An Experimental Study on the Heat and Mass Transfer of Adsorption Chiller

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Abstract: Adsorption chillers have been receiving considerable attentions as they are energy saving and environmentally benign systems. In this paper, heat and mass transfer experiments of adsorption bed were performed in the batch type adsorption apparatus. The adsorbent and the refrigerant used for the experiment is silica gel and water. Three types of adsorption bed heat exchangers ; fin-tube, heat pipe with both sides and heat pipe with one side, are proposed and experimented. The performance of adsorption bed was analysed by heat transfer rate and adsorption rate with inlet temperature of cooling water. The experimental results show that the adsorption bed of fin-tube type gave best heat transfer rate of 960 W. Also, it is found that the heat pipe with one side showed better performance in the heat transfer rate(540 W) than that of the heat pipe with both sides(340 W) by up to 60%.

Key Words: adsorption chiller, adsorption rate, heat and mass transfer, silica gel-water

1 INTRODUCTION

Thermally driven adsorption systems are considered promising candidates to replace vapor compression systems using CFC and HCFC refrigerants. These adsorption systems have a distinct advantage over other systems in their ability to be driven by heat of relatively low temperatures, so that waste heat below 100 ^{o}C can be recovered. And they do not use electricity or fossil fuels as driving sources. Moreover, water is used as an environmental-friendly refrigerants used in adsorption cycle and it has a large latent heat of vaporization.

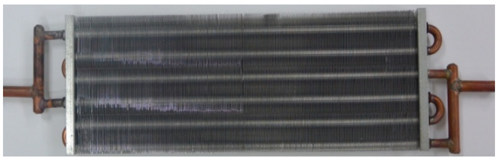
Adsorption chillers employs silica gel/water as an adsorbent-refrigerant pair. The adsorption bed is one of the most critical components in the adsorption system. In order to design a more effective adsorption system, many researchers have focused on how to improve the performance of the adsorption bed. Also, Freni et. al.,(2002) and Kwon et. al.,(2004) experimentally conducted the effective thermal conductivity of adsorbent under the operation conditions of adsorption bed. In order to develop a high performance adsorption bed heat exchanger, it is required to clarify the characteristics of heat and mass transfer in the adsorbent bed. However, few of such data have been obtained and also there are few studies discussing the influences of those factors comprehensively.

In this paper, three types of adsorption bed heat exchangers ; fin-tube, heat pipe with both side and heat pipe with one side, are proposed and experimented. The performance of adsorption bed was analysed by heat transfer rate and adsorption rate with inlet temperature of cooling water.

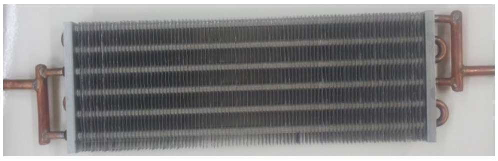
2 EXPERIMENTAL SETUP AND CONDITION

The adsorption bed of three types was manufactured in order to evaluate performance characteristics of adsorption bed with heat exchanger type and distance of fin. The size of three types of heat exchanger were designed by 400×150×22 mm equally. Adsorption bed of the fin-tube type was designed that the inlet and outlet pipes of cooling water branched from header. Also, adsorption bed of heat pipe type was designed heat transfer structure from the cooling water pipe to the heat pipe. The heat exchanger of each types was comprised of fin pitch with 2 mm or 4 mm. The heat exchangers used in the present experiment are shown in Figure 1 and Table 1. An adsorbent used for the adsorption experiment is a granular A type silica gel(0.2 mm to 0.5 mm of diameter). When the fin pitch increases from 2 mm to 4 mm, the amounts of adsorbent of fin-tube type adsorption bed were 946 g(2 mm fin pitch) and 990 g(4mm fin pitch), respectively. Also, the amounts of adsorbent of the heat pipe with both sides and one side were 775, 852 g and 774, 854 g. The silica gel adsorbents were fully charged between the fins of the adsorption bed heat exchanger and packed with a 150 mesh size net.

