJ kg^{-1} at an evaporator temperature of 7 °C along with a heat source of temperature 80 °C and thus the pair is recommended for solar cooling applications.

Etude expérimentale sur le couple charbon actif-éthanol pour les applications de refroidissement à adsorption solaire

Mots clés : Réfrigération ; Système à adsorption ; Charbon actif ; Éthanol ; Chauffage ; Énergie solaire ; Expérimentation ; Modélisation ; Simulation ; Performance

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Nomenclature

COP	Coefficient of performance (–)
C_p	Specific heat capacity (kJ kg^{-1} K^{-1})
E	Adsorption characteristic parameter in Eq. (1)
LH	Latent heat (kJ kg^{-1})
n	Exponent parameter of (D–A) equation
P	Pressure (kPa)
P_s	Saturation pressure (kPa)
Q	Energy (kJ)
T	Temperature (K)
q_{st}	Isosteric heat of adsorption (kJ kg^{-1})
R	Gas constant (kJ kg^{-1} K^{-1})
SCE	Specific cooling effect (kJ kg^{-1})
W	Equilibrium uptake (kg kg^{-1})
W_0	Maximum equilibrium uptake (kg kg^{-1})

Subscripts

ad	Adsorbent
ads	Adsorption
c	Condenser
des	Desorption
e	Evaporator
h	Heat added
latent	Latent heat
max	Maximum
min	Minimum
ref	Refrigerant
sens	Sensible heat

1. Introduction

Thermally driven adsorption cooling and heat pump systems have gained considerable attention because, (i) they could utilize low temperature waste heat or renewable energy sources and (ii) the adsorption cycle is suitable to employ waste heat at low temperatures, reducing the effects of global warming. In addition, the adsorption cycle has minimal moving parts, free of noise and low maintenance cost. Hitherto, many studies have investigated the performance of adsorption cooling cycle employing various adsorbent–refrigerant pairs. Sakoda and Suzuki (1984) proposed a transient simulation model of a solar powered adsorption cooling cycle using silica gel–water as adsorbent–refrigerant pair. Silica gel–water based adsorption cooling system has been analyzed experimentally by Boelman et al. (1995) and analytically by Saha et al. (1995). Multi-stage adsorption cooling cycles have also been developed and analyzed employing the same pair by Saha et al. (1997, 2003). Zeolite–water pair is used for solar adsorption cooling and air conditioning applications (Tatlıer and Erdem-Imageenatalar, 1999; Wang et al., 2006). The former system can be powered by heat source of temperature below 100 °C, while the latter required heat source of temperature above 100 °C. Pons and Guilleminot (1986) have experimentally investigated the performance of an activated carbon–methanol adsorption system for ice production by using renewable energy. Meunier (1989) proposed and analyzed a cascading adsorption cycle in which an activated carbon–methanol cycle is topped by zeolite–water cycle. Activated carbon–ammonia pair has also been widely used in adsorption cooling and heat pump systems (Critoph, 1994, 1998; Miles and Shelton, 1996). Kanamori et al. (1997) proposed activated carbon–ethanol adsorption heat pump with a disk-module type adsorber for refrigeration applications. Experimental results show that the proposed adsorption heat pump could be driven with a regeneration temperature of about 350 K to produce cooling energy at a temperature of about 260 K. An experimental study on activated carbon–methanol and activated carbon–ethanol for solar ice maker applications has been conducted by Li et al. (2004). The study shows the superiority of the former pair for solar ice maker applications. El-Sharkawy et al. (2006a, b) has been experimentally investigated the adsorption characteristics of activated carbon fiber (ACF)–ethanol pair for adsorption cooling applications and the transient model of a two bed ACF–ethanol adsorption chiller has also been theoretically investigated (Saha et al., 2007a, b). Other studies presented the achievements gained in the sorption refrigeration technology and summarized the environmentally benign adsorbent–adsorbate pairs which could be used in adsorption refrigeration (Wang and Oliveira, 2006; Wang et al., 2008; Cui et al., 2005). Even though various adsorption cooling systems have been proposed and developed, however, for widespread dissemination of such system the enhancement of system performance is inevitable. To improve the system performance, it is essential to determine accurately the adsorption characteristics and kinetics of the adsorbent–adsorbate pair.

The motivation of this study deals with the adsorption characteristics of an environmental friendly refrigerant namely ethanol onto a highly porous activated carbon such as the Maxsorb III. The high adsorption capacity of the Maxsorb III–ethanol pair makes it possible to use as the working pair in adsorption cooling systems. The cycle performance is also studied from the thermodynamic viewpoint.

2. Materials

The adsorbent employed in the present study is Maxsorb III and is developed by the Kansai Coke & Chemicals Co., Ltd., Japan. The porous properties of Maxsorb III were measured by using N_2 adsorption isotherm at a temperature of 77.4 K (Saha et al., 2008a). It is found that Maxsorb III possesses a surface area as high as 3200 m^2 g^{-1} and mean pore diameter 2 nm. Fig. 1(a) shows the breakthrough curves for Maxsorb III whilst the transmission electron microscopy (TEM) image of the assorted adsorbent is shown in Fig. 1(b). It can be seen from Fig. 1(a) that the adsorption–desorption processes for