

Development of a new synthesized adsorbent for refrigeration and air conditioning applications

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Abstract

This paper presents the results of a study concerned with the impregnation of microporous silica gel, as host matrix, with the calcium chloride, as hygroscopic salt promoter. The concentration of the aqueous solution of calcium used in the preparation of the samples was varied from 0% up to the limit of solubility of CaCl_2 in the water. At high humidity, the composite adsorbents obtained with the solutions at concentration greater or equal to 40% have been tested to yield a maximum capacity of adsorption approximately doubling their own weight and quadrupling that of the pure silica gel. Likewise, they were found to be desorbing faster compared to the substrate silica gel. The impact of these improved sorption properties on the performance of an adsorption air conditioning system was simulated. The results show a significant increase of the specific cooling power (SCP) and, consequently, a drastic reduction of the quantity of adsorbent needed to reach an intended target cooling power.

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Keywords: Silica gel; Calcium chloride; Composite adsorbent; Retention capacity; Target cooling power

1. Introduction

A solid sorption cycle using silica gel as adsorbent and sulphur dioxide as the refrigerant was commercially available since the 1920s [1]. With the invention of the high efficient electrically driven compressors, it was soon supplanted by the refrigerant vapour compression system. The current renewed interest for its utilisation in refrigeration and air conditioning realm stems from the rising concerns about the harms caused by the CFCs (chlorofluorocarbons) based refrigerant to the environment and the increasing awareness of the limitedness of fossil fuel energy resources which constitute, hitherto, the greatest part of World's current energy consump-

tion. The adsorption air conditioning system, however, does have some drawbacks hindering its commercial viability against the traditional refrigerant compression system. Among them, it can be cited the still low coefficient of performance (COP) and the bulkiness of the equipments.

Alongside the technological improvements actively pursued by researchers, utilisation of free energy resources such as waste heat and solar energy can offset the effect of the lowness of its COP on its competitiveness. Those energy sources, though, are available at temperatures very often lower than those required for regenerating most of adsorbents. The bulkiness is essentially explained by the important amount of adsorbent required to produce a desired meaningful cooling power.

In the effort to address the problems mentioned above, researchers have been actively searching for adsorbents that can be regenerated at low temperatures

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Nomenclature

S0	the pure silica gel	$m(\text{H}_2\text{O}, T)$	equilibrium water uptake [kg water/kg dry adsorbent]
S10	sample prepared in 10% concentration of aqueous solution of CaCl_2	x	equilibrium adsorption rate [kg/kg]
S20	sample prepared in 20% concentration of aqueous solution of CaCl_2	w_0	total volume of microspores [cm^3/g]
S30	sample prepared in 30% concentration of aqueous solution of CaCl_2	δ	standard deviation [%]
S40	sample prepared in 40% concentration of aqueous solution of CaCl_2	n	Dubinin–Astakhov (D–A) exponent
S45	sample prepared in 45% concentration of aqueous solution of CaCl_2	$t_{1/2}$	half-cycle time [s]
S50	sample prepared in 50% concentration of aqueous solution of CaCl_2	\bar{q}_u	the time average cooling power [W]
		SCP	specific cooling power [W/kg]
		TCP	target cooling power [W]
		M	amount of adsorbent [kg]
		H	relative humidity [%]

(preferably near-ambient temperature) while possessing enhanced adsorption capacity. Aristov has been the precursor in developing composite adsorbents by impregnating hygroscopic promoter salts (inorganic salts in general) into the pores cavities of host matrices [2]. A large variety of host matrices (silica gel, vermiculite, alumina, porous carbon, MCM-41) are used, equally diverse are the hygroscopic salts employed (CaCl_2 , LiBr , MgCl_2 , LiCl etc.). The enhanced adsorptivity products thus developed are known under the name of selective water sorbents (SWSs). Y. I. Aristov and other authors subsequently studied many characteristics of the SWSs, including the sorption properties [3–8] and the variation of their effective conductivity with their moisture loading [9,10]. The composite adsorbents obtained with the LiBr as hygroscopic salt were found to be decaying more rapidly than those developed with CaCl_2 .

The SWSs have been employed in applications as diverse as fresh water production [11–13], energy storage [14], heating and cooling [15,16] etc.

Although impregnation of inorganic hygroscopic salt into the porous matrices has been extensively investigated, the question of how high the concentration of the hygroscopic salt should be for the synthesized adsorbent to have significantly better adsorption capacity in comparison with that of the matrix host used remains unanswered in literature. This paper is intended to answer this question by presenting a study of the sorption properties of composites obtained by impregnating microporous silica gel with calcium chloride at various contents of CaCl_2 ranging from 0% up to the value corresponding to the solubility limit of CaCl_2 in the water. A simulation is also carried out to evaluate the impact of the improved sorption properties can have on the performance and the size of a hypothetical adsorption

air conditioning system employing the synthesized adsorbent.

2. Development process of the composite adsorbent

2.1. Characteristics of the host silica gel

The substrate silica gel employed in this impregnation operation was acquired from Shanghai Pengpu Chemical Works (SPCW), engaged mainly in the production of phosphorus chlorides, diketene derivatives, and phosphate esters. Being of the pore size varying between 1.5 nm and 3.0 nm, this variety of silica gel is considered by the supplier as being of microporous structure, although, according to the classification of International Union of Pure and Applied Chemistry (IUPAC), it encroaches on the domain of mesoporous structure which covers the pore size range of 2–50 nm [19]. The pore volume is $V_p = 0.35 \text{ cm}^3 \text{ g}^{-1}$ and the specific surface area lies in the interval stretching from 600 to $850 \text{ m}^2 \text{ g}^{-1}$. The particles are medium size beads having diameters ranging from 4 to 8 mm, which corresponds to an average particle size of 6 mm.

2.2. Samples preparation

Aqueous solutions of calcium chloride with increasingly varied concentrations 10 wt.%, 20 wt.%, 30 wt.%, 40 wt.%, 45 wt.%, and 50 wt.% of calcium chloride were prepared. The microporous host silica gel was afterwards immersed and kept in the solutions during twelve hours so as to permit the liquid solution to fill in its pore volumes. The samples were then taken out of the solution and laid on the shelves inside a thermostat–humidostat chamber (Fig. 1) where they were dried under a

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