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Study of the new composite adsorbent of salt LiCl/silica gel–methanol used in an innovative adsorption cooling machine driven by low temperature heat source

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ABSTRACT

An adsorption cooling machine with LiCl/Silica gel–methanol was designed and tested, which can work for air conditioning and cold storage. The machine can be driven by low temperature heat source, such as solar energy and industrial waste heat. The composite adsorbent of LiCl/Silica gel has higher adsorption capacity and the methanol has a higher working pressure. So, the cooling performance, system's reliability and the adsorbent's mass transfer performance can be improved. The adsorption machine was experimentally investigated. The test results show that the cycle time and heat recovery process has more influence on COP (Coefficient of Performance) than on cooling capacity. The mass recovery process has significant influence both on cooling capacity and COP. When the cycle time is prolonged from 460 s to 760 s, the cooling capacity and COP increased by 4.3% and 20.6%, respectively. When the hot water inlet temperature, cooling water inlet temperature, cooling medium outlet temperature and heat recovery time are 75 °C, 31 °C, 5 °C and 60 s, respectively, the cooling capacity is improved by 6.3% by heat recovery process while the COP is improved by 27.3%. When the mass recovery time extends from 50 s to 120 s, the cooling capacity and COP increase by 68.4% and 53.3%. When the hot water inlet temperature is about 88 °C, the cooling water inlet temperature is about 25 °C, the adsorption machine produced -4 °C of cooling medium, the cooling capacity and COP were about 1.0 kW and 0.13, respectively.

1. Introduction

In fact, more than 25–45% of total energy consumption is used for cooling and/or heating of domestic and commercial buildings. Furthermore, the demand of air conditioning in building is increasing because of the higher living and working standards. The vapour compression air-conditioning systems have impacts on the stratospheric ozone depletion due to the chlorofluorocarbons (CFC) and the hydro-fluorocarbon (HCFC) refrigerants. They contribute the increase of environmental pollution and global warming [1,2].

Adsorption cooling is one available possible way to reduce electricity consumption and greenhouse gases emission. Adsorption cooling machine can be powered by low temperature heat source. Moreover, adsorption cooling systems have the advantage of using absolutely harmless working fluids such as water, ammonia, etc.

Recently, many researchers investigate the adsorption cooling [3–9]. Chang et al. [10] discussed the parameters of silica gel on the metal in the air-conditioning adsorption cooling systems. Daou et al. [11,12] illustrated the impact of the adsorption properties on the performance of an adsorption air conditioning system. Critoph and Tamainottelto [13] studied the performance of a solar sorption refrigerator by experiment. Saha et al. [14] studied the use of adsorption cycles driven by waste heat of near ambient temperature. Li [15] tested a solid adsorption ice making system with activated carbon and methanol as the working pair. It produced about 4–5 kg/day of ice. Aristov et al. have developed some composite adsorbents that possess larger adsorption capacity and low regeneration temperature. They investigated the adsorption performance of composite adsorbent of silica gel with $CaCl_2$, Na_2SO_4, etc, [16,17]. A two-bed adsorption system arrangement using the bellows bed and zeolite13×/water working-pair and related mathematical analysis was also presented by R. Boukhanouf [18]. Shanghai Jiao Tong University studied the adsorption performance of LiCl/Silica gel–water, the result show that the adsorption capacity can be improved by about 48% [19–21].

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Nomenclature

COP	coefficient of performance
SCP	specific cooling power (W kg^{-1})
q	cooling/heating power (kW)
T	temperature (°C)
$\dot{m}$	mass flow (kg s^{-1})
C	the specific heat (kJ kg^{-1} $°C^{-1}$)

Subscripts

e	cooling
ch	chilled water
i	inlet
o	outlet
h	heating
w	water
a	adsorbent

However the adsorption capacity and reliability of the traditional adsorption cooling system are low. Recently, several researchers study the adsorption cooling machine with LiCl/silica gel–methanol. They have obvious differences in the research angle of view, research focus and research scope. For example, L.X. Gong's contribution is the comparison of LiCl/silica gel–methanol chiller and silica gel–water chiller. The experiment results showed that the SCP (Specific Cooling Power) and COP (Coefficient of Performance) of the former were improved by 16.3% and 24.2% [20,21]. L.G. Gordeeva studied the working materials. The results show that the composite adsorbent demonstrated outstanding methanol sorption ability (up to 0.6 g of methanol per 1 g of dry sorbent) [22]. The novelties of the results presented in this paper are: thermodynamic performance of a real refrigerator with LiCl/silica gel–methanol was studied; new designs of heat pipe heat transfer and advanced cycles are used to improve system's performance and reliability in the chiller.

