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Study on operation strategy of a silica gel-water adsorption chiller in solar cooling application

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ABSTRACT

Conventional operation strategy of silica gel-water adsorption chiller in solar cooling application uses fixed cycle time, but it deviates from real optimal cycle time because of varied solar hot water temperature. Mathematical model and simulation of a solar silica gel-water adsorption chiller was done and performance comparison in two operating strategies (fixed and varied cycle time) was made according to experiment data of a real solar system. An estimating equation for the optimal cycle time was developed by the simulation results, considering both COP and SCP by a weighting factor. Correlation of optimal cycle time and hot water temperature was fitted in a linear equation. Optimal half cycle time decreased with increasing hot water temperature and weighting factor. COPs of varied cycle time were much larger than those of fixed cycle time whereas SCPs of varied cycle time and fixed cycle time were nearly the same. So operation strategy of silica gel-water adsorption chiller with varied cycle time can significantly improve the whole utilization efficiency of solar cooling system without any decrease in cooling capacity.

1. Introduction

Demands of cooling are widely increasing because of dramatic growth of population as well as improvement in standard and comfort of human life. Most of cooling systems are driven by electricity so that large amount of electric power is consumed, contributing peak load of grid in summer (Montagnino, 2017). At the same time, solar energy is very rich in summer and much electric power can be saved if the cooling systems are powered by solar energy, which makes remarkable effect on peak shaving and load shifting of grid. Solar cooling systems call for thermally driven and environmentally friendly refrigerant technologies to meet more and more strict environment-protecting standards. Adsorption refrigeration, one of the green refrigeration technologies, can be powered by low-grade heat and use natural refrigerants so that solar cooling systems using adsorption chillers do not have any negative effects on environment (Wang et al., 2014). Furthermore, adsorption refrigeration can enjoy advantages of simple control, low operating cost and less vibration. So adsorption refrigeration is paid more and more attention by many researchers and scholars all over the world (Islam and Morimoto, 2016). Silica gel-water is one of the most common working pairs in adsorption refrigeration systems and its adsorption chillers have been successfully commercialized in 1980s (Wang et al., 2009). Silica gel is a stable substance with low price and water is safe substance with large latent heat of vaporization. Silica gel-water adsorption chillers can be driven by very low temperature heat source and produce 5–15 °C chilled water for air-conditioning under the conditions of 55–90 °C hot water temperature (Lu and Wang, 2013). Since the working temperature of cheap flat plate collector and evacuated tube collector are 60–80 °C and 80–150 °C, respectively (Mahesh, 2017), driving temperature of silica gel-water adsorption chiller can match well with their working temperature, which makes solar cooling systems more efficient.

Study on silica gel-water adsorption chiller mainly focuses on its performance improvement via modifying material properties, enhancing heat and mass transfer, applying advanced cycles, etc. A novel composite adsorbent with silica gel modified by calcium nitrate was tested for utilization in adsorption chillers driven by low-grade heat and its thermodynamic cooling coefficient of performance (COP) was estimated to be 0.51–0.71 (Freni et al., 2012). Equilibrium and dynamics of water adsorption on a commercial silica gel Siogel was studied and the data for theoretical analysis, mathematical modelling and evaluation of this kind of adsorption chiller was provided (Sapienza et al., 2017). To overcome the limitations of the general Linear Driving Force (LDF) kinetics equation, Sun and Chakraborty (2014, 2015) proposed kinetic formulation developed from the rigor of the partition function and the kinetics theory of adsorbate molecules with the analogy of Langmuir kinetics. Xia et al. (2008, 2010) investigated the heat transfer enhancement of water evaporation by capillarity and used in a silica gel-

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Nomenclature

A	coefficient
B	coefficient
Bi	Biot Number
C	specific heat capacity, J kg^{-1} °C^{-1}
COP	coefficient of performance
D_{s0}	surface diffusion coefficient, m^2 s^{-1}
E_a	surface activation energy, J mol^{-1}
F	heat transfer area, m^2
G	mass flow rate, kg s^{-1}
h	reaction heat, J kg^{-1}
K	heat transfer coefficients, W m^{-2} °C^{-1}
L	latent heat of vaporization, J·kg^{-1}
l	length, m
l_c	characteristic length, m
m	mass, kg
P	pressure, Pa
q	heat flux, W
R	universal gas constant, J mol^{-1}
r	radius, m
SCP	specific cooling power, W kg^{-1}
T	temperature, °C
t	time, s
x	adsorption capacity, kg/kg
z	axial length, m

