

## **SOLAR POWERED ADSORPTION COOLING SYSTEM USING SILICA GEL-WATER PAIR**

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### **Abstract**

Solar powered adsorption cooling system is very attractive for solar energy application. Metallic solar collector with fin have been used to solve the problem of the low thermal conductivity in solar collector. However, it also have a negative effect due to loss by reflection and sensible heat of metal. For this reason, direct-radiation absorption collector was proposed here. The influence of wavelength of light, types of silica gel, and adding some substances to improve radiation absorptivity, were investigated. The experimental results showed that blue silica gel had a good absorptivity in near IR region due to its blue color. In addition, blue silica gel yielded better performance compared to white silica gel due to its high absorptivity. Finally, adding activated carbon into silica gel improved desorption rate and regeneration temperature of packed bed.

### **1. Introduction**

Solar powered adsorption cooling system is a very attractive application for solar energy since the more solar energy is, the more cooling energy is needed. This system could be a useful technology in areas of the world where there are a demand for cooling, high insolation levels, and no firm electrical supply to power conventional systems such as the Southeast Asia and Africa countries. In addition, this system presents many interesting characteristics such as noiseless, non-corrosive and environmentally friendly components. Many combinations of adsorbent-adsorbate were proposed in [1]. Activated carbon (AC)-methanol [2-5], zeolite-water [6], and silica gel-water [7] are examples of those combinations. In this study, silica gel-water pair was chosen due to its simplicity, high latent heat of water, and non-toxicity of substances.

One of the most important elements of solar adsorption cooling system is solar collector design. Metallic solar collector with fin have been used to solve the problem of the low thermal conductivity in solar collector [2-5]. However, using metallic-finned collector also have the negative consequences due to loss by reflection and sensible heat of metal. For this reason, direct-radiation absorption collector was proposed here. But data of the effect of wavelength on desorption rate, absorptivity of silica gel is not yet sufficient. The purpose of this research is to study parameters which have influence on desorption rate in order to improve efficiency of solar collector, for example the effect of range of wavelength ( $\lambda$ ), types of silica gel, and adding some additives to improve the effective thermal conductivity and radiation absorptivity of silica gel etc.,

## 2. Adsorption Heat Pump Cycle

The principle of an adsorption heat pump system is shown in Fig.1. Basically, an adsorptive cycle is intermittent : the adsorber containing the adsorbent is alternatively connected with a condenser and with an evaporator. The cycle is the succession of two periods. First, a period of heating-desorption-condensation at high pressure, then a period of cooling-adsorption-evaporation at low pressure. High and low pressures are the saturation pressures of the adsorbate at the temperatures of, respectively, the condenser and the evaporator. A basic adsorption heat pump cycle can be well represented by the pressure-temperature (P-T) diagram as shown in Fig.2.

**Process 1-2** The adsorbent bed, rich in adsorbed refrigerant, is heated at a constant mass from an initial ambient temperature  $T_{a2}$  to a temperature  $T_{g1}$  and a pressure  $P_{con}$ . The level of the pressure  $P_{con}$  is determined by the condensation temperature.

**Process 2-3** While the adsorbent bed is heated, the refrigerant is desorbed at a constant pressure  $P_{con}$ . The adsorbent bed temperature also increases to the maximum desorption temperature  $T_{g2}$ . The desorbed gas of refrigerant from adsorbent bed is condensed at a constant  $P_{con}$ .

**Process 3-4** The adsorbent bed, having a weak concentration of refrigerant, cools down at a constant adsorbed mass. Then the vapor pressure is reduced from  $P_{con}$  to  $P_{ev}$  while temperature is reduced to  $T_{a1}$ . This process is similar to process 1-2.

**Process 4-1** During the cooling down of adsorbent bed from  $T_{a1}$  to  $T_{a2}$ , adsorbent starts to adsorb the refrigerant gas provided by the evaporation process in the evaporator at a constant pressure  $P_{ev}$  until state 1 is reached again.

