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Feasibility Study on the New Types of Adsorption Chiller

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Abstract: *The present research conducted a feasibility study on the application of new types of adsorption chiller, which have high potential to enhance the heat transfer and reduce the system size. The proposed types are an embossed plate heat exchanger (Plate HX) type and heat pipe type adsorption chiller. The plate HX and heat pipe have a relatively high heat transfer capacity and compact size, and this study is a first attempt to apply these news type HXs of adsorption chiller, as an improved alterative to the fin-tube type heat exchanger. A feasibility study was conducted on the base model and the result is comparable to the values for existing fin-tube type adsorption chillers. Furthermore, a parameter study was conducted for several important design parameters for each new type HXs of adsorption chiller.*

Keywords: *adsorption chiller, plate HX, heat pipe, COP, SCP soap nut*

1. INTRODUCTION

Due to global warming and economic development, demand for cooling has rapidly increased. However, vapor compression refrigerators that use Freon gas have many problems, including excessive electric power consumption and environmental damage. As a result, many studies have focused on the development of eco-friendly refrigeration systems driven by heat rather than electricity [1-3].

An adsorption refrigerator is a promising alternative cooling device and also an eco-friendly refrigeration system, which can be driven by low-grade heat (60°C~90°C) from solar energy, district heating, exhaust heat from an engine or discarded waste heat. Adsorption cooling is not being generally used yet mainly due to the system's large size and relatively low performance. Because the adsorption beds are the most important parts affecting system size and performance, many researchers have conducted the study of the adsorption beds for improvement. One of the goals has been to optimize the shape of the heat exchanger. Various types of heat exchangers have been examined.

In the early development stages, a simple-tube type heat exchanger was used for the adsorption beds. However, due to its low system performance (COP = 0.1 ~ 0.5, SCP = 50 ~ 200 W/kg) and long cycle times (about 1,000 ~ 10,000s), the simple-tube type adsorption chiller has been rarely used in these days. To overcome the disadvantages of the simple-tube type adsorption chiller, fin-tube HXs were introduced. Fin-tube HXs with extended fin surfaces can significantly improve heat transfer capacity, which leads to increased mass transfer capacity. Most products in the market use fin-tube HX in the adsorption bed, which have relatively high performance (COP = 0.5 ~ 0.7 and SCP = 100 ~ 600 W kg-1) and short cycle time (usually less than 1000s) compared to a simple-tube HX. However, the rate of improvement of system performance using fin-tube HX has apparently slowed recently, and seems to have reached near optimum.

Other types of HX with higher heat and mass transfer capacities are therefore required. Li et al. [4] reviewed on the efforts to introduce the new type of HXs in the adsorption bed such as plate-fined bed, spiral plate bed and porous bed, etc to increase heat transfer capacity of adsorption bed. Here we introduce two type of new suggestions, i.e. an embossed plate HX type and heat pipe type adsorption chillers. A feasibility study was conducted to examine whether these two types of adsorption bed show high enough performance, compared to the fin-tube type HX applied to adsorption chiller. After that, a parametric study was conducted, from which the guideline for each parameter can be determined for the optimal design of the newly suggested adsorption chiller.

2. NUMERICAL METHOD

In general, two adsorption beds are used in the adsorption refrigeration system. One is for adsorption process, the other is for desorption process and vice versa. During adsorption/ desorption process, endothermic/ exothermic reaction occurs, which is to be removed by cooling and heating water. During the adsorption process, the vapor from the evaporator enters the adsorption bed, while during the desorption process, the desorbed gas is evacuated to the condenser. By repeating two processes in each bed, consecutive cold energy can be obtained from the evaporator. More detailed description on the system is mentioned in the resent study of Hong et al. [3].

Figure 1 shows the newly suggested two types of adsorption beds. In order to save an enormous amount of simulation time, we took one repeating section of interest to model. A three-dimensional transient model was used, and a commercial CFD program called STAR-CCM+ v7.04 was applied. Since $D/r_{\mathrm{p}}^{2}=0.000368$ is larger than the critical value (0.000192) of silica gel, the non-isobaric model and linear driving force (LDF) model were used for the inter- and intra-particle mass transfer models, respectively. The assumptions, governing equations and boundary/initial conditions are given in detail in Hong et. [3] and Ahn et. al. [5].

