

Study of adsorption characteristics in silica gel–water adsorption refrigeration



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HIGHLIGHTS

- Many different silica gel samples were prepared and tested.
- Adsorption characteristics and adsorption isotherms were achieved.
- Deterioration phenomenon of adsorption property of silica gel is verified.
- Adsorption capacity of silica gel was influenced by many factors.
- Pollution by solid particulates causes a great decrease of adsorption capacity.

ARTICLE INFO

Article history:

Received 7 March 2013

Received in revised form 25 June 2013

Accepted 4 August 2013

Keywords:

Adsorption refrigeration

Silica gel

Water

Adsorption characteristics

Deterioration

ABSTRACT

As one of environmentally friendly refrigeration methods, solid adsorption refrigeration has tracked much interest over the world. Silica gel is popularly used in adsorption refrigeration systems as the adsorbent. Like a compressor in a compression refrigeration system, the adsorbent is vital to the performance of adsorption refrigeration systems. In this work, many different silica gel samples were prepared according to their application surroundings in silica gel–water adsorption refrigeration systems. The adsorption characteristics including variations, deterioration, and improvements of the adsorption property were detected. The specific surface area, silanol content, adsorption capacity, and pore size distributions of those samples were tested. The corresponding adsorption isotherms were achieved. The experimental results indicated that the adsorption capacity of the silica gel was influenced by many factors. But pollution by solid particulates was the primary factor to decline the adsorption capacity.

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1. Introduction

At present, heating, ventilation, and air conditioning (HVAC) has consumed a large amount of energy [1]. Given the energy crisis, saving energy of HVAC has evoked more attention from researchers and engineers in this field than before. Adsorption refrigeration is one kind of green technology that can supply refrigeration output for HVAC [2,3], especially when silica gel is adopted because of its great suitability for low grade heat source and contributions effectively to reduce greenhouse gas emission [4,5].

Commonly, silica gel pairs with water as the working pairs. Silica gel–water adsorption refrigeration is usually used in air conditioning, due to the evaporating temperature of water at higher than freezing point. Silica gel–water adsorption refrigeration systems are very popular in the utilization of low grade heat source, especially at below 85 °C.

In this context, many researchers focused on the theoretical and technical improvements of silica gel–water adsorption refrigeration. With their great efforts, many achievements were obtained and widely reported [4–8]. Since the 1990s, new cycles, new designs, new prototypes, and new applications were proposed. The typical two-bed cycle could continuously yield refrigeration output and was mostly adopted before other improved cycles emerged and even is popularly used today [9]. In order to be suitable for lower grade heat source utilization, cycles and prototypes with multi-bed, multi-stage, and multi-mode were developed. A two-stage adsorption chiller could obtain a coefficient of performance (COP) of 0.36 with driving source at 55 °C and a heat sink at 30 °C [10]. Khan et al. [11] reported a design and its simulation of a three-stage six-bed adsorption chiller with re-heat scheme that could be driven by 50–70 °C heat source at 30 °C coolant temperature.

In order to improve the reliability of the silica gel–water adsorption chillers, chillers combined by two adsorption/desorption cooling units were developed [12–15]. The newest results [15] were that the cooling capacity and the COP of such chillers

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were 3.6 kW and 0.32, respectively, at the hot water inlet temperature of 57 °C, cooling water inlet temperature of 27 °C, and chilled water outlet temperature of 15 °C; those were up to 5.7 kW and 0.41, respectively, when the hot water inlet temperature, cooling water inlet temperature were changed to 80 °C and 29 °C, respectively. Those efforts had resulted in closer and closer steps to commercial prototypes though so far those prototypes were not really commercial ones due to its high cost.

Indeed, commercialization of the silica gel–water adsorption refrigeration has been hindered because of some puzzlement about fundamental problems, such as low cooling capacity, low working reliability, and adsorption capacity deterioration of silica gel. Some improved silica gel–water adsorption chillers developed in the last decades experienced a high refrigeration capacity at first but their refrigeration capacity sharply declining after being used for about one year [12,13,16]. The similar conditions were that some advanced silica gel–water adsorption chillers were reported for their development and applications in the last two decades [9,17,18], but no information about the follow-down applications of those chillers was available. Some troubles had to arise. The water adsorption capacity deterioration of silica gel may be one of those problems. It aroused the researchers' attention. Henninger et al. [19] presented that about 5% decrease of water uptake had been observed after silica gel was used in the adsorption refrigeration system, though they pointed out that this loss must be further investigated. Wang et al. [20] preliminarily studied some possible factors to influence the adsorption performance deterioration in silica gel–water adsorption refrigeration and concluded that pollution caused by impurity ions and solid particles was the primary factor to lessen the adsorption capacity.

