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The Simulation Performance of Three-bed Silica Gel Conventional Re-heat Combined Adsorption Cycle

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Abstract. In this paper, a new operational strategy is proposed for re-heat adsorption chiller with multi beds. Silica-gel and water are using as the adsorbent and refrigerant pairs in this chiller. The chiller consists of three adsorbed/desorber heat exchanger, one evaporator and one condenser. Combined cycle refers to the adsorber/desorber of HEXs that are HEX1 and HEX2 operate in re-heat cycle while HEX3 operates conventional cycle respectively. MATLAB with ode 45 solver was the governing equations of the present chiller. The chilled water out temperature was kept constant at 9°C to produce cooling effect. The objectives of the present study were to operate the chiller at low heat source temperature so that it can be driven with solar or waste heat, and to reduce the chiller size. The effect of heat source temperature and the effect of mass recovery time are presented while the effect of the combination between adsorption/desorption and pre-heating/pre-cooling time also explored to predict the performance on COP and cooling capacity of the chiller. The proposed chiller provides COP values higher than provided by the four-hex reheat chiller and 42% higher of the cooling capacity values compared than the conventional cycle respectively.

Introduction

Heat driven adsorption system is one of the most promising systems due to use of low or near the environment temperature, as a driving heat source in its operation. By using water and silica gel as the adsorbent-refrigerant pair in the system indicates that the adsorption system is suitable for reduce the gas's emission and consume low energy can be achieved [1]. Some extensive investigations of the performances of the adsorption refrigeration chiller have been conducted considering various adsorbent/adsorbate pairs [2-3]. To achieve better COP and/or cooling capacity values, most of the advanced chillers in adsorption refrigeration/heat pumps have been proposed. Alam has introduced the four beds/hex adsorption chillers; namely, re-heat two-stage adsorption chiller and shows that the chiller can exploit the heat source temperature 50-90°C [4]. Wirajati et al. [5] identified the effect of the heat source temperature and the effect of cycle time on performance if the chilled water outlet temperature is fixed at 9°C experimentally. The possibility of reducing the adsorber/desorber hex's utilization is still promising since the consideration of the smaller adsorption machine to be constructed [6] and can be performed for the relative low heat source temperature below 60°C.

In this study, the author concern of reducing the number of hex utilization compare to the previous study that were based on the four-hex conventional and four-hex re-heat cycle has been investigated experimentally and numerically. By reducing the hex utilization and introducing the new mode operational strategy which is applied in the present chiller, the smaller compact machine can be designed. And the objectives of the recent study were to examine the performance of three-hex re-heat combined chiller and to optimized the cycle time of the present chiller. The comparison with those of four-hex conventional chiller and four-hex re-heat chiller also presented.

As a result, the present chiller with the new strategy can utilize the minimum heat source temperature 55°C while the chilled water out temperature keep in 9°C to produce cooling effect. The proposed chiller provides COP values higher than provided by the four-hex reheat chiller and 42% higher of the cooling capacity values compared than the conventional cycle respectively.

Three-hex Re-heat Combined Adsorption Chiller Process

The three-hex re-heat combined adsorption chiller schematic and the Pressure-Temperature-Concentration (PTX) diagram are present in Fig. 1 while the operational distribution process of the proposed chiller shown in Table 1 respectively. There are three HEXs namely HEX1, HEX2 and HEX3. To complete a full cycle, HEX1 and HEX2 consist of six processes while HEX3 only four processes respectively, based on the mode strategy. The HEXs operates continuously all together in ten modes.