Greek letters

δ	coefficient
θ	weighting factor
λ	thermal conductivity, W m^{-1} °C^{-1}

Subscript

a	adsorption
ads	adsorber
c	condensation
ch	chamber
ci	chilled water
con	condenser
cw	cooling water
e	evaporation
eva	evaporator
f	heat transfer fluid
hc	half cycle
hw	hot water
in	inlet
ou	outlet
res	reservoir
t	tube
w	water

water adsorption chiller with cooling COP of 0.49 for a 82.0/31.6/12.3 °C temperature triplet. Zhang et al. (2011) studied operating characteristics of a silica gel-water adsorption chiller powered by solar energy and found that short cycle time was suitable for open the hot water circulation and long cycle time was better for closed hot water circulation. Influence of cycle time and collector area on solar driven adsorption chillers was studied by Jaiswal et al. (2016) and more cooling capacity was obtained with increase in collector area and cycle time. Zajaczkowski (2016)) proposed a new cycle time allocation for a three-bed adsorption cycle driven by 60–65 °C heat source and COP and special cooling capacity (SCP) were improved at the same time. Similar research conducted by Sapienza et al. (2016, 2017) indicated 4.4 kW with a COP of 0.35 using 3 hybrid coated FAM Z02/granular silica gel adsorbers. In addition, heat recovery cycle, mass recovery cycle or both of them were employed to promoted system performance in numerous silica gel-water adsorption refrigeration systems (Lu and Wang, 2013; Kabir et al., 2015; Núñez et al., 2007; Chang et al., 2009; Rezk and Al-Dadah, 2012; Rahman et al., 2015; Pan et al., 2016; Pan and Wang, 2017).

Cycle time can significantly affect the silica gel-water adsorption chiller performance, especially in solar cooling system. Because optimal cycle time depends on operating conditions, but the supply temperature of solar collector varies with weather conditions and daytime. Though there is some previous study (Zhang et al., 2011; Jaiswal et al., 2016) on optimal cycle time, silica gel-water adsorption chillers were operating with fixed cycle time, which is not adjustable along with varied supply temperature of solar collector. In this paper, mathematical model of a silica gel-water adsorption chiller powered by solar energy was built and simulation under operating strategy with varied cycle time was studied. System performance comparison of silica gel-water adsorption chiller in two operating strategies (fixed cycle time and varied cycle time) was made based on a real solar cooling application.

2. Mathematical modelling

The schematic of silica gel-water adsorption chiller powered by

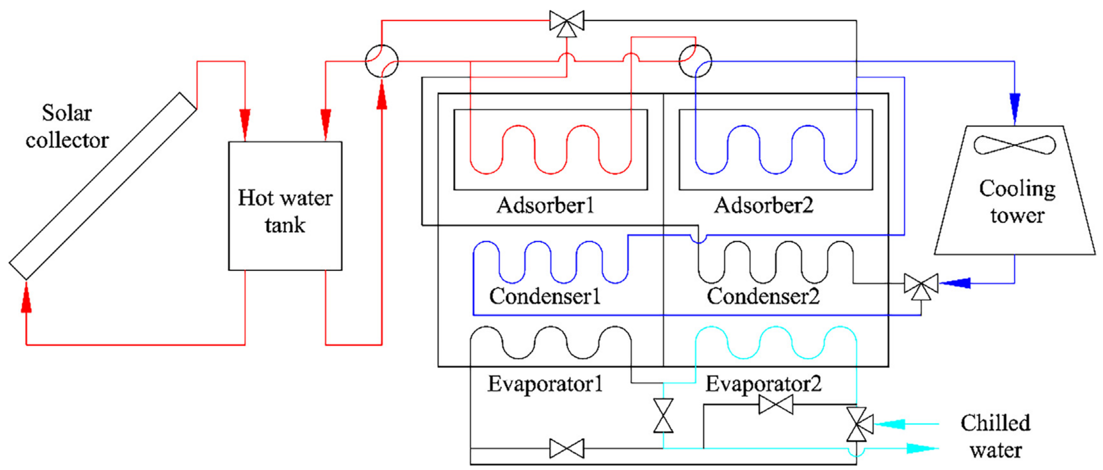

Fig. 1. Schematic of silica gel-water adsorption chiller powered by solar energy.