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Experimental study on adsorption–desorption characteristics of granular activated carbon/R134a pair

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ABSTRACT

Experimental runs were done to estimate the adsorption characteristics of granular activated carbon (GAC)/R134a pair. A laboratory scale test rig was designed and built to run the experiments. The adsorption capacity of the GAC was studied at different temperatures 25 °C, 35 °C, 45 °C and 65 °C. Pressure and time were recorded during the experiments. The maximum adsorption capacity was found to be 1.68 $kg_{R134a}\,{kg_{carbon}}^{-1}$ at 25 °C after 1000 s. The activation energy and the exponential constant were estimated to be 9575 J mol^{-1} and 1.83 respectively.

Etude expérimentale sur les caractéristiques d'adsorption / désorption d'un couple actif charbon actif granulé / R134a

Mots clés : adsorption ; charbon actif ; refroidissement ; R134a

1. Introduction

Adsorption heat pumps consume low-grade energy to achieve a cooling effect. This makes the development of these systems become an attractive research topic (Jung-Yang San and Wei-Min Lin, 2008; Wang et al., 2006). The adsorption cooling and refrigeration systems have the advantages of being compact, free or nearly free of moving parts, efficiently driven by low-temperature waste heat or renewable energy sources, free of toxic and environmentally harmful substances as these systems can use natural refrigerants such as water, ethanol, methanol, ammonia etc. and do not require any synthetic lubricants (Habib et al., 2011; Kashiwagi et al., 2002; Saha et al., 2001).

Applications of adsorption refrigeration are very limited. More efforts are necessary for development its performance and extend its area of application. The adsorption working pairs are vital in enhancing the performance of adsorption refrigeration systems. New adsorption pairs should be

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Nomenclature

A	Area of adsorbent particle, m^2
a	Constant
b	Constant
E	Characteristic energy, $J\,mol^{-1}$
h_{fg}	Latent heat, $kJ\,kg^{-1}$
n	Exponential constant
P	Pressure, bar
P_i	Pressure before desorption, bar
P_f	Pressure after desorption, bar
P_s	Saturation pressure, bar
q_{st}	Isosteric heat of adsorption, $J\,mol^{-1}$
R	Universal gas constant, 8.314 $J\,mol^{-1}\,K^{-1}$
S_d	Surface diffusion, $m^2\,s^{-1}$
S_{d0}	Pre-exponential coefficient
T	Temperature, K
T_{cr}	Critical temperature of R134a, K
T_{des}	Desorption temperature, K
t	Time, s
V	Volume of adsorbent particle, m^3
W	Adsorption mass capacity, $kg_{R134a}\,kg_{carbon}^{-1}$
W_0	Maximum adsorption capacity, $kg_{R134a}\,kg_{carbon}^{-1}$

investigated, and their characteristics in adsorption cooling should be defined.

The selection of any pair of adsorbent/adsorbate for refrigeration applications depends on certain desirable characteristics of their constituents. These characteristics range from their thermodynamic and chemical properties to their physical properties and even to their costs or availability. The characteristics of refrigerants and adsorbent were classified by Alghoul et al. (2007) and Wang et al. (2010).

The adsorption characteristics of R134a on three types of activated carbons were measured by Akkimaradi et al. (2001). El-Sharkawy et al. (2006) evaluated adsorption parameters of ethanol on activated carbon fiber of type (A-20). By using renewable energy source, Pons and Guilleminot (1986) studied activated carbon/methanol system for ice production. Chan et al. (1984) measured experimental data of hydrogen, helium, neon and nitrogen on activated charcoal. Riffat et al. (1997) determined adsorption blends of HFC-32, HFC-125 and R-134a with AX-21.

In this research, the adsorption capacity rates of R134a onto granular activated carbon (GAC) have been measured within the temperatures ranging from 25 to 65 °C for adsorption cooling and refrigeration applications purposes. Using the constant volume, constant temperature and variable pressure, the instantaneous capacity of R134a has been recorded at each 60 s. Desorption characteristics the pair were measured at different temperatures.

2. Experimental section

2.1. Experimental test rig

A test rig was designed and built as shown in Fig. 1a and b to run the experiments. The test rig consists of a water tank containing an adsorption bed, heater and a refrigerant bottle. The bed is a cylinder made of carbon steel contains 500 g of GAC. Properties of GAC based on bituminous coal are tabulated in Table 1. A refrigerant grader glass bottle has a capacity of 1.5 ± 0.001 L. An electric heater of 2 kW was used to heat the water inside the water tank. Type J thermocouples were established inside the bed and the water tank to measure temperatures. The adsorption cylinder and the bottle are connected to a pressure gauge to measure the pressure. The connection between the bed and the bottle is a non-return valve fixed at bed side and connected directly to a needle valve on the other side. When the bed is separated from the system to be weighted, the needle valve is closed and it is opened again after rejoining the bed. The non-return valve prevents outside air to enter the bed during weighing process. This mechanism was designed to be easy disassembly and reassembly the bed to avoid the effect of leakage on the system. The test rig was in a conditioned room at 25 °C during the runs.

2.2. Procedure

First of all the bed was evacuated using a vacuum pump to 0.1 bar. The bed was then heated gradually up to 100 °C during 4 h while the vacuum process is still running. This process was done to ensure that there are no residual gases in the carbon. The bed was weighed before and after this vacuum process. The pressure at the end of this process was recorded to be 25 Pascal.

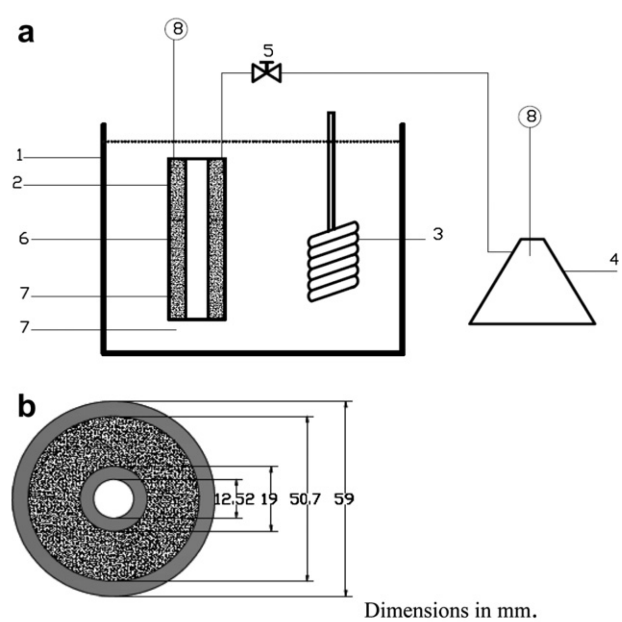

Fig. 1 – (a) Schematic diagram of the experimental test rig. 1, Water tank; 2, adsorption bed; 3, heater; 4, refrigerant glass bottle; 5, valve; 6, granular activated carbon; 7, thermocouple; 8, pressure gauge. (b) Cross-section in the adsorption cylinder.