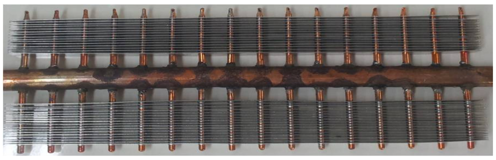
The schematic diagram and pictorial view of experimental setup are shown in Figure 2 and Figure 3. The experimental setup comprises an adsorption chamber, an evaporator, condenser, connecting pipes and refrigerant valves. Also, auxiliary facilities include the



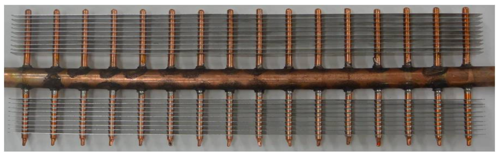
(a) Fin-tube HX (Fp : 2 mm)



(b) Fin-tube HX (Fp : 4 mm)



(c) Heat pipe : both side (Fp : 2 mm)



(d) Heat pipe : both side (Fp : 4 mm)

(e) Heat pipe : one side (Fp : 2 mm)

(f) Heat pipe : one side (Fp : 4 mm)

Figure 1: Optical images of heat exchangers

Table 1: Specification of heat exchangers

Item	Value
Type	Fin-tube, Heat pipe
Size (W×H×L)	150×22×398
Tube diameter (mm)	9.8 / 20.6
Fin pitch (mm)	2, 4
Heatpipe diameter / length (mm)	8 / 150
Tube material	Copper
Fin material	Aluminum, Stainless steel

vacuum pump to maintain the vacuum inside system and constant temperature water baths to simulate the adsorption and desorption conditions. Three constant temperature water baths were used to control the temperatures of cooling/hot water for adsorption/desorption and condensation. An evaporator including 2 kW cartridges heater was used in order to send water vapor to the adsorption bed. The water vapor uptake(mg/g) measured through a change in volume of level gauge. The temperatures of inside adsorption bed were measured at three places(bottom, center, top side) by T-type thermocouples. The temperatures of evaporator and the inlet and outlet temperatures of cooling/hot water were measured by the RTD sensors. Pressures of the adsorption bed and evaporator were measured by absolute pressure transducers.

The heat transfer rate of adsorption bed is expressed by Equation (1). Also, the overall heat transfer coefficient is given by Equation (2). The LMTD which was proposed by Saha et. al.,(2010) is used to fit the heat transfer coefficient of silica gel/water pair.

