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Design and experimental study of a silica gel-water adsorption chiller with modular adsorbers

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ABSTRACT

A silica gel-water adsorption chiller driven by low-grade heat is developed. System configuration without any vacuum valves includes two sorption chambers, a 4-valve hot/cooling water coupled circuit and a 4-valve chilled water circuit. Each sorption chamber is composed of one adsorber, one condenser and one evaporator. The design of this chiller, especially the design of modular adsorber, is suitable for low-cost industrial production. Efficient and reliable heat and mass recovery processes are also adopted. This chiller is tested under different conditions and it features the periodic variations of temperatures and cooling power. Through the experimental study, the optimal cooling time, mass recovery time and heat recovery time are 720 s, 40 s and 24 s, respectively. Besides, the obtained cooling power, COP and SCP are 42.8 kW, 0.51 and 125.0 W kg^{-1}, respectively, under typical conditions of 86/30/11 °C hot water inlet/cooling water inlet/chilled water outlet temperatures, respectively.

Conception et étude expérimentale d'un refroidisseur à adsorption de gel de silice-eau avec des adsorbeurs modulaires

Mots clés : Gel de silice-eau ; Refroidisseur à adsorption ; Module adsorbeur ; Récupération de chaleur ; Récupération de masse

1. Introduction

Nowadays, refrigeration technology is necessary and refrigeration demand grows rapidly due to the development of society and the improvement of human life. The main refrigeration technology – vapor compression refrigeration – is powered by electricity and uses CFC and HCFC refrigerants. Thus, the widespread use of vapor compression refrigeration causes large energy consumption, and discharge of its refrigerant brings about ozone depletion. Energy crisis and environmental disruption issues severely restrict the development of refrigeration technology. In order to avoid these issues, environment-friendly refrigeration technologies are paid great attention by researchers (Askalany et al., 2012; Cho et al., 2009). As one of the green refrigeration technologies, adsorption refrigeration can be driven by low temperature heat sources (like industrial waste heat and solar energy) and employs natural

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Nomenclature

COP	coefficient of performance
C	specific heat capacity [kJ kg^{-1} °C^{-1}]
J	volume flux [m^3 s^{-1}]
M	mass [kg]
Q	heat [kW,W]
SCP	specific cooling power [W kg^{-1}]
T	temperature [°C]
Greek letters	
ρ	density [kg m^{-3}]
Δ	error
Subscript	
ad	adsorbent
ci	chilled water
e	evaporation
h	heating
hw	hot water
in	inlet
ou	outlet

refrigerants (such as water, methanol, ammonia and so on) instead of ozone depleting substances (Wang et al., 2014). In addition, its advantages of simple control, low operating cost and less vibration make a promising application (Pan et al., 2014).

Silica gel-water adsorption refrigeration can be driven by low temperature source at between 60 and 95 °C (Saha et al., 2006). As one of the most common adsorption refrigeration technologies, silica gel-water adsorption refrigeration has been commercialized successfully in the early 1980s (Wang et al., 2009). NishiyodoKuchouki, Co. Ltd. developed its silica gel-water adsorption chiller about thirty years ago, and now this product is still sold by HIJC USA Inc (2005). After that, some silica gel-water adsorption chiller products have been successively developed by GBU (2000), SorTech AG (2002), PPI (2009) and Shanghai Jiao Tong University (SJTU) (Chen et al., 2010; Liu et al., 2005a; Wang et al., 2005). The products of NishiyodoKuchouki, GBU, SorTech and PPI use vacuum check valves to realize the switch of adsorption and desorption. These vacuum check valves need to work frequently and they are not easy to be replaced since they are generally installed inside the chiller. Therefore, quality requirements and cost of these vaccum check valves are very high, which restricts the application of these adsorption chillers. SJTU developed the silica gel-water adsorption chillers without any vacuum check valves by using the two-evaporator system construction. When this kind of adsorption chiller operates, one evaporator produces the cooling effect and the other one is regarded as the reservoir of condensed refrigerant liquid. The two-evaporator system construction leads to an extra loss in cooling power since the cooling output of evaporator needs to be cooled down first. As a result, the two-evaporator adsorption chiller has lower efficiency. From the above, the present silica gel-water adsorption chiller products have not been widely applied due to their disadvantages, like large size, low efficiency, high initial cost, etc.

In order to overcome these disadvantages, adsorbers with high heat and mass transfer performance and advanced adsorption refrigeration thermodynamic cycles were developed and studied. Several adsorbers with different structures (Wang, 2001a; Wang et al., 1998) (like shell and fin-tube, plate-fin and spiral plate) were employed to intensify the heat transfer performance by extending heat transfer surface.

Because of the good performance and low price, shell and fin-tube type adsorber is frequently used in adsorption chiller. Besides, a number of advanced adsorption refrigeration thermodynamic cycles (like heat recovery cycle, thermal wave cycle, mass recovery cycle, multi-stage cycle, etc.) were proposed and studied (Akahira et al., 2004; Douss et al., 1988; Pons, 1997; Saha and Kashiwagi, 1997; Saha et al., 1997, 2001; Taylan et al., 2012; Wang, 2001b). Since the great difficulty of fulfillment in practical machine, thermal wave cycle is still at the theoretical stage. Multi-stage cycles can make the system more efficient at very low temperature heat source (such as lower than 60 °C), but it would enlarge the system size and increase cost. Heat recovery and mass recovery cycles have been successfully employed in practical application because of their easy implementation. Especially in the two-evaporator adsorption chiller, heat recovery and mass recovery cycles can significantly improve system performance and overcome its disadvantage of low efficiency.

In this paper, the authors aimed to develop a high performance and low cost silica gel-water adsorption chiller by using not only advanced system cycle (heat and mass recovery cycle), but also modular fin-tube type adsorbers. The design of the modular adsorber meets the requirements of mass production (for wide application) and it can greatly lower the cost and difficulty of manufacture. Besides, the subcomponent of modular adsorber can be regarded as a standard component; therefore, the repeatability of the adsorber design for different scales of adsorption chillers can be avoided, and adsorber maintenance cost can be reduced due to easy replacement. Another benefit of modular adsorber is less metal consumption; therefore, the heat loss of adsorption/desorption switch can decrease. In this paper, a silica gel-water adsorption chiller with modular adsorbers was designed and built. To obtain its performance data, an experimental study of this chiller was also implemented.

2. System design

2.1. System description

Schematic of this silica gel-water adsorption chiller with modular adsorber is shown in Fig. 1. The chiller is composed of two adsorbers, two condensers, two evaporators and eight valves (V1, V2 and V5 are three-way valves and V3 and V4 are four-way valves). The chiller has two independent sorption chambers, and each sorption chamber contains one adsorber, one condenser and one evaporator. Such design can greatly reduce the flow resistance of refrigerant vapor when vapor flows between adsorber and condenser/evaporator, which is significant for the vacuum system. The independent structure of the sorption chamber guarantees conservation of refrigerant in each chamber and nonequilibrium problem of refrigerant between