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Experimental performance investigation of small solar air-conditioning systems with different kinds of collectors and chillers

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Abstract

Different types of solar collectors should be integrated with different sorption chillers. Traditional evacuated tube U pipe solar collector, high efficient CPC (Compound Parabolic Concentrating) solar collector and PTC (Parabolic Trough Collector) solar collector can provide 60–85 °C, 85–125 °C and 125–150 °C of hot water. So, they can drive silica gel–water adsorption chillers, single-effect LiBr absorption chillers and double-effect LiBr absorption chillers, respectively. This paper will present the experimental performance investigation and economic analysis of three small solar cooling systems with these different kinds of collectors and chillers. The test results show that the solar COP (Coefficient of Performance) of the solar cooling system with adsorption chiller and U pipe solar collectors is about 0.15 and the silica gel–water adsorption chiller can be driven by 55 °C of hot water. The solar COP of the system with CPC solar collector and single effect absorption chiller can reach 0.24 in the sunny weather condition. The solar COP of the solar cooling system with PTC solar collectors is about 0.5 and the double-effect LiBr absorption chiller is more attractive because of its higher solar COP (Coefficient of Performance) and better economy.

Keywords: CPC; PTC; Adsorption chiller; Absorption chiller

1. Introduction

It is a well-known fact that air conditioning facilities consume a significant portion of energy supply. According to survey data in warm and humid countries, on average 30–40% of total energy consumption comes from cooling and/or heating of houses and commercial buildings. Moreover, the trend on consumption from air conditioning causes electricity supplies to constantly run short, especially in summer. Apart from the energy consumption, vapor compression air-conditioning technology also has some negative effects on the environment, as a result of their usage in the chlorofluorocarbons (CFCs) and the hydro-fluorocarbon (HCFC) refrigerants which induce ozone depletion and the consequent greenhouse effect.

In search of sustainable energy utilization technologies, the sorption system considerably appears as an alternative way to reduce consumption of electricity and CFCs. Sorption cooling machines can be powered by solar energy and industry waste heat to save energies. Moreover, sorption cooling systems have the advantage of using environment-friendly working fluids such as water, ammonia, etc., where the latter is a natural refrigerant with the excellent environmental properties. They have zero ozone-depletion

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Nomenclature

COP	Coefficient of Performance
SCP	Specific Cooling Power (W kg^{-1})
q	cooling/heating power (kW)
T	temperature (°C)
$\dot{m}$	mass flow (kg s^{-1})
T^*	normalized temperature
C	the specific heat (kJ kg^{-1} $°C^{-1}$)
I	solar radiation intensity (kJ m^{-2} s^{-1})
A	solar area (m^2)

Subscripts

e	cooling
ch	chilled water
i	inlet
o	outlet
h	heating
av	average
w	water
a	adsorbent
am	ambient

Greek symbols

η	efficiency of solar collector

potential (ODP) and zero global warming potential (GWP).

So far, many experiments have been conducted to investigate thermodynamic properties of different adsorbent-refrigerant working pairs. The following gives a brief review of recent important literature on this issue. Berdja et al. built a refrigerator prototype that uses activated carbon and methanol working pair, in which solar energy can be directly used. The solar COP was founded equal to 0.081 depending on the refrigerating effect and the solar radiation (Berdja et al., 2014). Nunez et al. developed and tested a silica gel–water adsorption chiller with nominal cooling power of 3.5 kW (Nunez et al., 2004). The chiller operated at generation temperatures of 75–95 °C, heat sink temperatures of 25–35 °C, and evaporation temperature ranging from 10 to 20 °C. The COP varied from 0.4 to 0.6. A silica gel–water adsorption chiller was developed and its performance is tested in detail in Shanghai Jiao Tong University (Wang et al., 2005a; Wang et al., 2005b). The experimental results show that the refrigerating COP of the chiller could reach 0.4 when it was powered by 85 °C hot water with 15 °C chilled water outlet temperature and 30 °C cooling water temperatures. The chillers were used in the air-conditioning system of green buildings located in the Shanghai Research Institute of Building Science, Himin solar company and Linuo solar company.

Li et al. analyzed the optimal temperature of collector for solar double effect $LiBr/H_2O$ absorption refrigeration system in subtropical city. The corresponding maximum monthly average total efficiency of system from April to October is 0.241, 0.278, 0.304, 0.407, 0.43, 0.434 and 0.458, respectively (Li et al., 2014). Izquierdo et al. developed to test a new solar-powered air-cooled absorption refrigeration system. This installation consists of a-48 m^2 field of flat-plate solar collectors, a 1500-L hot water storage tank and a single and-double effect air-cooled lithium bromide absorption prototype. In August 2009, the cooling system was tested in the single-effect operation mode. The results show that the system is able to meet approximately 65% of the laboratory's seasonal cooling demand, although 100% may be reached for a few days (Izquierdo et al., 2014). Arum et al. carried out a thermodynamic analysis of the working pair $LiBr–H_2O$ and the energy and mass balances in each component of the chiller. The results showed how the operating temperatures affect the low pressure generator temperature and other internal variables for maximum COP (Arum et al., 2000). Li presented the simulation of a solar-powered absorption air conditioning system with the absorption pair of lithium bromide and water (Li and Sumathy, 2001). An attempt was made to increase the COP of the system by partitioning a single storage tank into two parts. In the morning when sunshine was low, the upper part was activated, and in the afternoon, the whole (upper and lower) tank was connected to the collector. The analysis indicated that it was preferable to utilize a partitioned water tank rather than the normal stratified water tank because the cooling effect can be realized much earlier compared to the normal stratified water storage tank. Also, the overall cooling efficiency (cooling load to total solar energy ratio) was found to be higher for the partitioned storage air conditioning system.

Hu simulated the system performance by considering unsteady heating in the collector, including the thermal capacitance of the collector components in obtaining the useful energy (Hu et al., 1991). Although a large potential market exists for this technology, existing solar cooling systems are not competitive with electricity driven vapor compression air-conditioning systems because of their high first costs (Li and Sumathy, 2000). Lowering the cost of components and improving their performances could reduce the cost of solar cooling systems. However, the above study usually considered a particular solar cooling technology, without looking at the whole picture. In this paper, there are three objectives. The authors develop small solar cooling systems in three temperature ranges (60–85 °C, 85–125 °C and 125–150 °C); compare the three solar