

Effects of operation parameter on the performance of solar-powered adsorption chiller

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ABSTRACT: A novel solar-powered adsorption chiller with heat and mass recovery cycle was designed and constructed. The operation parameter effects on system performance were tests successfully. Test results indicated that the coefficient of performance and cooling capacity of the solar-powered adsorption chiller could be improved greatly by optimizing some key operation parameters, such as solar hot water temperature, heating/cooling time, mass recovery time, and chilled water temperature. With optimum operation parameters, this solar-powered adsorption chiller can produce a cooling capacity about 66 to 90W per m² collector area under the climatic conditions of daily solar radiation being about 16 to 21 MJ/m². Its daily solar cooling COP is about 0.1 to 0.13.

Keywords: Solar, Adsorption chiller, Parameter optimum

NOMENCLATURE

A_c	solar collecting area (m ²)	I	solar radiation intensity on the top surface of collector (W/m ²)
COP	coefficient of performance	$\dot{m}$	mass flow rate (kg/s)
C_{pw}	isobaric specific heat of water (J/kg°C)	Q_c	cooling power (W)

SCP special cooling power (W/m^2)

T temperature ($^{\circ}\text{C}$)

t time (s)

Subscripts

ci solar collector inlet

cw chilled water

hw hot water

in inlet

out outlet

1. INTRODUCTION

Solar adsorption refrigeration system seems to be a promising alternative refrigeration device since cooling load of building is roughly in phase with solar energy availability. Much research on solar adsorption refrigeration has been accomplished during the past decades; many solar adsorption refrigeration systems have

also been developed with technical success [1-4]. However, most of the existing solar adsorption systems are intermittent and mainly used for ice making characterized by small cooling output. For solar thermal utilization, continuous solar adsorption systems with large cooling capacity are also valuable. Moreover, farther research and efforts are still required to make solar adsorption refrigeration systems more efficient and economical.

In this study, a novel solar-powered adsorption chiller was designed and constructed. The operation parameter effects on system performance were tests successfully. Test results indicated that the COP (coefficient of performance) and cooling capacity of the solar-powered adsorption chiller could be improved greatly by optimizing some key operation parameters.

2. DESCRIPTION OF THE SOLAR ADSORPTION CHILLER

The solar-powered adsorption chiller mainly consists of four subsystems, namely, a solar water heating unit, a silica gel-water adsorption chiller, a cooling tower and a fan coil unit. Fig. 1 shows the schematic diagram of the solar-powered adsorption chiller. The solar water heating unit is utilized to produce

hot water to drive the adsorption chiller. The cooling tower offers the cooling water to cool the condensers and adsorbers. The cooling production is transferred to a air conditioning space through a fan coil unit. The characteristics and main parameters of the solar-powered adsorption chiller are shown in Table 1.

