

## A PERFORMANCE TEST OF ADSORPTION REFRIGERATION SYSTEM APPLYING SUPERABSORBENT POLYMERIC ADSORBENT

Chang Y.S.<sup>1\*</sup>, Kim T.H.<sup>1</sup>, Lee D.Y.<sup>2</sup> and Kang B.H.<sup>1</sup>

\*Author for correspondence

<sup>1</sup>School of Mechanical Engineering,  
Kookmin University,  
Seoul, 02707  
Korea

E-mail: yschang@kookmin.ac.kr

<sup>2</sup>Center for Urban Energy System Research,  
Korea Institute of Science and technology,  
Seoul 02792,  
Korea

### ABSTRACT

Embedded Adsorption refrigeration technology has an advantage of providing efficient cooling with the heat supplied from the community energy supply system including the feed water of district heating system, industrial waste heat, and others. however, conventional adsorption refrigeration system shows a low COP. In this study, SAP(superabsorbent polymer) was coated on a fin-tube heat exchanger by about 100 um thickness to enhance heat and mass transfer performance during adsorption and desorption processes. Adsorption and desorption test were performed to analyze the performance of SAP coated adsorber. System performance such as SCP(mass specific cooling power) and COP was measured according to cycle duration from 14 to 70 minutes. The SCP shows a nearly constant value with respect to period except 70 minutes of period. As the cycle time gets longer, the SCP decreases but the COP increases. COP was estimated to be 0.2 to 0.45 and SCP was 170 W/kg.

### INTRODUCTION

The adsorption chiller constitutes a similar cycle to an absorption chiller. The difference is that the absorption type uses a liquid absorbent whereas the adsorption type adsorbs a refrigerant evaporated from the evaporator in a solid-state adsorbent to obtain a refrigerating effect. When the adsorption process of the refrigerant proceeds and the refrigerant content of the adsorbent increases, the adsorption performance decreases. The adsorbent can be heated and desorbed to obtain a continuous refrigerating effect. The released refrigerant is condensed in the condenser, expanded and evaporated in the evaporator.

Recent energy issue has been caused by increasing energy demands, shortages of energy resources and environmental problem. Adsorption refrigeration technology has an advantage of providing efficient cooling with the heat supplied from the community energy supply system including the feed water of district heating system, industrial waste heat, and others.

Various theoretical and experimental studies have been conducted on adsorption refrigeration systems with these advantages. In particular, new adsorbents, high-efficiency cycles,

enhancing heat and mass transfer performance, and practical system design methods are being researched and developed [1].

The adsorbent is the most important factor in relation to the performance of the adsorption refrigerator. Good adsorbent should have a large adsorption capacity, a large adsorption capacity change with respect to temperature, high heat and mass transfer performance, and good compatible refrigerant [2, 3].

Various adsorbent-refrigerant combinations have been studied, and silica gel and zeolite are commonly used as adsorbents that use water as a refrigerant for the air conditioning system. Silica gel can be desorbed even at a low temperature of 75 °C, so it is energy-efficient and can be used by recovery of low-temperature waste heat. The zeolite requires a desorption temperature of 200 °C or more, so it can be applied to a direct-burning type or directly heated by exhaust gas from the engine.

In this study, the performance of adsorption refrigeration system using polymer adsorbent [4], which is known to have better adsorption performance than silica gel or zeolite, was analyzed.

polymer adsorbent was coated on a heat exchanger to constitute an adsorption refrigeration system and performance tests were conducted to analyze the performance characteristics of the system.

### NOMENCLATURE

COP	[-]	Coefficient of performance
Cp	[kJ/kg·K]	Specific heat
$\dot{m}$	[kg/s]	Mass flow rate
P	[kPa]	Pressure
Q	[kJ]	Heat transfer rate
SCP	[kW/kg]	Refrigerating capacity per unit mass
T	[K]	Temperature

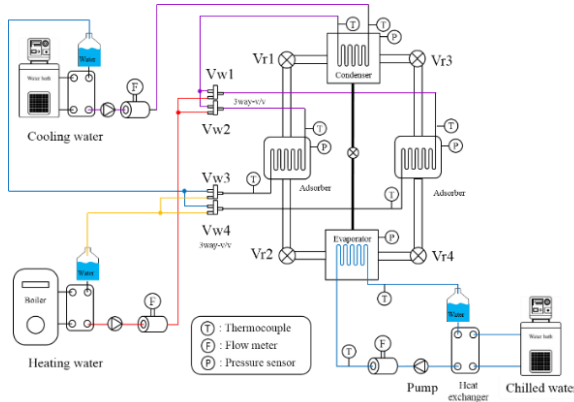
#### Subscripts

<i>ads</i>	Adsorption process
<i>ch</i>	Chilled water
<i>des</i>	Desorption process
<i>hot</i>	Hot water
<i>in</i>	Inlet
<i>out</i>	Outlet

