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Accurate adsorption isotherms of R134a onto activated carbons for cooling and freezing applications

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ABSTRACT

The objective of this article is to improve the performance of thermally powered adsorption/cooling systems by selecting a new adsorbent/refrigerant pair. Adsorption equilibrium data of R134a onto granular activated carbon (AC) and Unitika activated carbon fiber (ACF) of type (A-20) have been measured experimentally using Rubotherm ISOSORP 2000 within evaporation temperatures range between −20 and 40 °C and adsorption temperatures range from 30 to 80 °C. Experimental data have been correlated using various popular isotherm models. The isosteric heat of adsorption of the assorted adsorbent/refrigerant pairs has also been extracted from the present experimental data.

Isothermes d’adsorption précises pour le R134a sur du charbon actif dans les applications de refroidissement et de congélation

Mots clés : Charbon actif ; Isotherme d’adsorption ; Refroidissement ; R134a

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Nomenclature

B	Van der Waals volume ($m^3\ kg^{-1}$)
b	Adsorption affinity constant (kPa^{-1})
b_0	Adsorption affinity constant at an infinite temperature (kPa^{-1})
C	Adsorption uptake at equilibrium condition ($kg\ kg^{-1}$)
C_0	Maximum adsorption uptake at equilibrium condition ($kg\ kg^{-1}$)
COP	Coefficient of performance (–)
c_p	Specific heat capacity ($kJ\ kg^{-1}\ K^{-1}$)
D	Adsorption parameter used in Eq. (1) and Eq. (2) ($K^{1/n}$)
n	Exponent parameter of (D-A) equation
P	Equilibrium pressure (kPa)
P_s	Saturation pressure (kPa)
T	Temperature [K]
q_{st}	Isosteric heat of adsorption ($kJ\ kg^{-1}$)
R_g	Gas constant ($kJ\ kg^{-1}\ K^{-1}$),
SCE	Specific cooling effect ($kJ\ kg^{-1}$)
W	Volumetric adsorption equilibrium uptake ($cc\ g^{-1}$)
W_0	Volumetric maximum equilibrium uptake ($cc\ g^{-1}$)

Greek

α	isosteric coefficient of the expansion of the adsorbed volume (K^{-1})

Subscripts

a	Adsorbed phase
b	Boiling
cal	Calculated
crit	Critical
exp	Experimental

1. Introduction

Over the past few decades, adsorption cooling/heat pump systems have gained considerable attentions as they appear to be promising from the viewpoint of green house gas (GHG) emissions and Ozone layer depletion problems. The thermophysical properties of the adsorbent/refrigerant pair as well as the operating conditions have significant effects on the system performance. Extensive studies have been conducted to investigate the performance of adsorption cooling/heat pump systems considering various adsorbent/refrigerant pairs.

Of the adsorbent-refrigerant pairs working at subatmospheric conditions are silica gel-water (Saha et al., 2006, 2009a; Núñez et al., 2007), zeolite-water (Wang et al., 2006; Liu and Leong, 2008), composite adsorbents/water pairs (Aristov et al., 2002; Gordeeva et al., 2002), activated carbon-methanol (Passos et al., 1986; Jing and Exell, 1993; Wang et al., 2003; El-Sharkawy et al., 2009) and activated carbon fiber-ethanol (El-Sharkawy et al., 2006; Saha et al., 2007) pairs. On the other hand, adsorption refrigeration systems working in above but near atmospheric pressure, the refrigerant R134a seems to be a promising refrigerant as it has a relatively smaller GWP of 1300 compared with other HFCs (HFC404A, HFC410A), and the ozone depletion potential (ODP) is zero. Moreover, it is a non-flammable refrigerant and the level of acidity is significantly small (below 1.0 ppm). Akkimaradi et al. (2001) measured adsorption isotherms of R134a on three types of activated charcoal, namely, Chemviron, Fluka and Maxsorb. Recently, Saha et al. (2009b) measured the adsorption isotherms of R134a on highly porous pitch based activated carbon namely, Maxsorb III using the desorption method and Loh et al. (2010) studied the adsorption isotherms of R134a on Maxsorb III using the constant volume, variable pressure method. The above mentioned studies showed that the specific adsorbance of Fluka and Chemviron are about only one quarter of Maxsorb adsorbents. However, the realization of Maxsorb based adsorption refrigeration system is hindered due the high cost of the adsorbent and difficulty in packing the adsorbent in an adsorber/desorber heat exchanger.

The present article is the continuation of the ongoing efforts for generating experimental isotherm data for relatively cheaper but highly porous activated carbon samples for the sake of improving the performance of adsorption cooling systems. The adsorption isotherms of R134a on granular activated carbon that is commercially known as SRD 1352/3 and activated carbon fiber of type (A-20) were measured using Rubotherm ISOSORP 2000 within evaporation temperatures range between −20 and 40 °C and adsorption temperatures range from 30 to 80 °C. The adsorption parameters were evaluated using the Dubinin-Astakhov (D-A) equation with and without volume correction, Tóth and Langmuir equations. Further, the isosteric heat of adsorption data were extracted for the assorted two different activated carbon specimens. These data are useful in designing a pressurized-bed thermally powered adsorption chiller.

2. Experiments

Fig. 1 shows the schematic diagram of the experimental apparatus which comprises (i) Rubotherm ISOSORP 2000 unit, (ii) evaporator (iii) glycol water bath system, (iv) oil bath system, (v) vacuum pump, and (vi) data acquisition system connected to a personal computer. The Rubotherm ISOSORP 2000 is the main constituent of the experimental set up and it is equipped with an accurate magnetic suspension balance to measure the weight of the adsorbent sample before and after each adsorption test from which the adsorption uptakes were estimated accurately. The evaporator chamber is made from stainless steel and functions as a liquid refrigerant reservoir.

A series of experimental runs have been carried out at adsorption temperatures within a range from 30 to 80 °C and