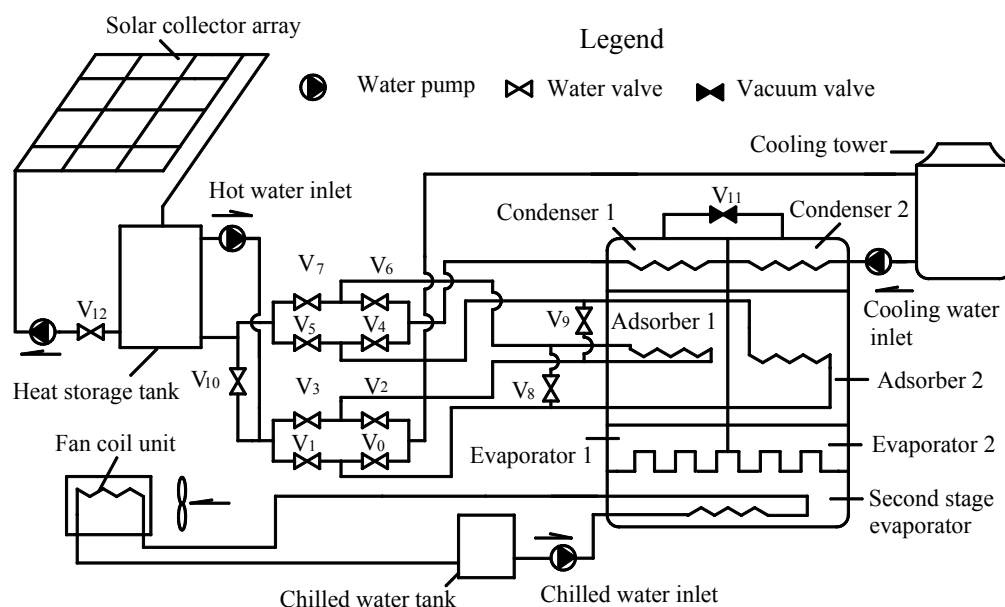


Fig 1: Schematic diagram of the solar-powered adsorption chiller.

Table1: Characteristics and parameters of the solar-powered adsorption chiller

Subsystem	Characteristics and parameters
1. Solar water heating unit	
Collector type	All-glass evacuated tube collector
Collecting area	49.4 m ²
Pump	Rated power: 290 W; Rated head: 25 m; Rated flow rate: 0.00042 m ³ /s
Hot water tank	Capacity: 0.6 m ³ ; Height: 1.2 m
2. Adsorption chiller	
Adsorbent	Micro-pore silica gel; Mass: 50 kg/adsorber
Hot water pump	Rated power: 250 W; Rated head: 10m; Rated flow rate: 0.0013 m ³ /s
Chilled water pump	Rated power: 120 W; Rated head: 8m; Rated flow rate: 0.00054 m ³ /s
Chilled water tank	Capacity: 0.03 m ³
3. Cooling tower	
Fan	Rated power: 250 W; Rated flow rate: 0.306 m ³ /s
Pump	Rated power: 370 W; Rated head: 12 m; Rated flow rate: 0.0017 m ³ /s
4. Fan coil unit	
Fan	Rated power: 750 W; Rated flow rate: 0.417 m ³ /s
Heat exchanger	Type: Tube-fin; Heat exchanger area: 5.87 m ²

The solar water heating unit includes an all-glass evacuated tube collector array, a water pump and a hot water tank, etc. The water pump, controlled by a differential temperature controller, independently works

without considering whether the adsorption chiller is in the operation.

The adsorption chiller (see Fig. 1) includes two identical adsorption units and a second stage evaporator with methanol working

fluid. Each adsorption unit consists of one adsorber, one condenser and one evaporator (the first stage evaporator). Continuous refrigeration can be achieved with two adsorption units to shift between adsorption and desorption phases. During the operation of the adsorption chiller, liquid methanol in the second stage evaporator is continuously heated by circulating chilled water. The evaporated methanol vapor goes up and is condensed on the surface of the first stage

evaporator in the adsorption unit being in adsorption phase, then drops back to the bottom of the second stage evaporator. The advantages of mass recovery have been demonstrated in previous literatures [5]. With the help of water valves (V0 - V10) and vacuum valve V11, the adsorption chiller can be operated with a two-adsorber continuous refrigeration cycle with mass recovery. The operation scheme of the refrigeration cycle is listed in Table 2.