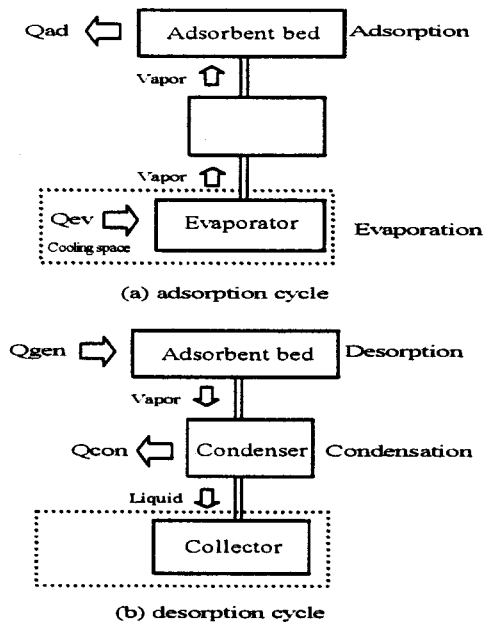


Fig.1 An adsorption heat pump system.  
(a) adsorption cycle (b) desorption cycle

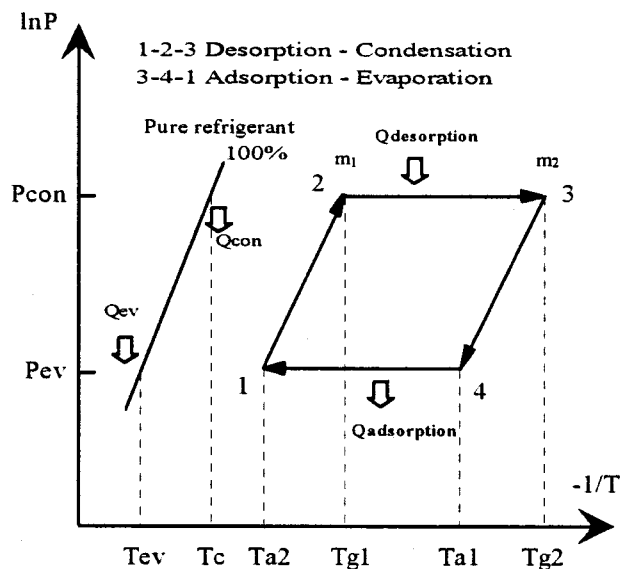


Fig.2 P-T diagram for a basic adsorption heat pump system.

### 3. Materials and Methods

#### 3.1 Experimental Apparatus

The schematic diagram of experimental apparatus is shown in Fig. 3. It consisted of a glass separable flask ( $\phi_{out} = 14$  cm) used as adsorbent bed, a volumetric flask as collector, a condenser, a lamp, a vacuum pumping system and a temperature controller. Chromel-Alumel thermocouples were inserted into condenser and into adsorbent bed to measure temperature distribution in packed bed which were recorded continuously by computer. The details of position of thermocouples and size of adsorbent bed is shown in Fig. 4. The condenser was made of Pyrex with a heat transfer area of about  $1.13 \times 10^{-2} \text{ m}^2$ . The collector was a  $50 \text{ cm}^3$  volumetric flask of 0.025 m ID and 0.22 m height. The overall heat transfer coefficient between the outside and the inside of adsorbent bed was determined in advance on the basis of temperature difference between ambience and the center of the bed. The value of  $6.276 \text{ W}/(\text{m}^2 \cdot \text{K})$  was obtained.