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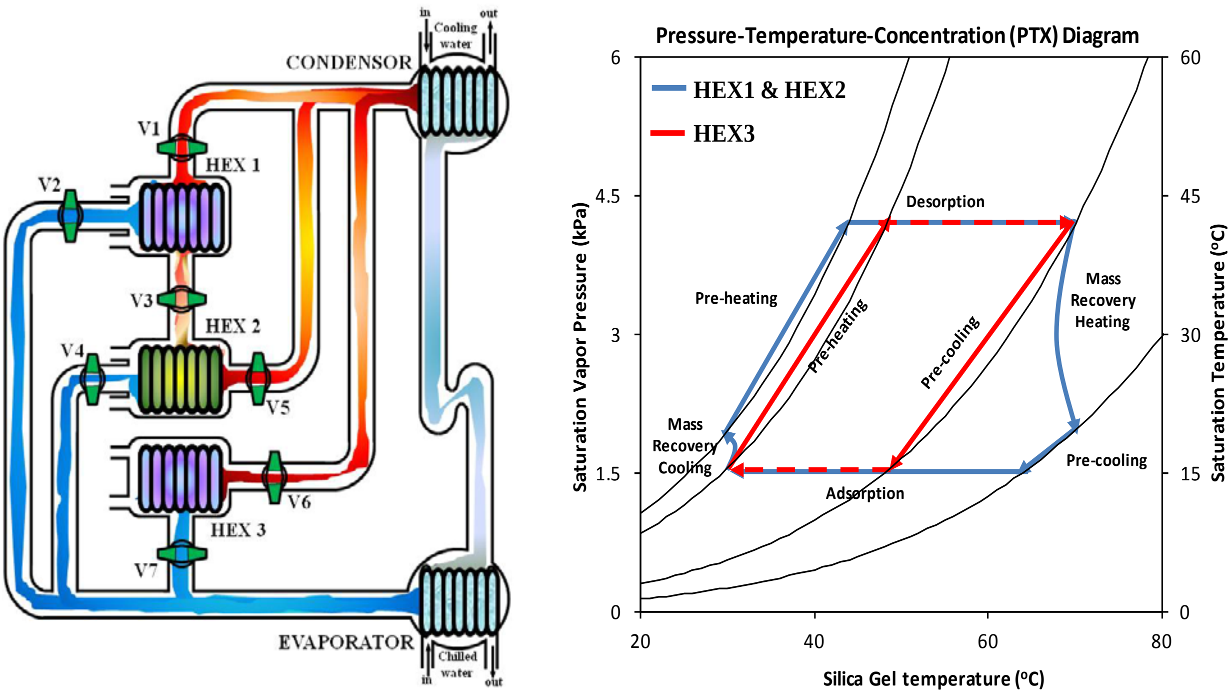

Fig. 1. The cycle schematic of the proposed chiller and the PTX diagram

In the beginning of the process (mode A - C), the valves (V1, V4 and V6) are opened. HEX1 and HEX3 will connect to the condenser and the desorption process started, while HEX2 will connect to the evaporator and the adsorption process started as well. Since the concentration of refrigerant in the desorber (HEX1) and adsorber (HEX2) are near to the equilibrium levels, the process continue to the mode D. In the mode D, all HEXs out of connects to the condenser or evaporator. HEX1 was at the end position of desorption process and HEX2 was at the end position of adsorption process. HEX1 is connected with HEX2 through opened the valve (V3) with continuing cooling water in HEX2 and hot water in HEX1. The process called mass recovery with cooling for HEX2 and mass recovery with heating for HEX1. In the mode, HEX3 is cooled down by cooling water called pre-cooling process. When the pressure of both HEX1 and HEX 2 nearly

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equals, then the process will continue to the mode E. In the mode E, all HEXs are in warm up process. HEX1 and HEX3 are cooled down by cooling water, called pre-cooling process, and HEX2 is heated up by hot water, called pre-heating process. When the pressure of HEX1 and HEX3 nearly equal to the pressure of evaporator; and the pressure of HEX2 nearly equal to the pressure of condenser, then the valve (V2, V5and V7) are opened to flow the refrigerant. HEX1 and HEX3 are connected with evaporator and HEX 2 is connected with condenser respectively. The mode E is the end of half cycle of the process. To complete a full cycle, the next process is the same as the previous half-cycle. But, HEX1 and HEX3 is working in adsorption process while HEX2 in desorption process.

