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Research paper

Simulation study of a combined adsorption refrigeration system

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HIGHLIGHTS

- Development of a thermodynamic model for a combined adsorption refrigeration system.
- Zeolite 13X/CaCl2 is considered as a new adsorbent in a combined adsorption refrigeration system.
- Zeolite 13X/CaCl2-water are more advantageous than the other working pairs.

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ABSTRACT

In this study, we have divided combined ADRS into four types based on different arrangements of two working pairs, Zeolite 13x/$CaCl_2$-water and Silica gel (RD type)–water, to analyze the performance of combined ADRS. After validating mathematical models with available experimental data, ADRS is simulated by using Simulink–Matlab software to achieve optimum times for various processes. The results of simulation show that the cooling capacity of the system with Zeolite 13x/$CaCl_2$-water is more than the other types. The results have shown that the arrangement of adsorbents affects cooling capacity of combined ADRS significantly. In Type A, Zeolite 13x/$CaCl_2$-water has been used as an adsorbent for both top and bottom cycles. This type not only has more cooling capacity than the other types, but also the effect of hot water temperature on cooling capacity of this type is less than the others. Furthermore, a sensitivity analysis has been done to determine the importance of each parameter on ADRS system because the cooling capacity and the COP are influenced by many constant parameters.

1. Introduction

The necessity of using renewable energy sources and environmental friendly refrigerants is increasingly recognized due to the ozone layer depletion and global warming. In the recent years, various technologies have been developed to make best use of renewable energies; ADRS is one of these technologies [1]. This system, in comparison with conventional vapor compression systems, which consumes less electrical energy and is capable of storing energy when it is run by solar or industrial waste energy. Better control and less vibration can be accounted as advantages of this system. Furthermore, the operating and maintenance cost of ADRS is less than that of the vapor compression cooling system [2]. The researches which have been done on adsorption refrigeration systems can be categorized in three main groups: First we see researchers such as Saha et al. [3], Chua et al. [4] who presented simulated models. Boalman et al. [5] experimentally have analyzed the effects of various parameters on performance of simple cycle of ADRS (two-bed ADRS). Mahdavikhah and Niazmand numerically have studied the effects of geometric parameters of heat exchanger on the adsorption chiller performance. They have used a three-dimensional model to predict the dynamic performance of an intermittent adsorption cycle working with the composite sorbent SWS-1L and water. The results show that COP increases as the bed height increases. It is less sensitive to the fins spacing, though. Furthermore, the SCP decreases dramatically with increasing fin height due to the increase in cycle time and adsorbent mass. Therefore, the geometric specifications of the adsorption heat exchanger are of great practical importance in the design of the adsorption cooling systems [6]. Niazmand et al. has shown that optimum diameter is influenced by different parameters such as fins height and spacing and heating/cooling temperatures of the thermal fluid. They have show that the COP of system remains almost constant for the selected range of particle sizes at fixed geometrical and operational conditions; whereas, SCP of system has its maximum value at a specific particle diameter [7]. Another

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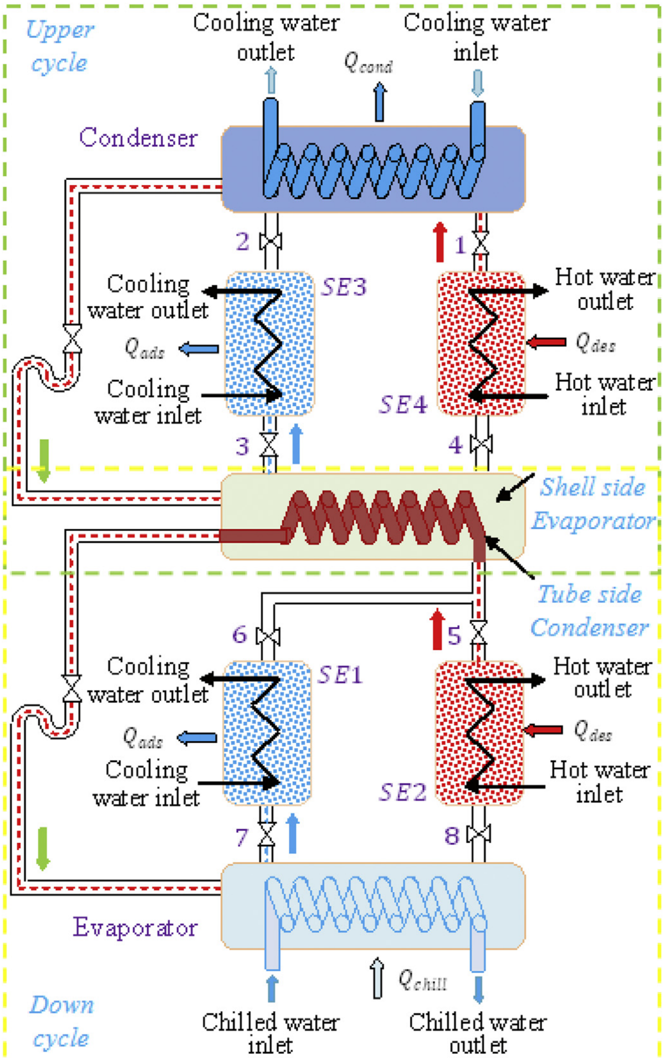

Fig. 1. Schematic configuration of combined ADRS.