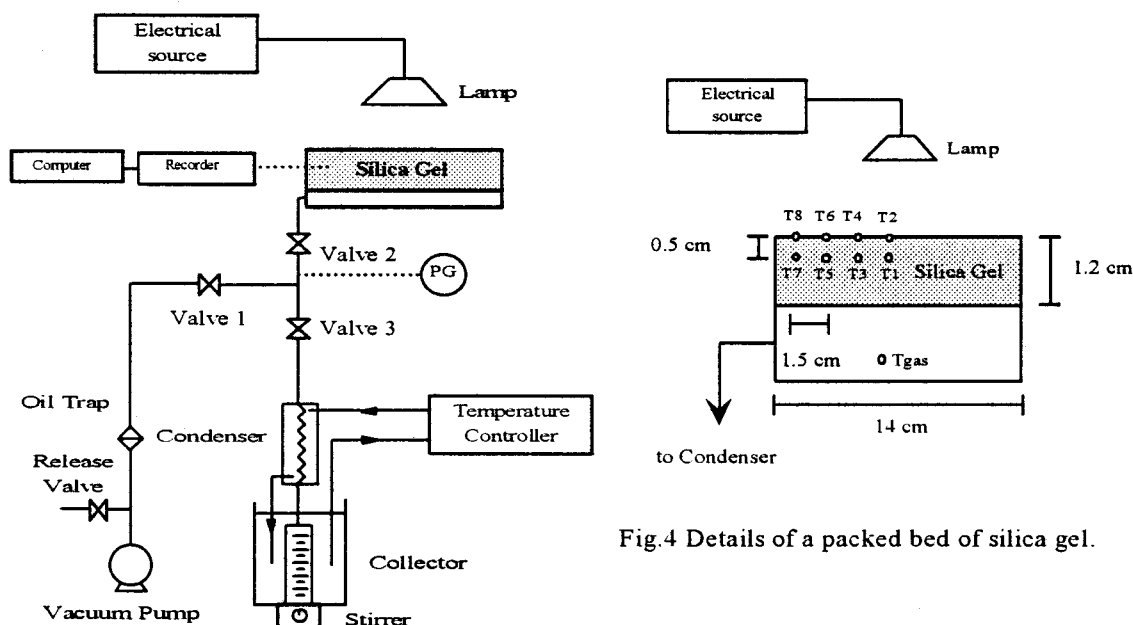


Fig.4 Details of a packed bed of silica gel.

#### 3.2 Experimental Procedure

As a pre-treatment, 6-20 mesh (0.841-3.36 mm) of 0.2 kg of silica gel was desorbed at a temperature of  $180^\circ \text{C}$  in an oven before starting the experiment and then put into a desiccator including 30 g of a beaker of distillation water. To control the temperature of silica gel, the desiccator was inserted into incubator which was set at  $30^\circ \text{C}$  for 24 hours. From this result, 15 % water content of silica gel can be obtained by this method. The prepared silica gel then put into adsorbent bed and was vacuumed for 2 minutes by vacuum pump. The wall temperature of condenser was kept constant by circulating the constant-temperature water. Also, water remaining in the collector was stirred by a

magnetic stirrer to keep the temperature at the same level as the wall temperature. The amount of water remaining in collector was recorded by scale and assumed to be the amount of desorbed water of silica gel.

In the beginning of experiment, infrared lamp and solar lamp were set at the both appropriate position and voltage that gave the same energy flux profiles for both lamps. The temperatures of silica gel in adsorbent bed ( $T_1$ - $T_8$ ), temperature of water vapor ( $T_{gas}$ ), temperature of condenser ( $T_{con}$ ), and room temperature ( $T_{room}$ ) were read by thermocouples and recorded by computer via RS-232C serial port minutely. Amount of desorbed water was registered manually for every 2 minutes at the beginning and for every 10 and 30 minutes at the end of experiment.

#### 4. Results and Discussion

Figure 5 presents one of examples of experimental data. A desorption cycle can be divided into two periods: sensible heat period and desorption period. During sensible heat period, light energy provided by lamp was changed into sensible heat of silica gel only. Therefore, desorption did not occur in this period. This phenomenon can be seen from Fig.5 that  $T_1$  and  $T_2$  increased suddenly in this period. Secondly, in desorption period: light energy was used in sensible heat and heat of desorption of silica gel. It can be observed by slowly increasing of  $T_1$  and  $T_2$ . The difference of  $T_1$  and  $T_2$  shown in Fig.5 was considered to be the result of low thermal conductivity of silica gel.

The effect of wavelength on desorption rate was accomplished by using different light energy sources: infrared lamp and solar lamp. The wavelength profiles of both lamps were checked in advance by monochrometer and shown in Fig.6. This figure shows that infrared lamp provided a higher intensity in near IR region. Then, the experiments were carried out and obtained data were plotted in Fig.7. As

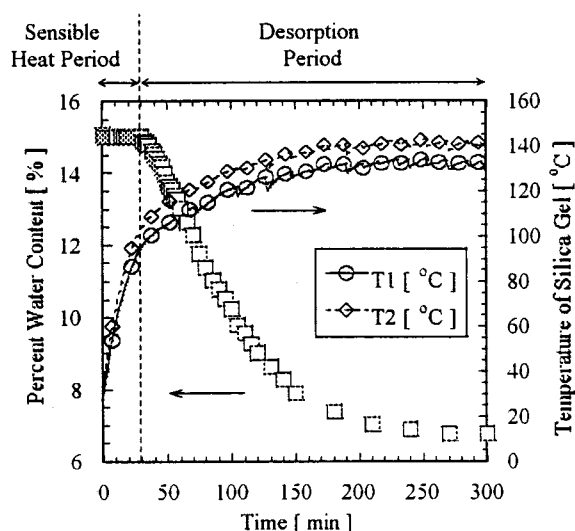


Fig.5 Variation of water content and temperature. (Using infrared lamp, 25 cm from lamp,  $V = 80$  V)