Table 2: Operation scheme of the refrigeration cycle with heat and mass recovery

Cycle stage	State of valves*											
	V ₀	V ₁	V ₂	V ₃	V ₄	V ₅	V ₆	V ₇	V ₈	V ₉	V ₁₀	V ₁₁
Adsorber 1 being heated Adsorber 2 being cooled	On	Off	Off	On	On	Off	Off	On	Off	Off	Off	Off
Mass recovery (adsorber 1→adsorber 2)	On	Off	Off	On	On	Off	Off	On	Off	Off	Off	On
Heat recovery (adsorber 1→adsorber 2)	On	Off	Off	Off	Off	Off	On	Off	Off	On	On	Off
Adsorber 1 being cooled Adsorber 2 being heated	Off	On	On	Off	Off	On	On	Off	Off	Off	Off	Off
Mass recovery (adsorber 1←adsorber 2)	Off	On	On	Off	Off	On	On	Off	Off	Off	Off	On
Heat recovery (adsorber 1←adsorber 2)	Off	Off	On	Off	On	Off	Off	Off	On	Off	On	Off

* “Off” represents a valve being closed; “On” represents a valve being open.

3. PERFORMANCE INDEX

For the solar-powered adsorption chiller, the cooling power, Q_c , and special cooling power of per m² collector area, SPC, are calculated by the following two equations respectively:

$$Q_c = \dot{m}_{cw} C_{pw} (T_{cw-in} - T_{cw-out}) \quad (1)$$

$$SCP = \frac{\dot{m}_{cw} C_{pw} (T_{cw-in} - T_{cw-out})}{A_c} \quad (2)$$

For the adsorption chiller, the cooling COP during one cycle is defined by

$$COP_{cycle} = \frac{\int \dot{m}_{cw} C_{pw} (T_{cw-in} - T_{cw-out}) dt}{\int \dot{m}_{hw} C_{pw} (T_{hw-in} - T_{hw-out}) dt} \quad (3)$$

The solar cooling COP of the system, COP_{solar} , is defined as ratio between the useful cooling production of the second stage evaporator and the total incident solar energy on the surface of solar collectors:

$$COP_{solar} = \frac{\int \dot{m}_{cw} C_{pw} (T_{cw-in} - T_{cw-out}) dt}{\int A_c I dt} \quad (4)$$

4. RESULTS AND DISCUSSION

4.1 Heat recovery time effects on the performance of the adsorption chiller

During the heat recovery stage, the resident hot water in the adsorber being in desorption phase is pushed into the other adsorber being in adsorption phase by cooling water (see Fig. 1 and Table 2). So, the adsorber being in adsorption phase is heated preliminarily, and the sensible heat of resident hot water in the adsorber being in desorption phase is recovered partially. When the resident hot water in the adsorber being in desorption phase is almost pushed out, the heat recovery stage terminates. Hence, the optimum time of heat recovery

time is determined by cooling water flow rate. For improving reliability and simplifying operation of the chiller, the flow rates of all circuiting water pumps are keep constant. The optimum time of heat recovery time is about 40 s [6].

4.2 Mass recovery time effects on the performance of the adsorption chiller

Variations of average cooling power and cycle COP during one cycle with mass recovery time is shown in Fig. 2. Here, Q_c and COP_{cycle} represent average cooling power and cycle COP during one cycle respectively. It is seen that with one-minute mass recovery process, a peak cooling power of 5.03 kW is achieved when heating/cooling time is fixed at 900 s, the corresponding cycle COP is about 0.317. With three-minute mass recovery process, a peak cycle COP of 0.324 is achieved when heating/cooling time is fixed at 900 s, the corresponding cooling power is 4.96 kW. These indicate that, the suitable mass recovery time for the adsorption chiller is about 60-180s.

