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Experimental analysis of an adsorption air conditioning with micro-porous silica gel–water

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HIGHLIGHTS

- Micro-porous silica gel was used as adsorbent in one novel adsorption chiller.
- The cooling performance rises as hot water temp and chilled water temp rise and cooling water declines.
- The chiller was applied in one green building, the COPs is 0.16.

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ABSTRACT

In this paper, one novel heat pipe solar adsorption chiller with mass-heat recovery was designed. 65 kg of micro-porous silica gel was used as adsorbent in each adsorbent bed. The influence of operating conditions on the chiller was investigated. The chiller was applied in Green Building in Dezhou city (north latitude of 36°41′) in China. Under the typical summer weather conditions, the average thermal efficiency of solar collector, the average COP (coefficient of performance) of the adsorption refrigerator and the average solar COP of the system are 0.36, 0.44 and 0.16, respectively. The results show that the adsorption cooling performance rises as the hot water inlet temperature, chilled water outlet temperature rise, and it declines as the cooling water inlet temperature rises. The performance can be improved by mass-heat recovery significantly. When the hot water inlet temperature, cooling water inlet temperature, chilled water outlet temperature are 79.0 °C, 25.4 °C, 13.7 °C, respectively, the cooling capacity and COP are 17.9 kW and 0.63, respectively.

1. Introduction

With the development of society and economic, more and more attention is being paid to energy conservation and environmental issues. "The Montreal Protocol on Substances that Deplete the Ozone Layer" shows that CFC and HCFC will be replaced by the green refrigerants, which have zero or very low ODP (Ozone Depletion potential) and GWP (Global Warming Potential) [1]. According to statistics, China's annual urban housing construction and public construction area are about one billion square meters. Officially, residential and commercial energy use account for 19% of China's total consumption. Moreover, the percentage is expected to rise further in the coming years, due to the continuous development of China's cities construction. In the south of China, 30–50% of total electricity consumption is used in air conditioning. Therefore, many technologies are developed to reduce the electric power consumption in air conditioning.

Adsorption air-cooling system has good energy-saving potential. Adsorption chiller can be powered by waste heat or solar energy. In addition, it uses non-polluting refrigerants and is friendly to environment. During recent years, many solar adsorption refrigeration units were successfully tested. For example, Meunier [2] and Ismail [3] studied zeolite–water absorption refrigeration system. Pons [4] investigated activated carbon–methanol adsorption refrigeration systems. Nishiyodo Air Conditioning Co., Ltd [5] developed a commercial silica gel–water chillers. When the hot water inlet temperature, cooling water inlet temperature was 85 °C and 31 °C, respectively, the cooling capacity was 10 kW. Saha [6], Boelman [7], Chua [8] and Alam [9] studied the adsorption performance of silica gel–water cooling systems.

However, the conventional adsorption refrigeration system has a low coefficient of performance (COP). Many advanced adsorption refrigeration cycles were researched. Shelton [10] studied the thermal wave cycle, in which cycle, the heat transfer fluid is used to cool the hot bed, and then it is used to heat the cold bed, so the

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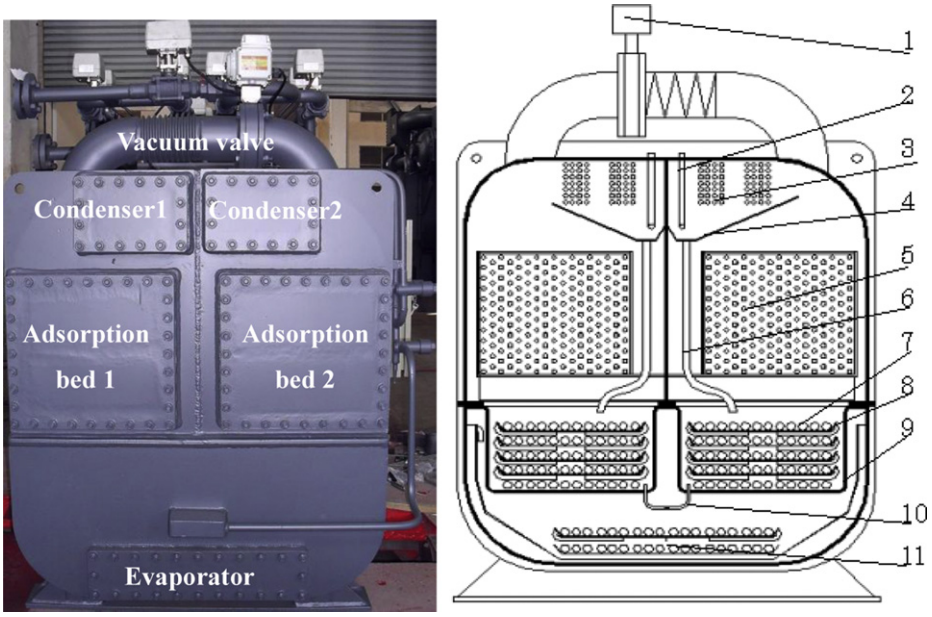