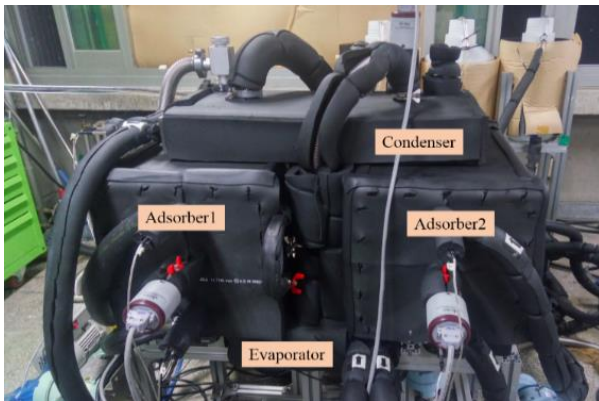
**EXPERIMENTAL APPARATUS**

An experimental system consisted of an adsorption refrigeration system consisting of two adsorbers, an evaporator, a condenser and four refrigerant valves, heat source devices for setting the operating conditions of the system, water circulation devices, and 4 water valves for cyclic operation of adsorption and desorption.

Pressure sensors were installed in the adsorbers, evaporator and condenser to observe the pressure variation in the system. Mass flow meters and RTD sensors were installed to measure water flow rates and temperature of main components (adsorber, evaporator, condenser), respectively. The schematic and actual views of the system are shown in Figures 1 and 2.



**Figure 1** Schematic of experimental apparatus



**Figure 2** Photo of experimental apparatus

**Table 1** Specification of polymer adsorbent coated heat exchanger

Parameter	Adsorber1		Adsorber2	
	A	B	C	D
Heat exchanger size [mm]	403 × 122 × 272			
Heat exchanger area [m <sup>2</sup> ]	13.8	13.8	13.8	13.8
Heat exchanger weight [g]	3830	3825	3824	3828
Adsorbent [g]	1746	1405	1443	1600



**Figure 3** Polymer desiccant coated heat exchanger

Two adsorbers are installed to obtain a continuous cooling effect by cyclic operation, and two heat exchangers coated with polymer adsorbent of about 100µm are installed in each adsorber. The actual shape and specifications of the heat exchangers installed in the adsorber are shown in Figure 3 and Table 1.

**EXPERIMENTAL METHODS**

Since the adsorption refrigeration system operates under the vacuum condition, the system was first vacuumed using a vacuum pump. The third round of distilled water was used as refrigerant and charged into the evaporator. Cooling, heating, chilled waters were supplied to each component according to respective temperature conditions.

An adsorption and a desorption processes of the system make one cycle. Adsorption progresses during the half of the cycle, and the remaining half of the cycle is given for desorption. The adsorption and desorption processes are controlled by the operation of the four refrigerant valves and the four water valves. Each valve control was automatically configured by NI LabVIEW program.

Table 2 and Table 3 show the control process of switching the adsorption and desorption according to the valve opening and closing and the operating conditions of the system, respectively.

**Table 2** Operation chart for controlling valves

Parameter		Refrigerant valve (Vr)				Water valve (Vw)				Conditions
Adsorber conditions		1	2	3	4	1	2	3	4	
Ads(1) Ads(2)	preparation process	X	X	X	X	O	X	X	O	T=0, T=Period
	Ads(1) adsorption	X	O	X	X	O	X	X	O	Pads(1) < Peva
	Ads(2) desorption	X	O	O	X	O	X	X	O	Pads(2) > Pcond
Ads(2) Ads(1)	preparation process	X	X	X	X	X	O	O	X	T=Period/2
	Ads(2) adsorption	X	X	X	O	X	O	O	X	Pads(2) < Peva
	Ads(1) desorption	O	X	X	O	X	O	O	X	Pads(1) > Pcond

**Table 3** Experimental conditions

Parameter		Unit	Conditions
Cooling water	Inlet temp.	°C	30
	Mass flow rate	kg/min	3
Chilled water	Inlet temp.	°C	14
	Mass flow rate	kg/min	3
Heating water	Inlet temp.	°C	80
	Mass flow rate	kg/min	3
Period		min	14 / 28 / 42 / 70

### EVALUATION PROCEDURE

The cooling and heating capacity rates are calculated as shown in equations 1 and 2. The COP of the adsorption refrigeration system is expressed by the integrated values of cooling and heating capacity rates for a cycle. The SCP is defined by the cooling capacity per unit mass of the coated adsorbent and is given by equation 4.

