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Experimental investigation adsorption chillers using micro-porous silica gel–water and compound adsorbent-methanol

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ABSTRACT

Compound adsorbent of macro-porous silica gel/LiCl-methanol and micro-porous silica gel–water were used as working pairs in two adsorption cooling systems respectively. The adsorption performance was experimentally investigated and compared. The experiment results are that mass recovery process can improve cooling capacity significantly while heat recovery process can improve coefficient of performance (COP) more significantly. The silica gel/LiCl-methanol cooling system has higher adsorption capacity and working pressure. When the hot water inlet temperature, cooling water inlet temperature and chilled water outlet temperature are about 85 °C, 31 °C and 15 °C, the specific cooling power (SCP) of silica gel/LiCl-methanol cooling system is higher by 59.5% than that of silica gel–water cooling system. The silica gel/LiCl-methanol cooling system can also work for cold storage. When the hot water inlet temperature, cooling water inlet temperature and chilled water outlet temperature are about 88 °C, 25 °C and −4 °C, the cooling capacity and COP are 1.0 kW and 0.13.

1. Introduction

The world is facing more challenges to balance energy source shortage, environmental protection and sustainable development. 25–45% of the total energy is consumed for building heating, cooling and hot water. One green technology of adsorption cooling/heating can save energy and reduce the emission of greenhouse gas, because it can be powered by industry waste heat or solar energy. And it employs friendly refrigerant (water, ammonia, etc.) instead of the ozone depleting substance of CFCs and HCFCs.

A lot of adsorption working pairs have been studied. The typical working pairs are physical adsorbent, chemical adsorbent and composite adsorbent. For example, the physical adsorbents-refrigerant are silica gel–water [1], zeolite–water [2], activated carbon–ammonia [3], activated carbon–methanol [4–9]. However, the typical physical adsorption capacity is relatively small and the effective thermal conductivity is very low, which result in the big size of the chiller.

The chemical adsorbent usually has large adsorption capacity. The typical chemical working pairs are $CaCl_2$–ammonia [10–12], etc. But, there are usually two issues of performance degradation and corrosion in chemical adsorbent.

The composite adsorbent can improve adsorption performance significantly and without corrosion problem. Due to their physical structure, the composite materials take an intermediate position between solid adsorbents and pure hygroscopic salts and can be organized in a way to demonstrate the best features of both systems. The typical composite adsorbent are $CaCl_2$/activated carbon, silica gel/LiCl. Yu.I. Aristov 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. [13–14]. Gordeeva presents experimental data on synthesis and the phase composition of novel composites '(LiCl + LiBr) confined to the silica gel pores' as well as their sorption equilibrium with water and methanol vapor [15]. A novel composite sorbent of methanol "LiCl in mesoporous silica gel" has recently been proposed by Gordeeva for adsorption cooling. Its testing in a lab-scale adsorption chiller resulted in the specific cooling power of 210–290 W/kg and the cooling COP of 0.32–0.4 [16]. Shanghai Jiao Tong University studied the adsorption performance of silica gel/LiCl-water, the result show that the adsorption capacity can be improved by about 48% [17–20]. Bonaccorsi discussed the preparation of a metal supported in situ grown adsorbent bed for adsorption heat pump applications [21].

However few papers investigate the experimental performance of adsorption performance of adsorption cooling machine with compound adsorbent of macro-porous silica gel/LiCl-methanol, and compare the performance with micro-porous silica gel–water. The objectives of this paper are: (1) to experimentally study the adsorption performance of the adsorption cooling machine with

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Nomenclature

COP	coefficient of Performance	$\dot{m}_h$	mass flow of hot water, kg s^{-1}
SCP	specific cooling power, W kg^{-1}	C_w	specific heat of water, kJ kg^{-1} °C^{-1}
q_e	cooling capacity, kW	$T_{h,i}$	inlet temperature of hot water, °C
$\dot{m}_{ch}$	mass flow of chilled water kg s^{-1}	$T_{h,o}$	outlet temperature of hot water, °C
C_w	specific heat of water, kJ kg^{-1} °C^{-1}	σ	measurement error
$T_{ch,i}$	inlet temperature of chilled water, °C	E	measurement uncertainty
$T_{ch,o}$	outlet temperature of chilled water, °C		
q_h	heating capacity, kW		

composite adsorbent of LiCl/silica gel-methanol; (2) to compare the adsorption cooling performance of macro-porous silica gel/LiCl-methanol with that of micro-porous silica gel–water chiller.