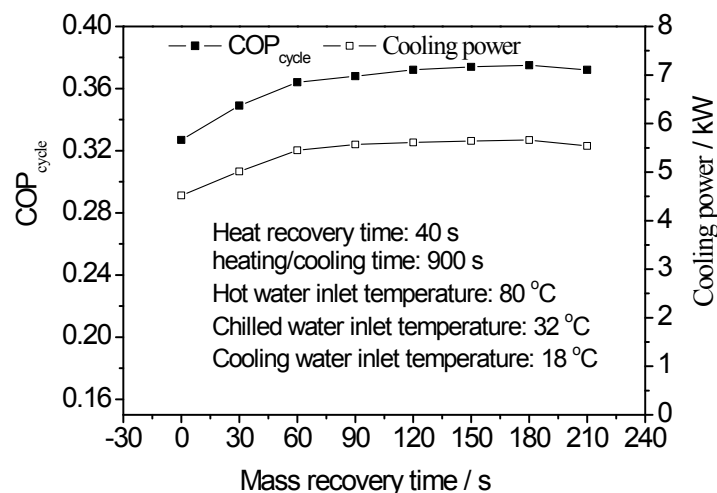


Fig 2: Variations of cycle COP and cooling power with mass recovery time.

4.3 Heating/cooling time effects on the performance of the adsorption chiller

Variations of average cooling power and cycle COP during one cycle with heating/cooling time are plotted in Fig. 3. It is seen that cooling power increases with the

increase of heating/cooling time. However, a peak cycle COP of 0.324 is achieved when heating/cooling time is 720s. AS shown in Fig.3, the optimum time of heat recovery time is about 720-900 s.

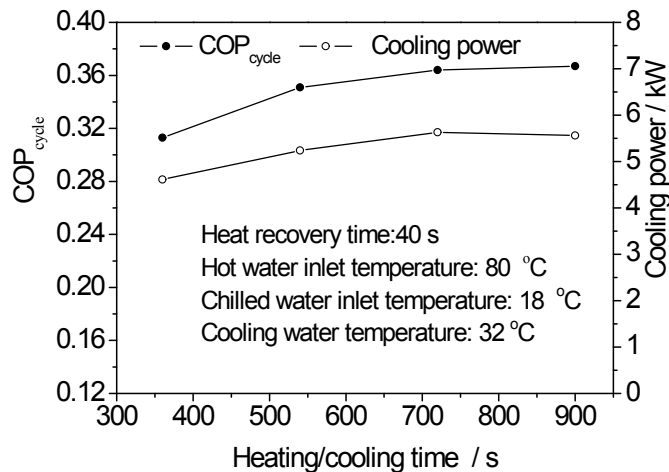


Fig 3: Variations of cycle COP and cooling capacity with heating/cooling time.

4.3 Hot water inlet temperature effects on the performance of the adsorption chiller

Variations of average cooling power and cycle COP during one cycle with hot water inlet temperature are plotted in Fig. 4. It is found that both cooling power increase with the increase of hot water inlet temperature. When hot water inlet temperature is above about 75 °C, the increment rate of cycle COP

becomes slow. Moreover the cycle COP is almost constant when the hot water inlet temperature exceeds 85 °C. On the other hand, the higher the hot water inlet temperature, the lower the collector efficiency. When both adsorption chiller and collector efficiency are taken into account, the suitable hot water inlet temperature is about 65 -85 °C [6].

4.4 Chilled water inlet temperature effects on the performance of the adsorption chiller

The average cooling power and cycle COP during one cycle of the adsorption chiller under different chilled water inlet temperature conditions are presented in Fig. 5. It is seen that both cooling power and

cycle COP increase quickly with the increase of chilled water inlet temperature. To improve cooling power and cycle COP, it is reasonable to increase the chilled water inlet water temperature of the adsorption chiller appropriately.

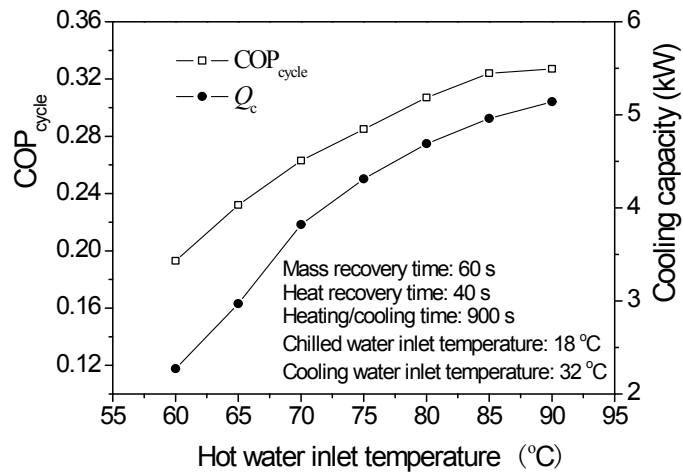


Fig 4: Variations of cycle COP and cooling power with hot water inlet temperature