$$\dot{Q}_{ch} = \dot{m}_{ch} C p_{ch} (T_{ch,in} - T_{ch,out}) \quad (1)$$

$$\dot{Q}_{hot} = \dot{m}_{hot} C p_{hot} (T_{hot,in} - T_{hot,out}) \quad (2)$$

$$COP = \frac{\int Q_{ch}}{\int Q_{hot}} \quad (3)$$

$$SCP = \frac{\int Q_{ch}}{M_{adsorbent}} \quad (4)$$

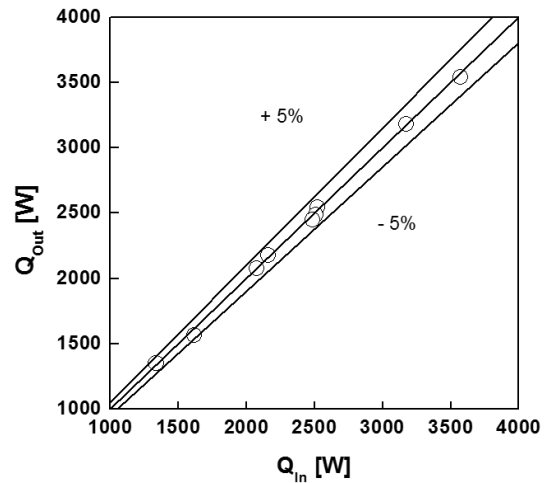
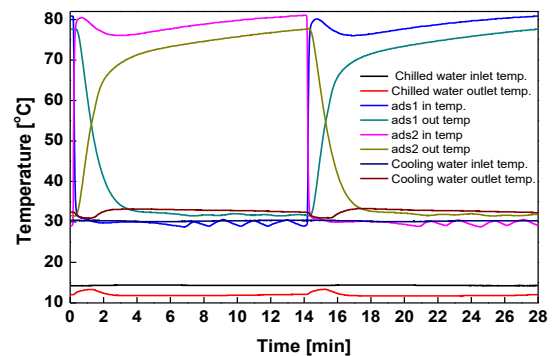
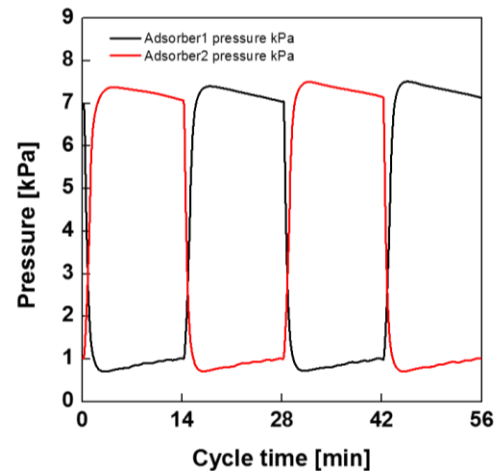
### EXPERIMENTAL RESULTS

In order to confirm the reliability of the experimental results, thermal energy supplied to the system is compared with discharged heat from the system during one cycle in Figure 4 and agrees within an error range of 5%.

Figure 5 shows the temperature variations of heating, cooling, and chilled water at a cycle of 28 minutes. The adsorption process proceeds in the adsorber 1. The temperature difference between the inlet and outlet of the cooling water is great until hot water inside adsorber 1 is discharged and the heat exchanger is cooled to such an extent that it can be adsorbed.

At the same time, the desorption process proceeds in the adsorber 2. At the initial stage of the desorption process, cooling water is discharged, and adsorber is heated to a temperature at which the adsorbent can be desorbed, so that the temperature difference between the inlet and outlet of adsorber 2 is also very large. By excessive initial load in the initial desorption process, heating water is supplied lower than 80 °C due to limited capacity of the water vessel. When the adsorbent is heated to some extent, the inlet condition of heating water approaches the experimental condition of 80 °C.

In the case of chilled water, the adsorption does not proceed

**Figure 4** Energy balance of heat input and output**Figure 5** Temperature variations of heating, cooling, and chilled water at a cycle of 28 minutes**Figure 6** Pressure variation in the adsorbers during adsorption and desorption processes

for a while after desorption and adsorption are switched, so that the inlet and outlet temperature difference decreases in this section and the temperature difference recovers when adsorption occurs.

As shown in Figure 6, the water vapor pressure inside the adsorber is changed by the cyclic operation of adsorption and desorption.