Fig. 1. Silica gel chiller (1-mass recovery valve, 2-vacuum-pumping pipe, 3-condenser, 4-condensed water baffle plate, 5-adsorbent bed, 6-condensed water honeycomb duct, 7-condensing side of heat pipe type evaporator, 8-overflow pipe of condensing side, 9-water tray of condensing side of heat pipe type evaporator, 10- capillary pipe of 1 mm of Inside diameter, 11-evaporating side of heat pipe type evaporator).

heating capacity can be effectively reduced. But, the thermal wave cycle is still in theory stage. Douss [11] investigated the cascade cycle of adsorption cooling system. In his paper, experiments on a cascading adsorptive heat pump were reported. The cascading cycle comprises of zeolite–water high temperature stage and an intermittent active carbon–methanol low temperature stage. Driving heat is supplied by a boiler to the zeolite adsorber. Active carbon adsorber is heated by heat recovered from zeolite adsorber under adsorption. Saha [12] investigated the performance of the advanced three-stage adsorption chiller. The chiller was powered by low-grade waste heat of 50 °C. Eight vacuum valves were used in that system. Vichan [13] added activated carbon in the silica gel adsorption refrigeration systems to improve the heat transfer. Several adsorption water chiller or ice maker were studied by Shanghai Jiao Tong University [14–19]. Methanol is used as heat pipe working fluid. In that chiller, only one vacuum valve was installed between the adsorption and desorption vacuum chambers for mass recovery.

The objectives of this paper are: (1) to research dynamic characteristic, adsorption performance and mass-heat recovery performance etc. of the micro-porous silica gel–water solar adsorption air conditioner under different working conditionings; (2) to investigate the solar adsorption cooling performance when it was applied in the real green building in one city of north China (latitude 36°41′).

2. Working theory of adsorption chiller

2.1. Description of the adsorption chiller

The conventional two-bed adsorption chiller must have four or five vacuum valves at least. These vacuum valves have caused a low reliability problem in the commercialization. In this study, the compact solar micro-porous silica gel–water adsorption chiller, designed by Shanghai Jiao Tong University, is composed of two heat pipe type evaporators, two adsorbers, two condensers, mass recovery vacuum valve, several water valves and control box, etc.

There are two main advantages in this adsorption chiller: (1) Few valve installed: There is only one vacuum valve in the system. Thus, the potential leakage, caused by vacuum valve, can be avoided. (2) Heat pipe type evaporator: Heat pipe evaporator was designed, which can improve heat transfer performance and provide cooling capacity continuously. The adsorption structure is shown in Fig. 1. The flowchart is: on the top of the chiller, water valves and the vacuum valve are installed. In the chiller body,

Table 1
The design parameter of the adsorption chiller.

Item	Hot water			Cooling water			Chilled water		
	In	Out	Mass flow	In	Out	Mass flow	In	Out	Mass flow
Value	80	75	5.1	30	35	7.7	20	15	2.6
Unit	°C	°C	m^3h^{-1}	°C	°C	m^3h^{-1}	°C	°C	m^3h^{-1}

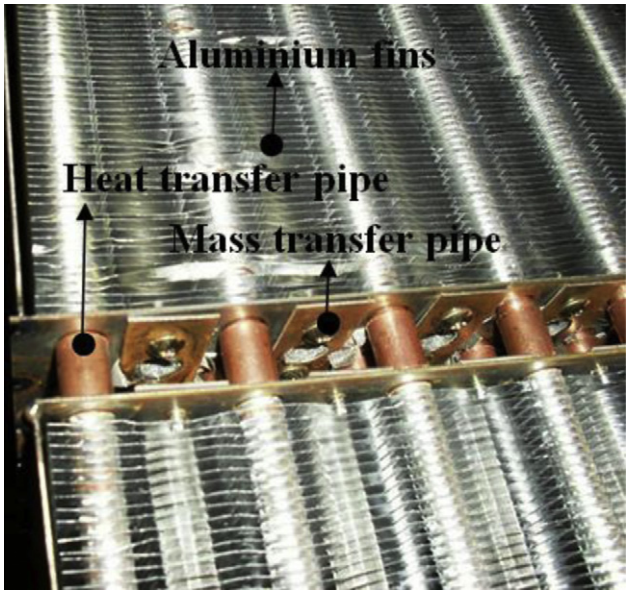

Fig. 2. Adsorption bed structure.