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Design and performance of a solar-powered heating and cooling system using silica gel/water adsorption chiller

W.-S. Chang *, C.-C. Wang, C.-C. Shieh

Energy & Environment Research Laboratories, Industrial Technology Research Institute, Bldg. 64, 195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu 310, Taiwan

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ABSTRACT

In this paper, a solar-powered compound system for heating and cooling was designed and constructed in a golf course in Taiwan. An integrated, two-bed, closed-type adsorption chiller was developed in the Industrial Technology Research Institute in Taiwan. Plate fin and tube heat exchangers were adopted as an adsorber and evaporator/condenser. Some test runs have been conducted in the laboratory. Under the test conditions of 80 °C hot water, 30 °C cooling water, and 14 °C chilled water inlet temperatures, a cooling power of 9 kW and a COP (coefficient of performance for cooling) of 0.37 can be achieved. It has provided a SCP (specific cooling power) of about 72 W/(kg adsorbent). Some field tests have been performed from July to October 2006 for providing air-conditioning and hot water. The efficiency of the collector field lies in 18.5–32.4%, with an average value of 27.3%. The daily average COP of the adsorption chiller lies in 33.8–49.7%, with an average COP of 40.3% and an average cooling power of 7.79 kW. A typical daily operation shows that the efficiency of the solar heating system, the adsorption cooling and the entirely solar cooling system is 28.4%, 45.2%, and 12.8%, respectively.

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1. Introduction

Adsorption refrigeration technology is attracting more and more attention in recent years because it can save energy and is environmentally friendly. Adsorption cycles can be driven by low-grade waste heat or solar energy under 80 °C. They do not have to use ozone-depleting chlorofluorocarbons (CFCs) and do not need electricity or fossil fuels as driving sources.

Silica gel–water adsorption chiller can be used in combination with solar energy because of the possibility of using the low-grade solar energy under 80 °C, which can be easily obtained with flat-plate collectors or vacuum tube collectors. Although the adsorption chillers are thought to be very promising in the future for the application of solar cooling and waste heat recovery, the wide spread of this technology is not yet possible. The reason is mostly attributed to the poor COP value (COP, coefficient of performance, defined as the ratio of the output cooling power and the input heating power) and higher product cost of adsorption chillers.

In summer of a subtropical land like Taiwan, about one third of the electricity may be consumed for air-conditioning in buildings. The need of air-conditioning is consistent with the solar radiation of the day and the season. If one can use the excessive solar energy, the total system efficiency of energy utilization would be significantly improved.

In an authors' previous study [1] an integrated, one-bed, closed-type silica gel–water adsorption chiller was developed and experimentally studied. Flat-tube heat exchangers with corrugated fins were adopted as an adsorber and evaporator/condenser. To further realize commercialization of this kind of adsorption chiller, a two-bed silica gel–water adsorption chiller that can provide chilled water continuously was also developed and studied [2].

Many researchers have devoted themselves to adsorption refrigeration technology and many studies have been conducted. Among these works the silica gel–water adsorption systems have been analytically [3–7] and experimentally [8–11] investigated.

Recently, a solar-powered hybrid energy system with adsorption chiller in an ecological building has been conducted. The adsorption cooling COP of 0.28 has been attained and the average efficient (Collector efficiency is defined as the ratio of the absorbed energy and the input irradiation.) of collectors (U-type and heat pipe evacuated collectors) is about 40% [12]. Additionally, some field tests of the solar adsorption cooling system driven with all-glass evacuated tube collectors were introduced. Daily solar cooling COPs ranging from 0.1 to 0.13 were reported [13–14].

In this paper, a two-bed silica gel–water adsorption chiller with plate fin and tube heat exchangers was newly developed. In order to conduct a field test, a solar-powered compound system for heating and cooling was designed and constructed in a golf course located in Hsinchu, Taiwan.

* Corresponding author. Tel.: +886 3 6570882; fax: +886 3 6570883.
E-mail address: wschang@clean-power.com.tw (W.-S. Chang).

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Nomenclature

COP	coefficient of performance, ratio of the output cooling power and input heating power	T_i	inlet water temperature of collector [°C]
SCP	specific cooling power, produced cooling power per kg adsorbent [W/kg]	T_{amb}	ambient air temperature [°C]
		G	global irradiance [W/m^2]
		η_c	collector efficiency [-]