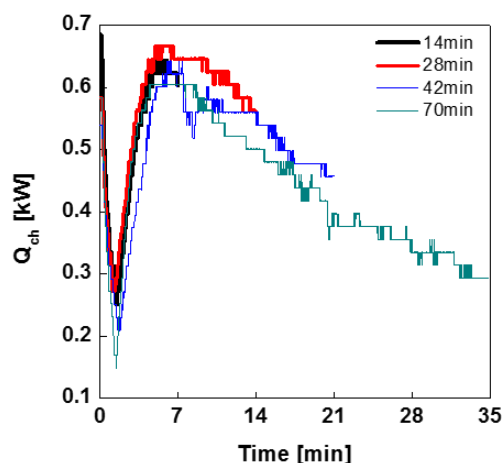


Figure 7 Cooling capacity rate according to period of cycle

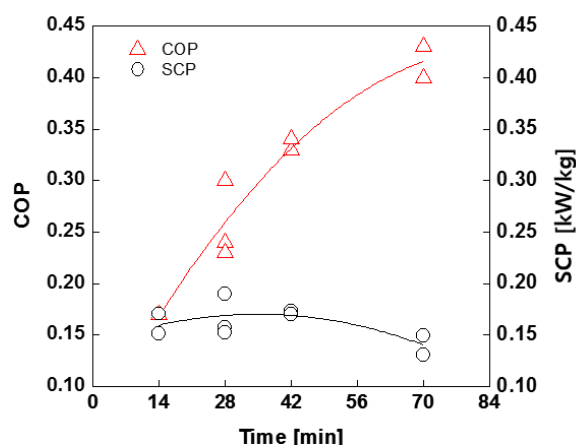


Figure 8 COP and SCP according to period of cycle

During the adsorption process, pressure is maintained by about 1 kPa, which corresponds to the evaporation pressure, and pressure of about 7 kPa, which corresponds to the condensation pressure, is maintained during the desorption process.

In the case of switch from desorption to adsorption, the pressure drops from the condensation pressure due to the cooling of the adsorbent to reach the evaporation pressure. As the adsorption does not occur until the adsorbent is sufficiently cooled and the pressure of adsorbent reaches the evaporation pressure, the cooling capacity can be expected to decrease if the adsorption stops for a longer period of time.

The cooling capacity rate according to period of the cycle is shown in Figure 7. At the beginning of the desorption to adsorption switch, the adsorption does not occur until the cooling process of the adsorbent is completed. When the adsorption starts, the refrigerating capacity is recovered and the maximum value of about 650 W is reached. As a result, the cooling capacity rate decreases with time, and after about 30 minutes, it decreases to half of the maximum capacity.

The SCP and COP are shown in Figure 8. The shorter period, the larger the ratio of the halt time in adsorption to the period of cycle, which reduces the cooling capacity. In other words, the longer the period, the smaller the influence of the halt time in adsorption and the less the effect of the performance degradation.

As the adsorption period becomes longer, the cooling capacity decreases due to the degradation of the adsorption performance, so that the SCP tends to decrease due to the increase of the period of cycle. Therefore, by these two opposing effects on the period, the SCP shows a nearly constant value with respect to period except 70 minutes of period.

The heating capacity is not only used for desorption, but also for heating the adsorbent owing to cyclic operation of adsorption and desorption. If the period is longer, the COP increases because the fraction of the heating capacity for heating the adsorbent decreases with respect to the total heating capacity. The COP shows 0.33 at 42 minutes and 0.42 at 70 minutes of period.

In order to improve the SCP of the adsorption refrigeration system, adsorption characteristics of the adsorbent, heat and mass transfer performance need to be improved. Research is needed to reduce the heat capacity of the heat exchanger or to improve the coefficient of performance by adopting a cycle for heat recovery.

## CONCLUSION

In this study, SAP(superabsorbent polymer) was coated on a fin-tube heat exchanger by about 100  $\mu\text{m}$  thickness to enhance heat and mass transfer performance during adsorption and desorption processes. Adsorption refrigeration system was constructed, which has two SAP coated adsorbents, a condenser, an evaporator, and measurement devices. Adsorption and desorption test were performed to analyse the performance of SAP coated adsorbent. Due to the low diffusivity of SAP, the time required for adsorption or desorption is relatively long compared to silica-gel and zeolite. System performance such as SCP(mass specific cooling power) and COP was measured according to cycle duration from 14 to 70 minutes. The SCP shows a nearly constant value with respect to period except 70 minutes of period. As the cycle time gets longer, the COP increases. COP was estimated to be 0.2 to 0.42 and SCP was 170 W/kg. Based on the experimental results, design improvements for enhancing system performance were discussed.

## ACKNOWLEDGMENT

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