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Experimental study on adsorption refrigeration system with stratified storage – Analysis of storage discharge operation

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Abstract

Intergrating heat recovery can improve the coefficient of performance (COP) of adsorption refrigeration system, and stratified storage enables recovery of a large fraction of the total heat that can be recovered in an ideal cycle. In some applications, like solar cooling or CHCP, the stratified storage unit used for heat recovery between adsorption and desorption half cycles can serve an additional purpose as a buffer storage for the heat driving the cycle. In this study, two experiments, based on the adsorption refrigeration test platform of Karlsruhe Institute of Technology (KIT), were conducted to research the variations of cooling capacity and COP when the system was disconnected from any other heat source but the storage, i.e., in a storage discharge operation mode.

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Keywords: Adsorption refrigeration, stratified storage, alternative energy source

1. Introduction

Nomenclature

Q_{evap}	the total cooling amount of one cycle, kWh or kJ
Q_{desrop}	the energy expensed during desorption half cycle, i.e. the energy consumed in one cycle, kWh or kJ
$\Delta Q_{storage}$	the storage discharge of every cycle, kWh or kJ

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Adsorption refrigeration is an energy conversion system, which utilizes heat energy as driving power (such as solar energy, natural gas, waste heat recovery and etc.). Adsorption refrigeration takes advantage of the adsorption effect between a given adsorbent (e.g. silica gel) and a refrigerant gas (adsorbate, e.g. water vapour). Adsorption and desorption alternate through cooling down and heating up the adsorbent periodically. During desorption half cycle, adsorbent releases refrigerant gas and refrigerant gas condenses into liquid; during adsorption half cycle, the refrigerant liquid evaporates to absorb heat and produce cooling effect.

Adsorption refrigeration is usually implemented in the power shortage areas and the CHCP system, where CHP operation is a grid-oriented mode, so thermal storage would be a need to match the cooling supply and demand. As the peak-valley load difference of cities is increasing in summer, adsorption refrigeration with a storage can be an alternative air-conditioning system temporarily when power shortage happens.

The coefficient of performance (COP) of adsorption refrigeration system has attracted attention of researchers for a long time. L. L. Vasiliev, D. A. Mishkinis, A. A. Antukh and L. L. VasilievJr [1] designed a solar and electrical solid adsorption machine, which was a hybrid power system and utilized solar and electrical energy simultaneously. The researchers studied its COP through experiments, indicated the cooling COP could reach 0.75 through heat recovery. C. Hildbrand, P. Dind, M. Pons and M. Buchter [2] only took solar energy as the driving power, pointed out that for the operating conditions considered, the COPs of working pair silica gel-water (adsorbent–adsorbate) were better than other adsorption system, such as the adsorption systems of zeolite–water [3] and carbon–methanol [4][5][6].

The Building Technology Group of Institute of Fluid Machinery (FSM), Karlsruhe Institute of Technology (KIT) have been researching the heat recovery of adsorption refrigeration system for several years[7][8][9] (patent US 8,631,667 B2 granted on Jan 21, 2014). They introduced a stratified storage into the adsorption system as the heat recovery unit of the system. It is well known that under the same average temperature, stratified storage can store more energy than traditional mixed storage. In the adsorption cycle, the stratified storage can reduce the entropy production due to the external coupling of the adsorber to the heat source and sink. The group studied on the heat recovery of adsorption system with stratified storage for a stationary cycle, i.e. for an operating mode in which the storage is in the same state after the completion of each cycle. However, the stratified storage could also be utilized as a buffer storage for the driving heat, i.e. as an alternative energy source, which can be used to supply the heat energy to adsorption chiller continuously when there is shortage of the energy supply [7].

In this paper, based on the adsorption refrigeration system of KIT, the cooling capacity and COP variations of adsorption refrigeration with stratified storage system were studied under two situations, one was without the heater and used the stratified storage as an alternative energy source, the other was a standard one in which the heater operated continuously.

The principle of using stratified storage in order to realize the heat recovery of adsorption refrigeration is introduced in section 2; section 3 is the control strategy, in which the external energy sources are disconnected; two experiments are described in section 4 to compare the control strategy to a standard one; the conclusions and further work are shown in section 5.

2. Principle of the adsorption refrigeration system

Heat recovery of adsorption refrigeration system can be realized through stratified system, for there is an overlap between the adsorption and desorption differential heat curves. Fig. 1 shows the adsorption and desorption curves of silica gel-water working pair at a given working condition (given evaporation temperature, condensation temperature and regeneration temperature). The area under desorption curve (solid line) represents the heat required for desorption, and the area under adsorption curve (dashed curve) represents the heat released during adsorption for the given conditions. The overlap represents the heat that can be recovered in an ideal cycle, which is a considerable amount. For different working condition and different working pairs, but in many cases a considerable temperature overlap of the sorptive heats exists.

A particular cycle for adsorption heat pumps that enables recovery of a large fraction of this recoverable heat is the "Stratisorp" cycle (patent US 8,631,667 B2) which is based on the idea to store the recoverable heats at various temperatures in a stratified heat storage equipped with temperature-controlled loading and unloading mechanism [7]. The cycle concept was first published by F.P. Schmidt et al. [10] and was further developed in his research group. The system sketch of a "Stratisorp" cycle is shown in Fig. 2. The system consists of heater, cooler, adsorber, evaporator,