2. System description

The structure of the system is shown in Fig. 1, which is composed of left adsorption bed, right adsorption bed, left condenser, right condenser, left thermal isolator, right thermal isolator, heat pipe type evaporator, self-balancing device of refrigerant, mass recovery vacuum valve, etc. There are three evacuated chambers. The left adsorption bed, left condenser and left thermal isolator is the top-left evacuated chamber. The right adsorption bed, the right condenser and the right thermal isolator is in the top-right evacuated chamber. The heat pipe type evaporator is in the bottom evacuated chamber. There is only one mass recovery vacuum valve in this system, so, the reliability can be improved. Two adsorption cooling machines were built. The structure of these two machines is the same, but silica gel–water and silica gel/LiCl-methanol were used as working pair in each machine. The picture of adsorption cooling machine is shown in Fig. 2.

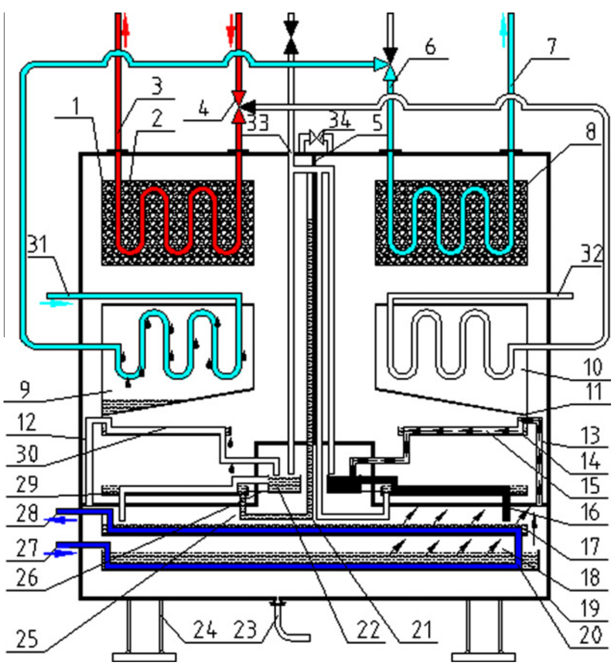

Fig. 1. The schematic diagram of adsorption chiller (1 – left adsorber, 2 – silica gel in adsorber, 3 – hot (cooling) water outlet pipeline of left adsorber, 4 – hot water inlet pipeline of left adsorber, 5 – clapboard between two adsorbers, 6 – hot water inlet pipeline of right adsorber, 7 – hot (cooling) water outlet pipeline of right adsorber, 8 – right adsorber, 9 – left condenser, 10 – right condenser, 11 – eliminator for condensed refrigerant, 12 – left thermal isolator, 13 – right thermal isolator, 14 – tray in right thermal isolator, 15 – heat transfer pipeline in right thermal isolator, 16 – clapboard between adsorber and evaporator, 17 – tray in evaporator, 18 – evaporator, 19 – shell of chiller, 20 – heat transfer pipeline in evaporator, 21 – U type pipeline, 22 – self-balancing device of refrigerant, 23 – outfall, 24 – support leg, 25 – vertical pipe of condensed refrigerant, 26 – Limiting pipe, 27 – chilled water inlet pipeline, 28 – chilled water outlet pipeline, 29 – tray in left thermal isolator, 30 – heat transfer pipeline in left thermal isolator, 31 – cooling water inlet pipeline of left condenser, 32 – cooling water inlet of right condenser, 33 – vacuum-pumping pipeline, 34 – mass recovery valve).

The evaporator is designed as a gravitation (thermo-syphon) heat pipe heat exchanger, as shown in Fig. 3. The top tray serves as the condensing side of heat pipe. When the adsorption bed is cooled, the refrigerant in the top tray will evaporate and be adsorbed by adsorption bed. The temperature of top tray salver declines.

The bottom tray serves as the evaporating side of heat pipe, wherein the heat pipe liquid evaporates and the temperature will decline. The evaporating vapor will go into the top heat transfer pipe, wherein it is condensed into liquid. The liquid will go back into the bottom tray through downward pipe. Thus, heap pipe type evaporator can work and provide cooling capacity by chilled water.

There are three working process in this adsorption cooling system. The detailed description is shown as the following:

(1) HLCR process (Heating the left adsorber, cooling the right adsorber), as shown in Fig. 1: in this process, the left adsorber is heated, and the refrigerant is desorbed from adsorption bed. The vapor is condensed in the left condenser, and the condensed water will drop to the tray in the left thermal isolator directly. When the top tray is full of water, the excess condensed water will overflow into the bottom tray in the left thermal isolator. Heat pipe theory was utilized in the design of evaporator to improve heat transfer performance and reduce the number of valves. As shown in Fig. 1, the part of 15 works as the condensing side of the right heat

Fig. 2. The picture of adsorption cooling machine (there are two machines, silica gel–water was used for chiller in one machine, and silica gel/LiCl-methanol was used for refrigerator in the other machine).