Table 1. Operational distribution process

HEX	**Mode**									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
1	Desorption	Desorption	Desorption	Mass recovery heating	Pre-cooling	Adsorption	Adsorption	Adsorption	Mass recovery cooling	Pre-heating
2	Adsorption	Adsorption	Adsorption	Mass recovery cooling	Pre-heating	Desorption	Desorption	Desorption	Mass recovery heating	Pre-cooling
3	Desorption	Desorption	Desorption	Pre-cooling	Pre-cooling	Adsorption	Adsorption	Adsorption	Pre-heating	Pre-heating

Note:
Desorption; Mass recovery heating; Pre-heating
Adsorption; Mass recovery cooling; Pre-cooling

Simulation Equation

Adsorber/desorber energy balance. The heat transfer and energy balance equation of adsorbent hex can be described as follows:

$$T_{o}=T+\left(T_{i}-T\right)\exp\left(\frac{U_{bed}A_{bed}}{\dot{m}_{w}C_{w}}\right) \tag{1}$$

$$\left(W_{s}C_{s}+W_{s}C_{w}q+W_{bed}C_{bed}\right)\frac{dT}{dt}=W_{s}Q_{s}\frac{dq}{dt}-W_{s}C_{w}\delta\left[\gamma\left(T-T_{eva}\right)+\left(1-\gamma\right)\left(T-T_{wv}\right)\right]\frac{dq}{dt} + \dot{m}_{w}C_{w}\varepsilon_{bed}\left(T_{i}-T\right) \tag{2}$$

Evaporator energy balance. Equation 3 represents the heat transfer of evaporator and Equation 4 as energy balances for evaporator, respectively:

$$T_{ch,o}=T_{eva}+\left(T_{ch,i}-T_{eva}\right)\exp\left(-\frac{U_{eva}A_{eva}}{\dot{m}_{ch}C_{ch}}\right) \tag{3}$$

$$\left(W_{eva,w}C_{w}+W_{eva,bed}.C_{eva,bed}\right)\frac{dT_{e}}{dt}=\dot{m}_{ch}C_{ch}\varepsilon_{eva}\left(T_{ch,i}-T_{eva}\right) -W_{s}\left(\frac{dq_{ads\text{-}eva}}{dt}+\frac{dq_{des\text{-}con}}{dt}\right)\left(L+C_{v}\left(T_{con}-T_{eva}\right)\right) \tag{4}$$

Condenser energy balance. Equation 5 represents as the heat transfer of condenser while Equation 6 as energy balances for condenser, and can be expressed as:

$$T_{con,o}=T_{con}+\left(T_{cw,i}-T_{con}\right)\exp\left(-\frac{U_{con}.A_{con}}{\dot{m}_{cw}.C_{w}}\right) \tag{5}$$

$$\left(W_{con,w}.C_{w}+W_{con,bed}.C_{con,bed}\right)\frac{dT_{c}}{dt}=\dot{m}_{cw}C_{w}\varepsilon_{con}\left(T_{cw,i}-T_{con}\right)-W_{s}\left(\frac{dq_{des\text{-}con}}{dt}\right)\left(L+C_{v}\left(T_{des}-T_{con}\right)\right) \tag{6}$$

System performance. Coefficient of performance (COP) and cooling capacity (CC) are mainly characteristics of the performance of the chiller, can be measured as:

$$\text{COP} = \dot{m}_{ch} C_w \int_0^{t_{cycle}} \left(T_{ch,i}\text{-}T_{ch,o}\right) \;/\; C_w \int_0^{t_{cycle}} \left(T_{hw,i}\text{-}T_{hw,o}\right) dt \quad (7)$$

$$\text{CC} = \dot{m}_{ch} C_w \int_0^{t_{cycle}} \left(T_{ch,i}\text{-}T_{ch,o}\right) dt / t_{cycle} \quad (8)$$

The values of physical properties parameters used in calculation and the standard operating condition adopted in simulation are shown in Table 2 and Table 3 respectively.

Table 2. Parameter's adopted in simulation

Symbol	**Value**	**Unit**
C_s	924	J/kg K
C_v	1.89E+03	J/kg K
C_w	4.18E+03	J/kg K
D_o	2.54E-4	m^2/s
E_a	2.33E+06	J/kg
L_w	2.50E+06	J/kg
Q_s	2.86E+06	J/kg
R	4.62E+2	J/kg K
R_p	3.00E-04	m
UA_{ads}	2.00E+3	W/m^2K
UA_{des}	2.23E+3	W/m^2K
UA_{eva}	2.36E+3	W/m^2K
UA_{con}	4.06E+3	W/m^2K
W_s	16	kg
$W_{con,w}$	5	kg
$W_{eva,w}$	25	kg