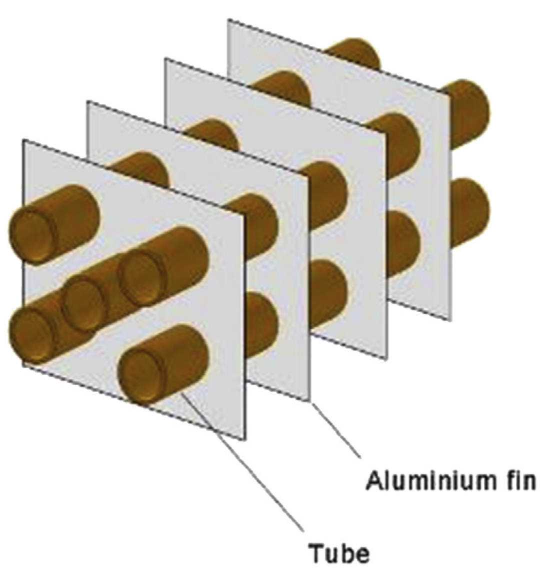

Fig. 2. Schematic configuration of combined evaporator-condenser unit.

Table 1
Different type of adsorbents which are used in simulation of combined ADRS.

	Down cycle adsorbents		Upper cycle adsorbents	
Type	SE1	SE2	SE3	SE4
A	Zeolite 13X/$CaCl_2$	Zeolite 13X/$CaCl_2$	Zeolite 13X/$CaCl_2$	Zeolite 13X/$CaCl_2$
B	Zeolite 13X/$CaCl_2$	Zeolite 13X/$CaCl_2$	Silica gel (RD type)	Silica gel (RD type)
C	Silica gel (RD type)	Silica gel (RD type)	Zeolite 13X/$CaCl_2$	Zeolite 13X/$CaCl_2$
D	Silica gel (RD type)	Silica gel (RD type)	Silica gel (RD type)	Silica gel (RD type)

Table 2
Numerical constants of equations (1)–(4) [3,15].

Parameter subscript	0	1	2	3
A	−6.5314	0.072452	-0.23951×10^{-3}	0.25493×10^{-6}
B	−15.587	0.15915	-0.50612×10^{-6}	0.5329×10^{-6}
C- Adsorption	381.4	−3.463	10.08×10^{-3}	-9.153×10^{-6}
C- Desorption	400.8	−5.532	10.02×10^{-3}	-8.908×10^{-6}

Table 3
Values of parameters adopted in the simulation [15,26].

Symbol	Value	Unit
$(UA)_{cond}$	4115.23×3.73	W/K
$(UA)_{evap}$	2557.54×1.91	W/K
$(UA)_{bed}$	1724.14×2.46	W/K
M_{cond}	24.28	kg
M_{evap}	12.45	kg
M_a	47	kg
$M_{cond,ref}$	20	kg
$M_{evap,ref}$	50	kg
$Q_{is,RD\ silica\ gel}$	2800	kJ/kg
$Q_{is,zeolite}$	3394.48	kJ/kg
h_{fg}	2500	kJ/kg
$R_{p,RD\ silica\ gel}$	1.7×10^{-4}	m
$R_{p,zeolite}$	1×10^{-6}	m
$M_{f,Hex}$	64.04	kg
$M_{k,Hex}$	51.20	kg
$C_{p,w}$	4.186	kJ/kg K
$C_{p,Al}$	0.905	kJ/kg K
$C_{p,Cu}$	0.386	kJ/kg K
$C_{p,RD\ silica\ gel}$	0.924	kJ/kg K
$C_{p,zeolite}$	0.836	kJ/kg K
$E_{a,RD\ silica\ gel}$	4.2×10^4	kJ/kmol
$E_{a,zeolite}$	2.8035×10^4	kJ/kmol
$D_{so,RD\ silica\ gel}$	2.54×10^{-4}	m^2/s
$D_{so,zeolite}$	3.92×10^{-6}	m^2/s

Table 4
Nominal operating condition for the combined ADRS.

Parameter	Symbol	Value	Unit
Hot water inlet temperature	$T_{hw,in}$	75	°C
Hot water mass flow rate	$\dot{m}_{hw}$	0.65	kg/s
Adsorber and condenser cooling water inlet temperature	$T_{cw,(ads,cond),in}$	30	°C
Adsorber and condenser cooling water mass flow rate	$\dot{m}_{cw,ads+cond}$	(0.65 + 0.65)	kg/s
Chilled water inlet temperature	$T_{chill,in}$	15	°C
Chilled water mass flow rate	$\dot{m}_{chill}$	0.6	kg/s

group of researchers analyzed the performance of different adsorbents and refrigerants on ADRS such as Silica gel (A type)-water [8], Silica gel (RD type)-water [3,5], Zeolite-water [9] and Zeolite 13x-water [10,11]. Furthermore, these researchers enriched solid adsorbent with mineral salts such as $CaCl_2$, LiBr, and etc. So, they were able to increase both adsorption capacity and performance of