2. System description

A schematic diagram of the entire system is shown in Fig. 1. The system described in this paper is mainly composed of three subsystems, i.e., the solar heating circuit, the hot water supply circuit and the adsorption cooling circuit. The solar heating circuit possesses 108.5 m^2 flat-plate solar collectors, whose efficiency curve is described as $\eta_c = 0.76 - 4.7 \times \frac{(T_i - T_{amb})}{G}$, mounted on the roof ground surface of the building. Collector efficiency η_c is defined as the ratio of the absorbed energy and the input irradiation. It is experimentally decided and described by three parameters, i.e., inlet water temperature of collector T_i, ambient air temperature T_{amb}, and global irradiance G. Because of lower thermal loss factor of 4.7, the collector can obtain higher water temperature than 65 °C without significantly loosing the collector efficiency. The collectors are installed tilled at the angle of 20° to the ground and at an azimuth of 30° south by east in order to be in line with the orientation of the building. Furthermore, because most of the hot water will be used around noon for the air-conditioning, it is also appropriate to collect more solar heat in the morning. A solar hot water storage tank of 1300 L in volume is used to store solar heat with the design temperature of 80 °C. On the test run a temperature of 90 °C could be reached. This storage tank would not only provide hot water higher than 65 °C as heat source to drive the adsorption chiller, but also provide 50 °C hot water to the dormitory.

The hot water supply circuit is connected to the solar heating circuit via a plate heat exchanger. The cold makeup water will be heated to 50 °C by the solar hot water and stored in two buffer tanks (each 1000 L). The hot water will be supplied to the dormitory for bathing use of 50 persons for a day. Eventually, the backup gas-fired boiler will be automatically turned on to heat the water to the required temperature.

The core component of the cooling circuit is an adsorption chiller with about 10 kW cooling power, which was newly developed in this study. This adsorption chiller is driven by the solar hot water with the temperature of 65–95 °C and produce chilled water. The chilled water will then be circulated to the employee restaurant for 3 h around noon (from 11:00 to 14:00) in the summer time (from May to September).

The installation location Shinchu is located in the northern Taiwan. The geographical position of Shinchu is at latitude of 24.8° north and a longitude of 121° east. It belongs to the subtropical climate zone. Fig. 2 shows the monthly-average daily irradiation on a horizontal surface and the ambient air temperature. The irradiation in summer can be almost three times higher than in winter.

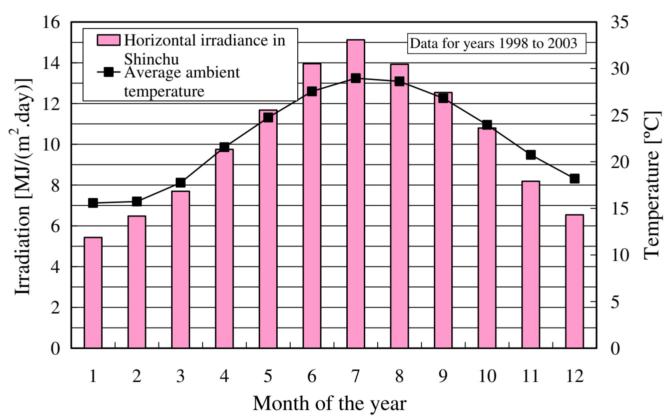

Fig. 2. Monthly average of horizontal irradiation and ambient air temperature in Shinchu.

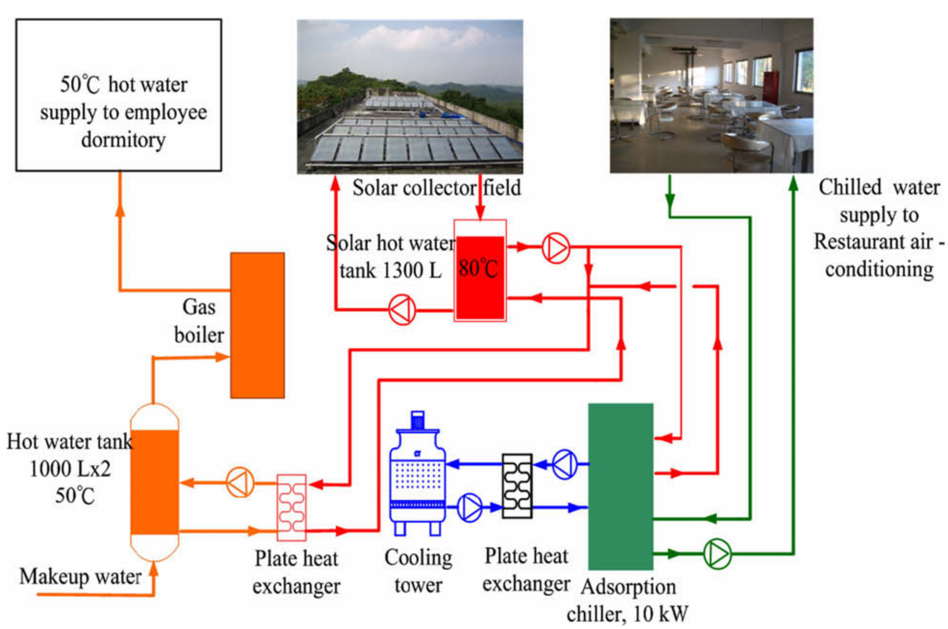

Fig. 1. Schematic diagram of the system for heating and cooling.

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