Table 3. Basic values for the standard condition

	Temperature (°C)	**Flow Rate (kg/s)**
Hot water	60	1
Cooling water	30	1(ads) + 0.8(des)
Chilled water	14	0.8
Cycle time (Ads/Des+Mrc/Mrh+Ph/Pc)	(420 + 200 + 30)s	

Noted;
Ads/Des : adsorption/desorption
Mrc/Mrh : mass recovery
Ph/Pc : pre-heating/pre-cooling

Results and Discussion

A complete simulation program was developed based on MATLAB software to solve all equations. In the beginning of the solution process, initial values are assumed and finally, those are adjusted by the iteration process. Once the satisfactory convergence criterion is achieved, then the process goes for the next time step. All input parameters such as adsorbent-refrigerant properties, flow rates of heat transfer fluids and heat exchangers specifications initially was given for which the system cyclic operation can be realized.

The Effect of Mass Recovery Time on COP and Cooling Capacity

The mass recovery process can effectively improve the performance of the adsorption chiller driven by a low heat source temperature. The process seems to be a second adsorption/desorption process for the adsorber/desorber hex.

Fig. 2 informed the effect of mass recovery time on COP and cooling capacity. Heat source temperature 60°C, adsorption/desorption time 420s and pre-heating/pre-cooling 30s applying to investigates not only the effect of mass recovery time 50-350s but also to compare it with without mass recovery time (0s mass recovery time). It is seen that the chiller without mass recovery worked quite inefficiently. The COP and cooling capacity without mass recovery are, respectively, 50% and 44% lower than those with 350s mass recovery times. By this point of view, the mass recovery is pivotal to this chiller, especially if operates for the low heat source temperature.

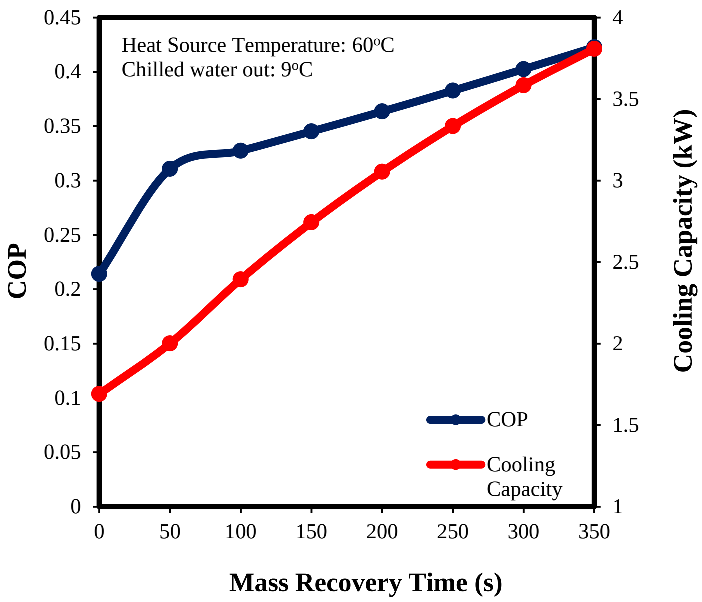

Fig. 2. The effect of Mass Recovery Time on COP and cooling capacity

Performance Comparison

COP is highly dependent on the temperature of heat source: the higher the temperature, the greater the COP value, as Fig. 8 informed. The COP of three-hex re-heat combined chiller is superior compared to other chiller and it is shown the significant advantage of the three-hex re-heat combined cycle since the consideration of reducing the hex utilization and introducing the new mode operational strategy of the chiller.

Another observation of the heat source temperature effect on cooling capacity presents in Fig. 3. From the figure we can observe that cooling capacity increased with the heat source temperature. For the low heat source temperature 55°C, the four-hex re-heat chiller offering 20% slightly better cooling capacity compared to the three-hex re-heat combined. The reason is that there are four adsorber/desorber of HEX applied in the chiller and there are two pairs of HEX conduct the adsorption process at the same time, thus the cooling capacity higher. But the values of cooling capacity showed 42% increment when the three-hex re-heat combined chiller was compared to the four-hex conventional chiller for the heat source temperature 60°C. On the other hand, the four-hex conventional cycle is not work for the low heat source temperature 55°C if the chilled water outlet temperature 9°C arranged in fixed condition. By this point of view, reducing the hexs while applying the mode strategy of three-hex re-heat combined chiller is promising since the consideration of the reducing of HEX's utilization.