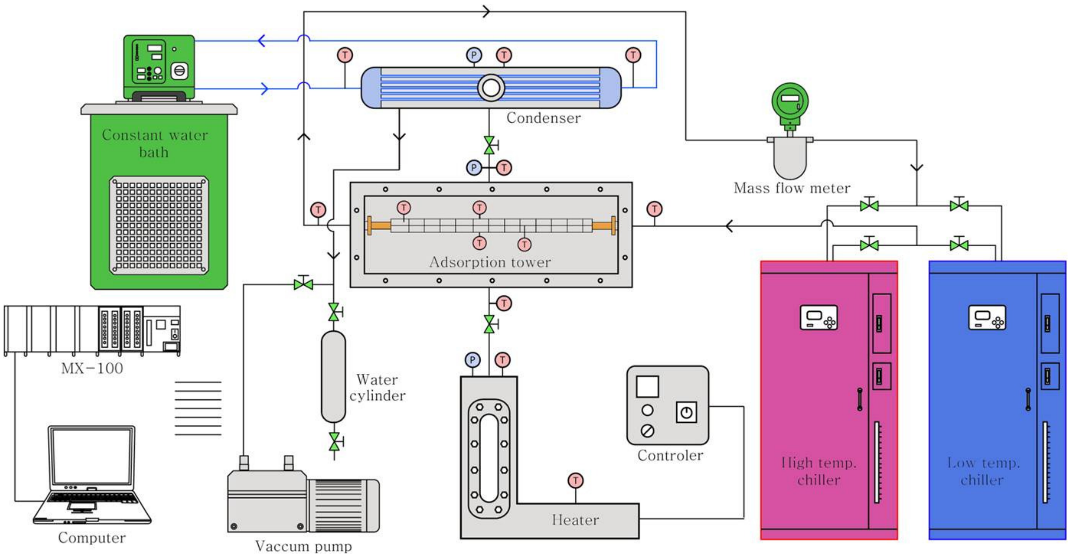


Figure 1: Schematic of adsorption experimental set-up

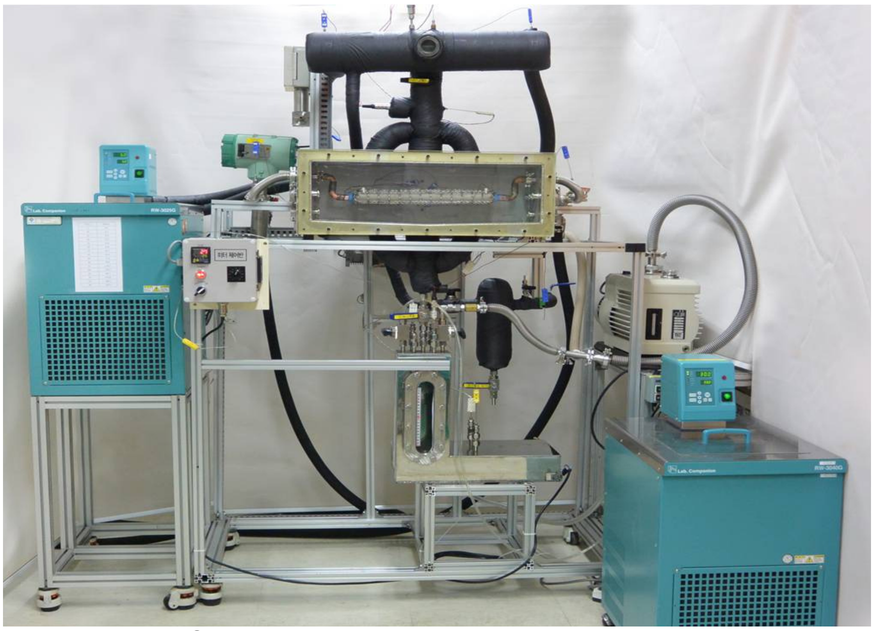


Figure 2: Optical image of adsorption experimental set up

$$Q_{ads} = \dot{m}_{cw} Cp_{cw} \left(T_{cw,out} - T_{cw,in} \right) \tag{1}$$

$$U_{overall} = \frac{Q_{ads}}{A_{bed} LMTD} \tag{2}$$

$$LMTD = \frac{\left(T_{cw,in} - T_{ads} \right) - \left(T_{cw,out} - T_{ads} \right)}{\ln \frac{\left(T_{cw,in} - T_{ads} \right)}{\left(T_{cw,out} - T_{ads} \right)}} \tag{3}$$

Where, T_{ads} is adsorbent temperature inside adsorption bed.

The experiment was set as cooling water inlet temperature 30 °C, cooling water flow rate to be 4 kg/min, and water vapor temperature to be 20 °C at basic conditions. The cooling water temperature is in range of 24 °C to 36 °C at basic condition 30 °C of the cooling water inlet temperature. At this time, the adsorption time was set equally 7 minutes. The experimental conditions are showed at Table 2.

