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The performance analysis of a novel dual evaporator type three-bed adsorption chiller

Takahiko Miyazaki [a,*], *Atsushi Akisawa* [a], *Bidyut Baran Saha* [b]

[a] *Institute of Symbiotic Science and Technology, Tokyo University of Agriculture and Technology, 2-24-16, Nakacho, Koganei-shi, Tokyo 184-8588, Japan*

[b] *Mechanical Engineering Department, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260, Singapore*

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ABSTRACT

This paper deals with the performance evaluation of an innovative, waste heat driven dual evaporator type three-bed adsorption cycle for cooling application. The innovative adsorption chiller has two evaporators, three adsorbent beds, and a condenser, and the evaporators work at different pressure levels.

The effects of hot water inlet temperature, chilled water inlet and outlet temperatures, and cycle time on the specific cooling capacity (SCC) and coefficient of performance (COP) were predicted by simulation. For the same operating condition, the SCC and COP of the dual evaporator type three-bed adsorption chiller were found to be 1.5 and 1.7 times higher than those of the two-bed single-stage adsorption chiller, respectively.

Analyse de la performance de deux nouveaux évaporateurs pour un refroidisseur à adsorption à trois adsorbeurs

Mots clés : Conditionnement d'air ; Système à adsorption ; Calcul ; Performance ; Modélisation ; Simulation ; Paramètre ; Géométrie

* *Corresponding author.*
E-mail address: tmiyazak@cc.tuat.ac.jp (T. Miyazaki).

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Nomenclature

C	water content (kg/kg)
C^*	water content at adsorption equilibrium (kg/kg)
c	specific heat (J/(kg K))
COP	coefficient of performance
D_0	pre-exponential factor
E_a	activation energy (J/mol)
H	enthalpy (J/kg)
M	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
N	number of adsorbent beds
NTU	number of heat transfer units
P	pressure (Pa)
P_s	saturated vapor pressure (Pa)
R	gas constant (J/(mol K))
r	radius (m)
SCC	specific cooling capacity (W/kg)
T	temperature (K)
t	time (s)

Greek symbols

ε	heat exchanger effectiveness

Subscripts

ah	higher pressure adsorption
al	lower pressure adsorption
b	metallic part of adsorbent bed
c	cycle
ca	cooling water to adsorbent bed
cc	cooling water to condenser
ch	chilled water
co	condenser
d	desorption
e	evaporator
eh	higher pressure evaporator
el	lower pressure evaporator
h	hot water
i	inlet
o	outlet
s	adsorbent or silica gel
v	refrigerant in vapor phase
w	refrigerant in liquid phase or water

1. Introduction

Adsorption chillers can provide environmentally friendly air conditioning because of the capability of low-grade heat utilization and the use of natural refrigerant. The adsorption chiller requires two processes of refrigerant transfer, which are induced by evaporation–adsorption and desorption–condensation. For the continuous production of chilled water, the adsorption chiller has to be equipped with at least two adsorbent beds because the adsorption and desorption processes have to be performed simultaneously.

The performance of adsorption chillers and heat pumps are well investigated for many years (Critoph and Zhong, 2005). The recent achievements of those studies related to low temperature driven adsorption chillers employing silica gel–water pair are as follows. Xia et al. (2009) developed a novel adsorption chiller that have a methanol evaporator to produce cooling effect. They obtained a COP of 0.39 with the heat source temperature of 82.5 °C, the cooling water temperature of 30.4 °C, and the chilled water outlet temperature of 12 °C. Kubota et al. (2008) tested an adsorption chiller equipped with a fin and tube type heat exchanger. They have optimized the fin pitch and the fin length of the heat exchanger to maximize the cooling output (Li et al., 2004), and it was experimentally confirmed that the optimized heat exchanger enhanced the cooling output of the adsorption chiller. Núñez et al. (2007) and Mittelbach et al. (2008) developed prototypes of a small adsorption chiller and heat pump. Their adsorption chiller achieved the compactness by a silica gel coated heat exchanger and a novel design of the chiller. Saha et al. (2009) investigated a two-bed adsorption chiller using a composite adsorbent called the SWS-1L ($CaCl_2$ confined to KSK silica gel). The SWS-1L has a high water sorption capacity (Aristov, 2007), which is a favorable characteristic as an adsorbent for adsorption chillers. The performances of the SWS-1L based adsorption chiller and the conventional, RD type silica gel based adsorption chiller were predicted by simulation, and it was shown that the SWS-1L based adsorption chiller could achieve better performance in terms of cooling capacity, COP and chilled water outlet temperature compared with those of the conventional adsorption chiller (Saha et al., 2009).

The innovative adsorption chiller with the driving temperature as low as 40 °C was first proposed by Saha et al. (1995a). By both the simulation and experiment, they verified that the three-stage adsorption scheme enabled the refrigeration cycle with a small temperature lift of 10–30 K between a heat source and a heat sink (Saha and Kashiwagi, 1997). The two-stage adsorption chiller was also designed by a similar concept, and it worked effectively with the heat source temperature around 60 °C (Saha et al., 2000, 2001). These multi-stage adsorption chillers used six adsorbent beds for three-stage operation or four adsorbent beds for two-stage operation. A dual-modal or a multi-modal operation of the adsorption chiller that had six adsorbent beds was also pursued to enhance the waste heat utilization ability (Saha et al., 2003a; Alam et al., 2003). The dual-mode adsorption chiller developed by Saha et al. (2003a) works as a single-stage adsorption chiller with the heat source temperature between 60 °C and 95 °C, and it switches the operation to the three-stage adsorption chiller mode with the heat source temperature of 40–60 °C.

On the other hand, the performance improvement of adsorption chillers was explored by three-bed design also. Saha et al. (2003b) proposed a three-bed non-regenerative adsorption chiller that would enhance the waste heat recovery efficiency as well as mitigate the fluctuation of the delivered chilled water temperature. The performance of the three-bed adsorption chiller could be further improved by implementing the mass recovery scheme (Khan et al., 2007).