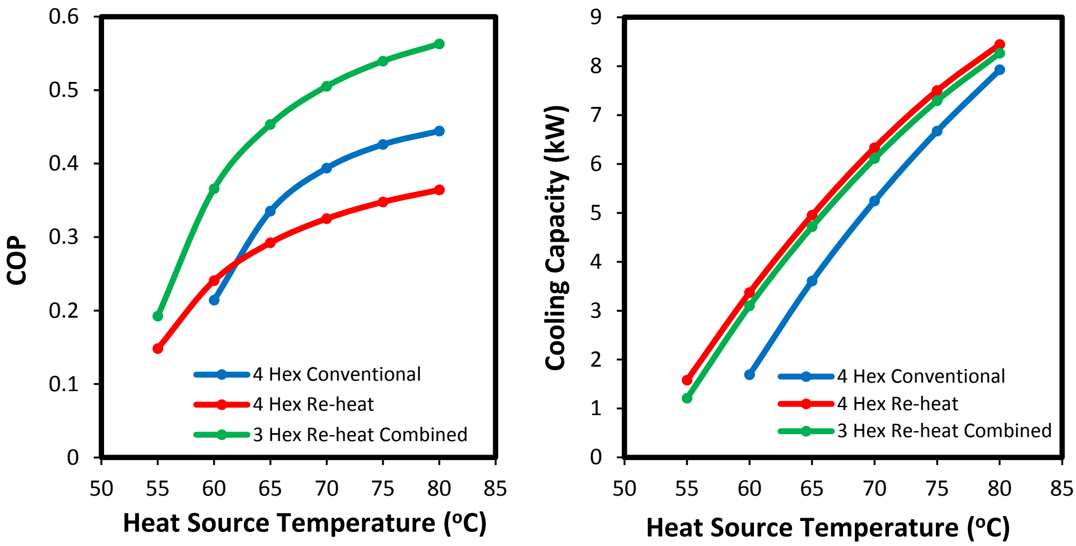

Fig. 3. The COP comparison on the effect of heat source temperature

Summary

The following concluding remarks can be drawn from the present study; The present chiller with the new operational strategy can utilize the minimum heat source temperature 55°C while the chilled water out temperature keep in 9°C to produce cooling effect. The performance (COP and cooling capacity) enhance with the heat source temperature. The proposed chiller provides COP values higher than provided by the four-hex reheat chiller and 42% higher of the cooling capacity values compared than the conventional cycle respectively.

References

[1] T. Kashiwagi, A. Akisawa, Y. Yoshida, K.C.A Alam, Y Hamamoto, Heat driven sorption refrigerating and air conditioning chiller in Japan, Proceedings of The International Sorption Heat Pump Conference, Sanghai, China, 2002, pp. 50–62.

[2] H.T.Chua, K.C.Ng, A.Malek, T.Kashiwagi, A.Akisawa, B.B.Saha, Modeling the performance of two-bed, silica gel-water adsorption chiller, Int. J. Refrig., 22(1999) 94–204.

[3] Mizanur Rahman, A.F.M.; Ueda, Y.; Akisawa, A.; Miyazaki, T.; Saha, B.B. Design and performance of an innovative four-bed, three-stage adsorption cycle. *Energies* 2013, 6, 1365-1384. [4] Alam, K.C.A.; Hamamoto, Y.; Akisawa, A.; Kashiwagi, T. Advanced adsorption chiller driven by low temperature heat source. *In Proc. of 21st International Congress of Refrigeration*, Washington DC, USA, August 2003, Paper no. 0136 in CD ROM 17-22.

[5] Wirajati, I.G.A.B.; Akisawa, A.; Ueda, Y.; Miyazaki, T.; Experimental investigation of a reheating two-stage adsorption chiller applying fixed chilled water outlet conditions. *Heat Transfer Research*, HTR-6774, DOI: 10.1615/HeatTransRes.2014007186, 2014.