Table 2 : Experimental conditions

Condition		Value
Cooling water	Inlet temperature (°C)	24, 27, 30*, 33, 36
	Mass flow rate(kg/min)	4
Steam inlet temperature (°C)		20
Adsorbent		Silica gel (KD-corporation)
Particle size (mm)		0.2~0.5
Pore size (nm)		0.45
Surface area (m^2/g)		770
Adsorption time (s)		420

Basic condition*

3 RESULTS AND DISCUSSION

Figure 4 shows the variation of heat transfer rate with inlet temperature of cooling water for the heat exchanger types of the adsorption bed. The heat transfer rate has the tendency to decrease with increase of cooling water inlet temperature. When the inlet temperature of cooling water is 30 °C, the heat transfer rate of fin-tube type adsorption bed shows maximum value of 570 W for the fin pitch of 2 mm. The heat transfer rate of heat pipe type adsorption bed with one side and both sides were 570 W and 340 W. The heat transfer rate of heat pipe type adsorption bed with one side was about 60% higher than that of both side type. The heat pipe was conducted iteratively to the condensing and evaporating process. The refrigerant which was supplied with heat from high temperature source is vaporized after the refrigerant releases heat to the low temperature source. Therefore, the performance of heat pipe was very sensitive to the ratio of evaporation and condensing area. The heat transfer rate of heat pipe type adsorption bed with one side was higher than that of both side type. It is because that condensing area was less than that of evaporating counterpart. In the all of adsorption bed, the heat transfer rate of the fin pitch 2mm type adsorption bed was higher than that of the fin pitch 4 mm.

Figure 5 shows the variation of overall heat transfer coefficient with inlet temperature of cooling water for the heat exchanger types of adsorption bed. In the basic conditions, the overall heat transfer coefficient of fin-tube type adsorption bed shows maximum value of 107 $W/m^2 \cdot {}^oC$. The heat pipe type adsorption bed with both sides and one side showed similar overall heat transfer coefficient by value of about 25 $W/m^2 \cdot {}^oC$. It is because that the heat transfer rate was similar owing to little temperature difference of two heat pipe type adsorption beds.

Figure 6 shows the variation of adsorption rate with inlet temperature of cooling water for the heat exchanger types of adsorption bed. As the inlet temperature of cooling water increased, the adsorption rate decreased. When the inlet temperature of cooling water varied from 24 ^oC to 36 ^oC, the adsorption rate decrease by 53 g and 38.6 g for the fin-tube type adsorption bed with fin pitch of 4 mm and 2 mm. The adsorption rate of heat pipe type adsorption bed was small decreased slightly compared to that of other adsorption bed. As the inlet temperature of cooling water rises, the decrease ratio of adsorption rate was increased. It is because that the adsorption rate decreased due to the rise of bed temperature.

Figure 7 shows the variation of water vapor uptake with inlet temperature of cooling water for the heat exchanger types of adsorption bed. The water vapor uptake has similar adsorption

