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Experimental and theoretical study of adsorption kinetics of Difluoromethane onto activated carbons

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ABSTRACT

This paper presents theoretical and experimental adsorption kinetics of Difluoromethane (HFC-32) onto activated carbon powder of type Maxsorb III and activated carbon fiber of type A-20. The experimental runs have been conducted on an apparatus that has been designed and built specially for this purpose. The adsorption kinetics have been determined at different adsorption temperatures ranging from 25 °C to 65 °C. The experimental data are reduced and fitted with linear driving force (LDF) and Fickian diffusion (FD) models. It has been found that both LDF and FD models are able to simulate the adsorption kinetics of HFC-32 onto activated carbon powder and fiber with an error of ±5%.

Etude expérimentale et théorique de la cinétique d'adsorption de de difluorométhane sur du charbon activé

Mots clés : Cinétique d'adsorption ; Charbon activé ; Difluorométhane ; Linéaire force motrice ; Diffusion de Fickian

1. Introduction

According to the dramatic increase of the global energy demand that has been occupied by a shortage in energy supply, renewable energy applications become one of the solutions for the energy crisis. One of these applications which may be aid in solving this problem is the thermally powered adsorption cooling system. Unremitting researches have been carried out to bring the adsorption cooling systems to the existence (Alam et al. 2013; Askalany et al., 2012, 2013a; Chan et al., 2012; Dabler and Mittelbach, 2012; Gordeeva and Aristov, 2014; Khattab et al., 2012; Sharafian and Bahrami, 2014; Tso and Chao, 2012).

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Nomenclature

A	surface area, m^2
C	adsorption uptake, kg kg^{-1}
C_0	equilibrium uptake, kg kg^{-1}
D_s	surface diffusion, m^2 s^{-1}
D_{s0}	pre-exponential coefficient, m^2 s^{-1}
E_a	activation energy, kJ kg^{-1}
F	constant
m	mass of adsorbate, kg
n	constant
R_p	particle radius, m
t	time, s^{-1}
V	volume, m^3

Subscripts

ads	adsorber
eva	evaporator
exp	experimental
f	final status
i	initial
pore	pore volume
sol	solid
theo	theoretical
tube	connecting tubes
void	void spaces between adsorbent particles
z	measurement number

In order to build an adsorption cooling system, there are some indispensable steps which should be followed. The first step is studying the adsorption isotherms of the adsorbent/refrigerant pair. The second step is studying the adsorption kinetics of the working pair. Adsorption kinetics could be defined simply as time-variation of the rate of adsorption capacity for an adsorbent/adsorbate pair. For better design of adsorption chillers, it is essential to determine accurately the kinetics of adsorption pair. Many researches have been conducted to determine the adsorption kinetics of different adsorption pairs (Atakan et al., 2013; Dawoud, 2013; Glaznev and Aristov, 2008). These results have been conducted to detect the most accurate theoretical model which fits the experimental data of the studied adsorption pair.

Difluoromethane (HFC-32) is a hydofluoroocarbon refrigerant that has been used either as a pure fluid for low temperature refrigeration or as an ingredient of 400 series nonazeotropic refrigerants 407a,b,c and 410a,b for packaged air conditioning applications. HFC-32 is also present in R-504 that was used as a refrigerant but now phased out under Montreal Protocol because of the presence of chloropentafluoroethane (CFC-115) which has large ozone depletion potential. Adsorption data on HFC-32 are expected to be beneficial for two distinct applications, namely, for possible thermal compression when used as a pure component and separation of the mixtures at the end of the life cycle (Askalany et al., 2013b).

2. Working pairs and experimental apparatus

Activated carbon fiber (ACF) of type A-20 and activated carbon powder (ACP) of type Maxsorb III, were developed by AD'ALL Co. Ltd., Japan, and Kansai Coke & Chemicals Co. Ltd., Japan, respectively. Table 1 summarizes the characteristics of the studied adsorbents. A detailed description and chemical analysis of the used adsorbents have been presented by Askalany et al., 2013b. Samples of HFC-32 were supplied by Daikin Co. Ltd., Japan and helium by Asahi Sanso Shokai Ltd., Japan, respectively with a stated purity of 99.995% for both HFC-32 and helium.

An experimental apparatus has been designed and built to investigate the adsorption kinetics of HFC-32 onto activated carbon based adsorbents. It consists mainly of an adsorber and an evaporator as shown in Fig. 1. The Adsorber and the evaporator are connected through 1/4 inch steel tube. In order to control the flow of refrigerant, seven ball valves are installed. The adsorber is 2500 cm^3 bottle made of a stainless steel (SUS 304) and withstands a maximum loading pressure of 3 MPa.

A copper tube coil of a diameter of 1/8 inch has been fabricated inside the adsorber to improve heating and cooling the adsorbent as shown in Fig. 2. The copper coil is connected to a water circulator. The circulator has a heating and cooling capacity of 1.7 kW which used to control the temperature of the water bath. The adsorber has a mesh which is used to prevent the migration of the adsorbent particles. The evaporator is made of stainless steel (SUS 304) bottle of a volume of 3 L (3000 cm^3). It has been designed to manage a maximum pressure of 3 MPa. Each of the adsorber and the evaporator is installed inside a water bath with 0.2 m^3 volume in order to manage and regulate its temperature. Each water bath is connected to a water circulator in order to heat or cool the water and to achieve a preselected temperature.

The apparatus has been connected to a vacuum pump which has been used for evacuation purposes. A number of type K thermocouples are attached at the locations in the test rig where the temperature has to be measured.

Pressure transducers are used to measure the pressure of the adsorber and the evaporator. A high precision Coriolis flow meter is installed between the evaporator and the adsorber to measure the flow rate of the refrigerant during the adsorption

Table 1 – Specifications of the adsorbents.

	ACP	ACF
Pore volume (cm^3 g^{-1})	1.7	1.0
Surface area/m^2 g^{-1}	3200	2200
Mean pore diameter/nm	2	2
Amount in adsorption cell (g)	10.10	2.75