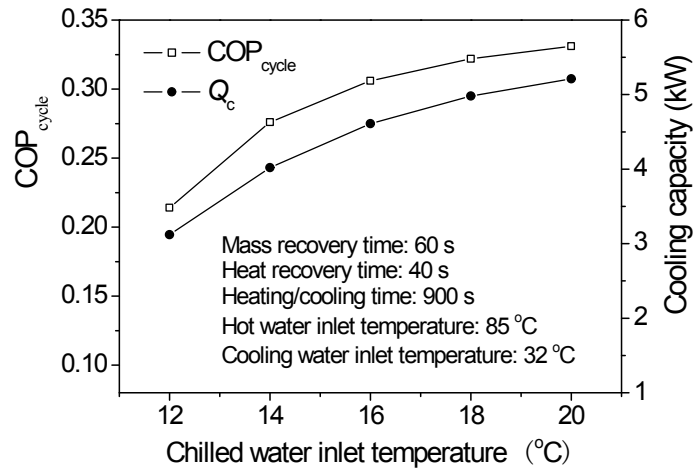


Fig 5: Variations of cycle COP and cooling power with chilled water inlet temperature

4.5 Performance of the solar adsorption chiller

During the field test, the optimum operation parameter conditions are as listed in Table 3. The representative measured daily performance of the solar-powered adsorption chiller is presented in Table 4. It is seen that the solar water heating unit can power the adsorption chiller for about 6.5 to 8.5 hours in a sunny day. The solar-powered adsorption chiller can produce an average SCP of being about 66 - 90 W/m². Its daily a solar cooling COP is about 0.096 to 0.13.

Table 3: Optimum operation parameter conditions during the field test

Parameters	Value
Heating/cooling time (s)	900
Mass recovery time (s)	60
Heat recovery time (s)	40
Hot water inlet temperature (°C)	65-85
Chilled water inlet temperature (°C)	16 – 18
Hot water flow rate (m ³ /s)	0.001
Cooling water flow rate (m ³ /s)	0.0014
Chilled water flow rate (m ³ /s)	0.0005

Table 4: Daily performance of the solar-powered adsorption chiller

Test date	Solar radiation (MJ/m ²)	Ambient temperature (°C)	Operation time (min)	COP _{solar}	Q _c (kW)	SCP (W/m ²)
2004/07/31	19.6	28.5 - 37.6	474	0.123	4.19	84.8
2004/08/06	20.3	29.4 - 37.5	508	0.125	4.14	83.8
2004/08/09	17.4	26.8 - 36.7	423	0.096	3.25	65.7
2004/08/15	19.5	27.3 - 36.4	474	0.131	4.43	89.7
2004/08/26	18.7	26.9 - 36.3	457	0.124	4.21	85.2
2004/09/19	16.2	25.2 - 33.6	382	0.109	3.87	78.3

5. CONCLUSIONS

A solar-powered adsorption chiller with heat and mass recovery cycle was designed and constructed. The following conclusions can be drawn based on the test results:

(1) The coefficient of performance and cooling capacity of the solar-powered adsorption chiller could be improved greatly by optimizing some key operation parameters.

(2) With optimum operation parameters, this solar-powered adsorption chiller can produce a cooling power about 66 to 90W

per m² collector area under the climatic conditions of daily solar radiation being about 16 to 21 MJ/m². Its daily solar cooling COP is about 0.1 to 0.13.

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