In order to further clarify those problems affecting the cooling capacity of the silica gel–water adsorption chiller, on the basis of the former work [20], the adsorption characteristics of silica gel in adsorption refrigeration were investigated in detail. According to the possible surroundings in which silica gel is exposed and modification methods, 14 samples were prepared and their adsorption property parameters were tested. The possible factors that cause changes of silica gel–water adsorption characteristics were detected and analyzed.

2. Experimental sets and methods

2.1. Adsorption refrigeration chiller for silica gel sample preparation

In order to prepare some silica gel samples for the experiments, a simple lab-scale adsorption refrigeration chiller was designed and built, as shown in Fig. 1. This chiller is a single-bed that is comprised of one adsorber, one condenser, and one evaporator. In this chiller, no vacuum valve is installed between the adsorber and the condenser or the evaporator so that the adsorption and desorption process are controlled by the cooling and heating switching system of the adsorber. That is, the adsorption process will begin once the adsorber is cooled by the cooling water and the desorption processes will start once the adsorber is heated by the hot water. In the adsorber, about 750 g silica gel is filled. The hot water temperature can be controlled in the range of 0–80 °C. The cooling water to cool adsorber and the condenser is controlled at 25 °C.

2.2. Sample preparation

Sample preparation is the key link in the research of adsorbent adsorption characteristics. Some samples of silica gel were prepared according to the possible environmental conditions in adsorption refrigeration systems. In order to detect the changes of active functional group content and adsorption properties of

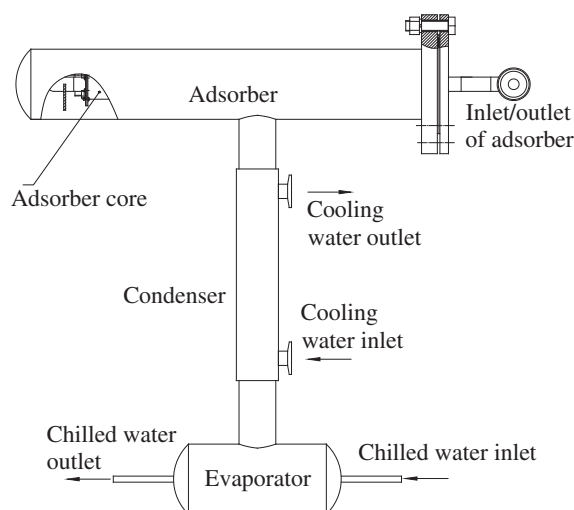


Fig. 1. Adsorption refrigeration chiller used for sample preparation.

the deteriorated silica gel sample, some samples were prepared through acid soaking and distilled water washing. Under consideration of hot water leakage into the adsorbent side in adsorber, the sample soaked in boiled city water was prepared. Samples obtained from the adsorption refrigeration chiller were prepared for the investigation of the adsorption performance with the operation time or the number of cycles. The consideration of samples polluted by the atmosphere is that the dust and other contaminants in the air will probably pollute the adsorbent during the storage and filling-into-adsorber of silica gel resulting in adsorption capacity deterioration. Additionally, aluminum, copper, and steel are commonly used as the materials in the adsorbent bed heat exchangers and therefore the samples should be prepared to study the influence of aluminum, cuprum, and ferrum ions on silica gel. The detailed description of each sample is listed in Table 1.

2.3. Measurement of silanol content

A thermogravimetric analyzer (TGA) manufactured by PerkinElmer Inc. was employed in the experiments to measure the functional group content in the silica gel. The temperature precision and accuracy of this TGA are ± 0.8 °C and ± 1 °C respectively. Its balance digital resolution is 0.2 μ g. Balance precision and accuracy are $\pm 0.01\%$ and $\pm 0.02\%$, respectively.

All the silica gel samples were tested under the same conditions: temperature range from 40 °C to 1250 °C, scanning rates at 10 °C/min, maintaining the temperature at 1250 °C for 5 min, being protected by inert atmosphere, flow rate of reaction gas at 30 ml/min, and flow rate of balance protection gas (N_2) at 20 ml/min.

2.4. Adsorption capacity test set and method

At present, the equipment to test adsorption capacity of adsorbent in the market generally uses nitrogen as adsorbate and cannot be directly used to measure the water uptake (water adsorption capacity) of silica gel. Therefore, an adsorption capacity test system was built in order to test the adsorption capacity of the samples, as shown in Fig. 2. The test system is composed of the adsorption set, data acquisition system, vacuum pumping set, and water bath. The adsorption set is housed by the adsorber shell, diaphragm valve, pressure transducer, and temperature sensor sleeve. The connector between pressure transducer and adsorber shell is also the inlet/outlet to fill/spill adsorbent. The temperature sensor and the electric connector of the pressure transducer are easily separated from

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