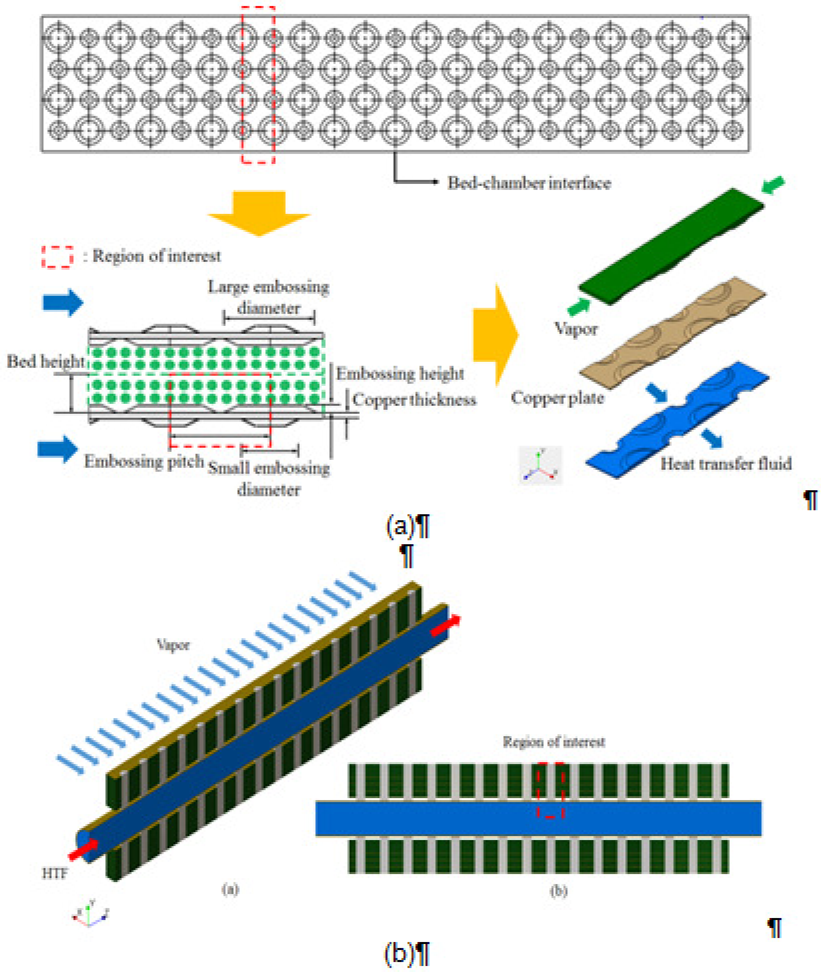

Fig.1. Schematics of (a) plate type adsorption bed and (b) heat pipe type adsorption bed

As the performance of an adsorption bed, coefficient of performance (COP) and specific cooling power (SCP) are used:

$$\mathrm{COP}=\frac{Q_{\mathrm{eva}}}{Q_{\mathrm{in}}} \tag{1}$$

$$\mathrm{SCP}=\frac{Q_{\mathrm{eva}}}{M_{\mathrm{b}}t_{\mathrm{cycle}}} \tag{2}$$

where Q_{eva} denotes the cooling energy obtained from the evaporator and Q_{in} denotes the input heat energy supplied to the adsorption bed during the desorption process. M_{b} is the total mass of the solid sorbent and t_{cycle} means cycle time.

$$Q_{\mathrm{eva}}=L_{\mathrm{v}}\int_{t_{\mathrm{des}}}^{t_{\mathrm{ads}}}\int_{\mathrm{interface}}\rho_{\mathrm{v}}\vec{u}_{v}\cdot d\vec{A}dt \tag{3}$$

$$Q_{\mathrm{in}}=\int_{t_{\mathrm{ads}}}^{t_{\mathrm{des}}}\int_{A_f}\rho_{\mathrm{f}}C_{\mathrm{P,f}}\left(T_{\mathrm{f,in}}-T_{\mathrm{f,out}}\right)\vec{u}_{\mathrm{f}}\cdot d\vec{A}dt \tag{4}$$

where L_{v} is approximated as follows:

$$L_v = L(T_{eva}) - C_{P,b}(T_{con} - T_{eva}) \quad (5)$$

3. RESULTS AND DISCUSSIONS

3.1 PARAMETER STUDY OF THE PLATE HX TYPE ADSORPTION CHILLER

We conducted a parameter study on seven parameters, i.e., (1) embossing diameter ratio, (2) embossing height, (3) embossing pitch, (4) bed height, (5) plate thickness, (6) heating temperature, and (7) fluid velocity. As the typical example, Fig. 2 shows the behavior of COP and SCP as a function of heating temperature. The heating temperature has been reported to have the most significant effect on the SCP of adsorption chillers [2, 6] and the result in the present study also shows it has a significant influence on SCP. Heating temperature determines the minimum value of water uptake. A large heating temperature creates a large difference in concentration between the inside and outside of a solid sorbent, which enhances the desorption rate of the adsorption bed. Therefore, SCP is increased by increasing the difference between maximum and minimum water uptake Δq. However, if the heating temperature is too high, the input heat energy Q_{in} becomes unnecessarily large, and COP is consequently decreased after the critical point of the heating temperature (75°C). This trend is also the same in the fin-tube type adsorption chiller [2].