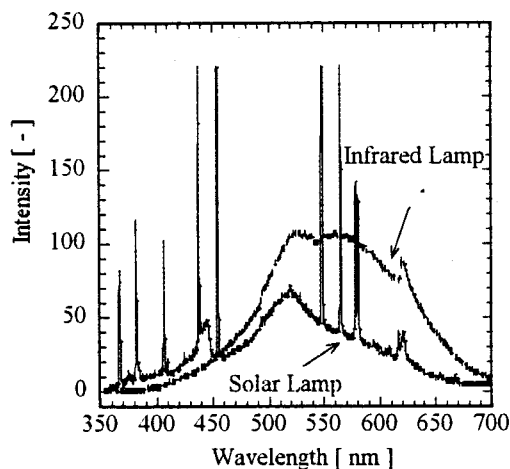


Fig.6 The wavelength profiles of infrared lamp and solar lamp.

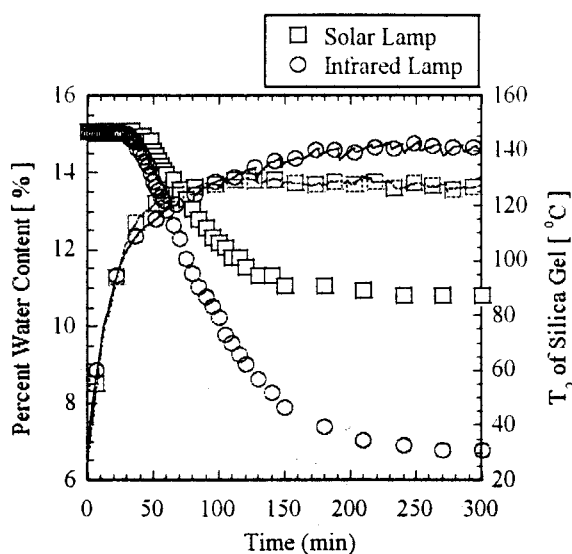


Fig.7 Comparison of water content and T<sub>2</sub> between infrared lamp and solar lamp.

described above, energy flux of both lamps was set equally. Therefore, the higher T<sub>2</sub> and desorption rate in case of using infrared points out that blue silica gel have good radiation absorptivity in near IR region compared to UV region. Concerning with theory of surface absorption and reflection of pigment, blue silica gel contains pigments which preferentially absorbs the red, green, and yellow components of light. This theory can explain why blue silica gel have good absorptivity in near IR region.

Figure 8 shows the comparison of water content, T<sub>2</sub>, and T<sub>gas</sub> between blue and white silica gel using infrared lamp as an energy source. Using blue silica gel caused a slightly higher T<sub>2</sub> and desorption rate. This can be explained as follows: from the radiation balance on the medium, portions of radiation may be reflected, absorbed, and transmitted. it follows that

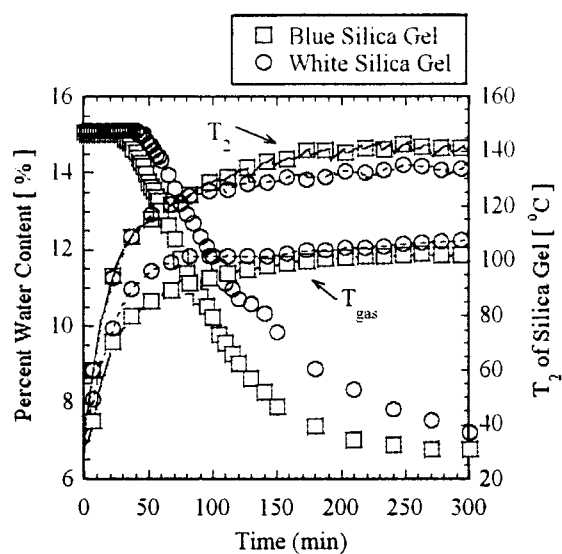


Fig.8 Comparison of water content, T<sub>2</sub> and T<sub>gas</sub> between blue and white silica gel. (Using infrared lamp)