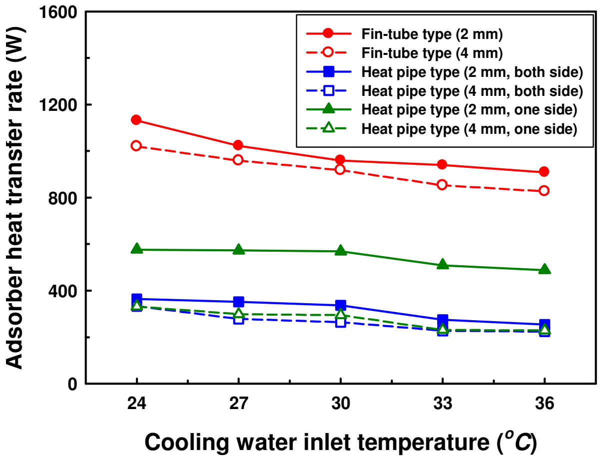


Figure 4: Heat transfer rate as a funcition of cooling water temperature

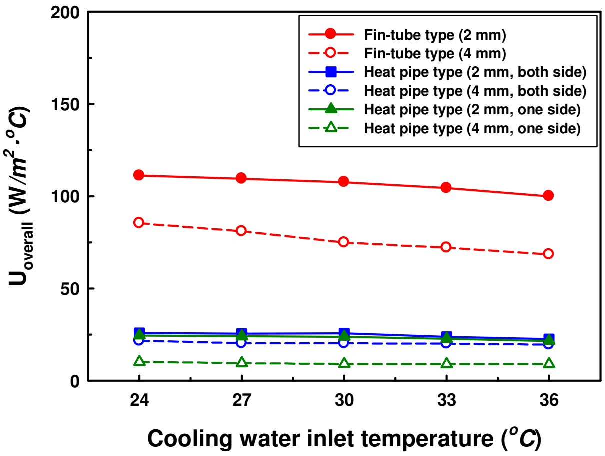


Figure 5: Overall heat transfer coefficient as a funciton of cooling water temperature

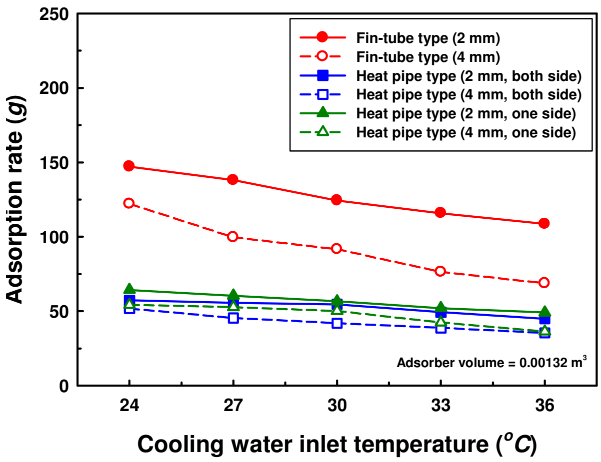


Figure 6: Adsorption rate as a function of cooling water temperature

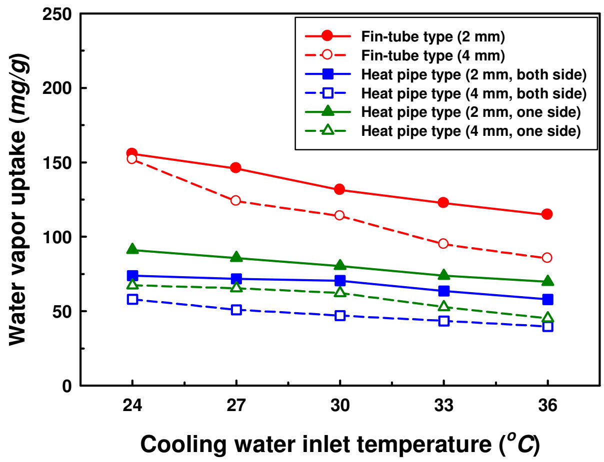


Figure 7: Water vapor uptake as a function of cooling water temperature

rate as shown in Figure 6 with inlet temperature of cooling water. Here, the water vapor uptake means the ratio of wet silica gel to dry silica gel. The adsorption bed with fin pitch of 2 mm showed high water vapor uptake because amount of silica-gel was larger than that of fin pitch 4 mm adsorption bed.

4 CONCLUSION

The performance characteristics and comparison of the heat exchanger types of adsorption bed have carried out by using experimental study.

(1) When the inlet temperature of cooling water is 30 °C, the heat transfer rate of fin-tube type adsorption bed shows maximum value of 570 W for the fin pitch of 2 mm. The heat transfer rate of heat pipe type adsorption bed with one side and both sides were 570 W and 340 W, respectively. The heat transfer rate of heat pipe type adsorption bed with one side was about 60% higher than that of both side type.

(2) The heat pipe type adsorption bed with both sides and one side showed similar overall heat transfer coefficient by value of about 25 $W/m^{2}\cdot{}^{o}C$

(3) When the inlet temperature of cooling water varied from 24°C to 36°C, the adsorption rate decreases by 53 g for the fin-tube type adsorption bed with fin pitch of 4 mm. As the inlet temperature of cooling water rises, the decrease ratio of adsorption rate was increased.

5 ACKNOWLEDGEMENTS

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