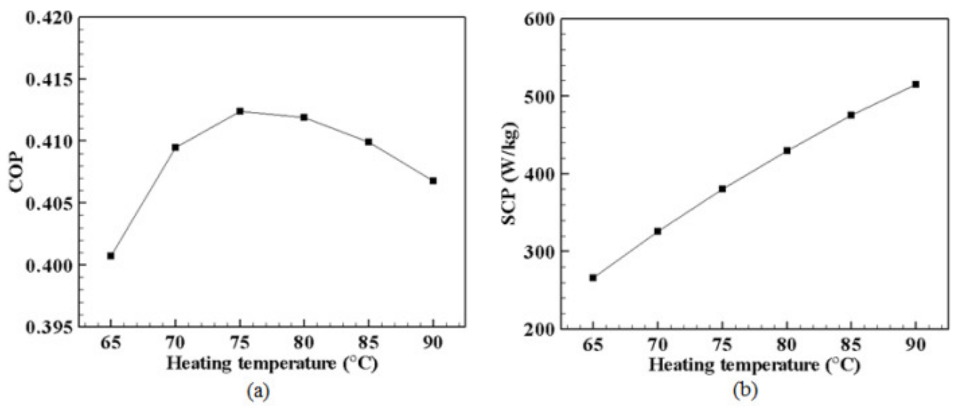

Fig. 2. Variations of (a) COP and (b) SCP with heating temperature.

3.2 PARAMETER STUDY ON THE HEAT PIPE TYPE ADSORPTION CHILLER

A parametric study was conducted on six parameters affecting the system performance of a heat pipe type adsorption chiller: (1) number of layer (2) heat pipe pitch (3) fin spacing (4) heat pipe radius (5) fin width (6) hot water temperature. The level of each parameter is shown in Table. 1. The base conditions are shown in grey color. As the typical example, Fig. 3 shows the behavior of COP and SCP as a function of the number of layers. When the number of layer increases, larger Q_{in} is required to heat up the extra volume of the bed during the desorption process. But, the amount of water uptake is also increased by addition of adsorbent amount. Thus, COP increases due to increased evaporation heat, that is Q_{eva}. SCP is inversely proportional to the adsorbent mass, thus SCP is decreased with increasing number of layers. The number of layers in the practical application is much larger than 7. However, due to limitation on the computer memory and calculation time, maximum 7 layers are considered in our numerical model. The performance of 7 layers (COP = 0.5204, SCP = 752.37 W/kg) turns out to be almost the same COP, while larger SCP compared to the fin-tube type adsorption bed (COP = 0.4944, SCP = 538W/kg).

Table 1 – Parameters of numerical condition

Parameter	Values						
Number of layer	1	3	5	7			
Heat pipe pitch [mm]	10	12	14	16	18		
Fin spacing [mm]	0.5	1	2	3			
Heat pipe radius [mm]	1	2	2.5	3	3.5	4	
Fin width [mm]	4	6	8	10	12		
Hot water Temp [°C]	55	65	70	80	85	95	100

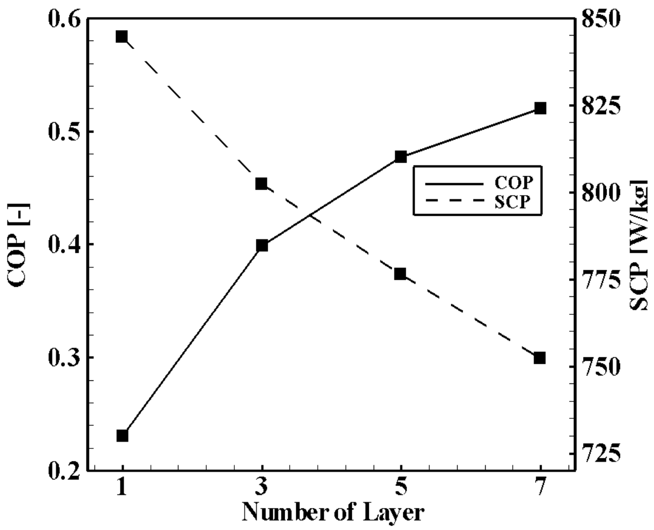

Fig. 3. Variations of COP and SCP according to the number of layer

4. CONCLUSIONS

In the present study, a feasibility study on two new types of HX applied to adsorption chiller, i.e. (1) plate HX type and (2) heat pipe type, and a parameter study were conducted, from which optimization guideline for each parameter was examined. All of these two types show similar COP but higher SCP, which means the new types of adsorption chiller have high potential to resolve one of the most serious disadvantages of the adsorption cooling system, i.e., system size.

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