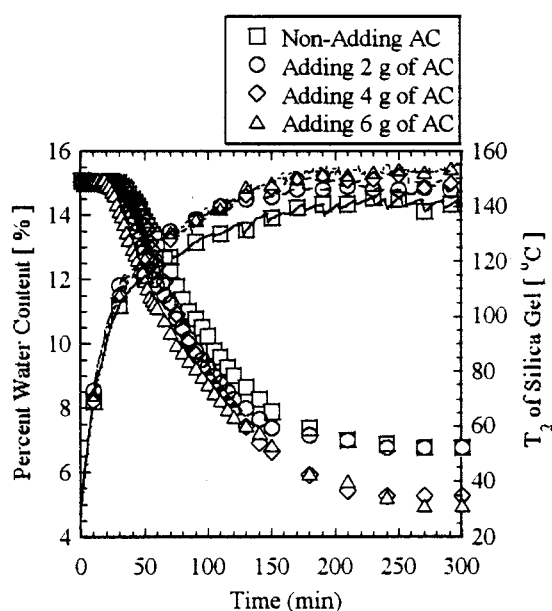


Fig.9 Comparison of water content and T<sub>2</sub> between non-adding and adding activated carbon. (Using infrared lamp)

$$\rho_{\lambda} + \alpha_{\lambda} + \tau_{\lambda} = 1 \quad (1)$$

where  $\rho_{\lambda}$  is absorptivity,  $\alpha_{\lambda}$  is reflectivity, and  $\tau_{\lambda}$  is transmissivity. For opaque medium such as blue silica gel,  $\tau_{\lambda}$  can be assumed to be 0. But for semitransparent such as white silica gel, the transmission is dominant. For this reason,  $T_{\text{gas}}$  in case of using white silica gel was higher than using blue silica gel but was contrary in case of  $T_2$  (See Fig. 8).

The Adding 12-20 mesh (0.430-0.710 mm) of AC into silica gel was proposed in order to improve the effective thermal conductivity and overall absorptivity of packed bed. These experimental results were shown in Fig. 9. Figure 9 shows that  $T_2$  and desorption rate increased with increasing of amount of AC. Theoretically, the low value of the effective thermal conductivity of silica gel can be improved by decreasing void fraction of packed bed. The calculation of effective thermal conductivity in case of non-adding and adding AC was carried out based on the assumption that all particles were sphere. The results showed that adding AC improved only 4 % of effective thermal conductivity. For this reason, it can be concluded that adding AC in packed bed can improve desorption rate and regeneration temperature due to the good absorptivity of AC.

## 5. Conclusion

Parameters which have influence on desorption rate and regeneration temperature were investigated. They can be concluded that blue silica gel have good absorptivity in near IR region due to its blue color. On the other hand, white silica gel performed a bad absorptivity because of its semitransparency and low absorptivity. Finally, the experimental results showed that adding AC in silica gel improved the desorption rate and regeneration temperature which can be explained by the good absorptivity of a black of AC. However, it should have the optimum value for amount of AC as the mass transfer problems in packed bed.

Again, these results emphasize the importance of adsorbent-adsorbate selection. The suitable adsorbents should adsorb a large amount of adsorbate and present some additional characteristics: wide concentration change in a small temperature range, reversibility of adsorption process for many cycles, cost effective, good thermal conductivity, and good radiation absorptivity.

## Nomenclature

$m$	= Mass ratio of adsorbed mass to adsorbent	[ - ]	$Q_{\text{ad}}$	= Heat of adsorption	[ kJ ]
$P_{\text{con}}$	= Saturated pressure at $T_{\text{con}}$	[ Pa ]	$Q_{\text{ev}}$	= Heat of evaporation	[ kJ ]
$P_{\text{ev}}$	= Saturated pressure at $T_{\text{ev}}$	[ Pa ]	$Q_{\text{gen}}$	= Heat of regeneration	[ kJ ]
$Q_{\text{con}}$	= Heat of condensation	[ kJ ]	$T$	= Adsorbent temperature	[ K ]
			$T_{\text{con}}$	= Temperature of condenser	[ K ]

$T_{ev}$	= Temperature of evaporator	[ K ]	$T_{g1}$	= Temperature at the beginning of	
$T_{room}$	= Atmospheric temperature	[ K ]		desorption	[ K ]
$T_{a1}$	= Temperature at the beginning of		$T_{g2}$	= Temperature at the end of	
	adsorption	[ K ]		desorption	[ K ]
$T_{a2}$	= Temperature at the end of				
	adsorption	[ K ]			

#### Greek Letter

$\rho$	= Absorptivity
$\alpha$	= Reflectivity
$\tau$	= Transmissivity
$\lambda$	= Wavelength

#### Subscript

1-8	Position of thermocouples in adsorbent bed. See Fig.4 for details.
gas	Position of thermocouple in adsorbent bed. See Fig.4 for details.
$\lambda$	Wavelength

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