2. System description

2.1. LiCl/silica gel–methanol

LiCl/mesopore silica gel–methanol was used for solar cooling system. Matrix granules of mesopore silica gel were filled with a LiCl solution of a fixed concentration, then they were dried. Salts content in the mesopore silica gel is 14 wt% when the concentration of the salt solution is 30 wt%. There is no crystalline solvates in silica pores during sorption. The parameters of mesopore silica gel are shown in Table 1.

In the adsorption process of the composite adsorbent of LiCl/silica gel–methanol, the uptake is low when the methanol pressure is low. As the methanol pressure rises, the salt LiCl starts to adsorb methanol due to the reaction (1). After the adsorption of the salt, it transforms to the solution of LiCl–methanol inside the silica gel pores. The total amount of methanol adsorbed in the composite adsorbent reaches 0.6 g/g [23], which is 2–3 times of adsorption capacity of zeolites and activated carbon.

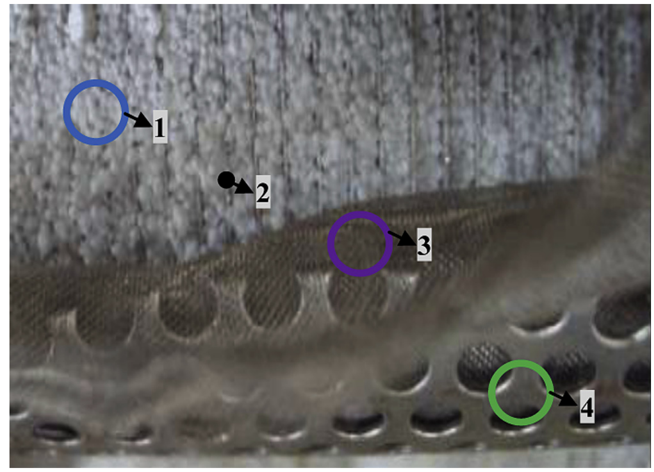

Fig. 1. Macro-porous LiCl/silica gel inside fins of adsorption bed (1-Macro-porous LiCl/silica gel, 2-aluminium fins, 3-metal mesh, 4-pore tube).

Fig. 2. The pipes bundle with adsorbent welded together in adsorption bed.

$$LiCl + 3CH_3OH + \Delta H \Leftrightarrow LiCl \cdot 3CH_3OH \quad (1)$$

Adsorption bed was made of finned tube heat exchanger. The composite adsorbent of LiCl/Silica gel was pressed inside the aluminium fins (as shown in Fig. 1) to enhance heat transfer performance. Then, a metal mesh was placed around the material to avoid the leakage of the adsorbent from the fins. The metal mesh was covered by a pore tube. The pipes with adsorbent were welded together (as shown in Fig. 2.). The schematic diagram of this compact adsorption chiller is shown in Fig. 3. The chiller is composed of left bed, right bed, left condenser, right condenser, tray salvers in desorption chamber, tray salver in evaporator, mass recovery vacuum valve, etc. There is only one mass recovery

Table 1
Parameters of mesopore silica gel.

Type	Pore diameter/ nm	Specific surface area/m^2 g^{-1}	Pore volume/ ml g^{-1}	Specific heat/ kJ kg^{-1} $°C^{-1}$	Thermal conductivity/ W m^{-1} $°C^{-1}$	Bulk density/ kg m^{-3}
Mesopore silica gel	7–12	300–400	0.72–0.85	0.90	0.167	500