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Performance analysis on a new type of solar air conditioning system

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ABSTRACT

A new system of solar air-conditioning, which adds the heat pump into the original solar air-conditioning, is proposed in order to improve the solar energy application grade. The new type of solar air-conditioning system is analyzed and compared with the original system. Calculations show that: (1) when the sun radiation intensity is high (0.8 kW/m^2), the cooling capacity of the new system is 1.7 times the original system under the given conditions of this paper. When the sun radiation intensity is low (0.2 kW/m^2), the cooling capacity of the new system is decreased by 70% compared to high radiation intensity conditions, and the original system could not provide refrigeration. (2) In a certain solar radiation intensity, new type solar air-conditioning system reduces the requirement of a high efficiency solar collection system (SCS). At a certain collector efficiency, it can operate stably by adjusting the water mass flow rate of SCS under different solar radiation intensities. (3) For the heat pump system (HPS) of the new type solar system, under the same rage of evaporation temperature and condensation temperature, R600a HPS has higher COP and less power consumption than R134a HPS under obtaining same cooling capacity condition.

1. Introduction

With the rapid development of science and technology, human is faced with the growing shortage of conventional resources and the threat of environmental pollution. Many countries began to develop and make use of low-grade energy sources such as solar, geothermal, industrial waste heat, etc. These sources become the object of concern because they are clean and green renewable energy, and have large reserves [1,2]. The concept of solar cooling is appealing because the refrigerating demand and the supply of solar radiation are almost in phase with each other [3–6]. But the intensity of solar radiation changes periodically and even becomes none at night, so how to get the solar refrigeration cycles to be able to steadily run is of great importance. Based on the above issues, scholars do lots of researches in the following three aspects:

Firstly, a new structure of system which uses low intensity solar energy to reduce the working temperature is developed. Ahachad proposed a two-stage solar machine which can be operated at lower hot source temperatures and can be obtained either from flat plate collectors or from thermal effluents [7]. Eicker analyzed the performance and economics of solar thermal absorption chiller systems [8]. Venegas brought forward a new triple-stage absorption cycles for refrigeration which ware adequate for low-temperature heat below 90 °C [9]. Wang demonstrated that a new improved cycle was able to run steadily when driven by low-grade thermal sources as low as 65 °C, and to produce deep refrigeration temperature as low as −40 °C for a three-staged cycle [10].

Secondly, an energy storage device or auxiliary heat source which suits low or none solar intensity conditions is equipped into the original system. Dennis proposed a solution which installed a cold storage indoors for the solar cooling system which cannot provide nocturnal refrigeration [11]. In order to relieve the impact of short-period cloudy weather, Henrik thought that it might be useful to store part of the regenerated solution and the refrigerant separately [12]. Xu presented a new solar powered absorption refrigeration (SPAR) system with advanced energy storage technology. The energy collected from the solar radiation was first transformed into the chemical potential of the working fluid and stored in the system. The proposed system can solve the problem of the unconformity between solar radiation and cooling demand [13]. Liu presented an innovative concept for a long-term energy storage system. The solar energy is absorbed and stored in the summer through the analytic function, and release heat in winter through the adsorption [14].

Thirdly, the parameters which influence system performance are explored and adjusted in order to ensure the working of cooling system in the best conditions. Tsoutsos studied the performance and economic evaluation of a solar cooling system by using the transient simulation program [15]. Yin experimented a mini-type solar absorption cooling system under different cooling modes [16]. Marc also experimented a solar cooling absorption system operating without any backup system under tropical climate [17].

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Nomenclature

$\dot{Q}$	Heat, W
$\dot{W}$	Power, W
X	Concentration
T	Temperature, °C
$\dot{m}$	Mass flow rate, kg/s
h	Enthalpy, J/kg

Subscripts

1-22	Status points as defined in Fig.1
*ref*1	Refrigerant of heat pump system
*ref*2	Refrigerant of absorption refrigeration system
com	Compressor
cond	Condenser
abs	Absorber
gen	Generator
evap	Evaporator
w	Water

Alkhamis researched the cooling system which was influenced by collector area and storage volume. The average yearly performance of the simulated system was shown to be more sensitive to the collector area than the storage volume [18]. Rodriguez-Hidalgo analyzed instantaneous performance of solar collector [19]. Sumathy presented that the adsorbent mass and the solar collector area had significant effect on the system performance as well as on the system size [20]. Kaushik's study found the coefficients of performance were reduced at high generator temperatures. However, an increase of condenser temperature of operation improved the performance of the systems at high generator temperature [21]. Nidal did a lot of research on activated carbon – methanol adsorption refrigeration. The results of model test and data analysis showed that the increase of adsorption mass quantity will lead to the increase of coefficient of performance (COP), the increase of tank capacity cause the increase of COP, the increase of collection hot area result in the increase the COP [22]. Fong adopted the approach of simulation–optimization to determine the optimal design parameters for the solar absorption refrigeration system and the solar adsorption refrigeration system [23]. Monne did the research and analysis on a lithium bromide solution absorption refrigeration system, and found that the outdoor temperature is higher, the lower the COP is. The high outdoor temperature will trigger the increase of solar energy collection quantity, but does not show that COP must increase [24].

In order to reduce the influence of the weather conditions and lessen the impact on the collector system requirements, a new type of the solar air-conditioning system which adds the heat pump system to enhance the quality of solar application is proposed based on the original solar air-conditioning system. By using flat-plate collectors to gather solar radiation, we can get a lower temperature heat source than the vacuum tube collectors. Through the heat pump system, the low-grade energy will be upgraded to a high-grade energy. Then this heat is used to drive the refrigeration equipment. In addition, the heat loss of the collector is also relatively reduced. Fig. 1 shows the difference between the original system and the new system. Here we select absorption refrigeration system as an object of study, just in order to show the performance of the solar cooling system adding a heat pump system. At the same time, taking account of the system performance and impact of the refrigeration working to the environment, the comparison of working fluid in heat pump has also become the focus of this study.

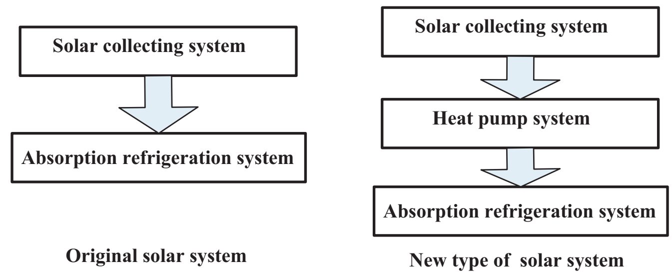

Fig. 1. Schematic diagram of the difference between the original system and the new system.

2. The new type of solar absorption refrigeration system

In Fig. 2 there is the schematic of the new type of solar absorption refrigeration system. It consists of three parts: solar collecting system (SCS), heat pump system (HPS), and absorption refrigeration system (ARS). The SCS mainly composed of the Collector, Water tank, and Pump 1. The HPS mainly includes the compressor, condenser 1, throttling valve 1, and evaporator 1. The ARS mainly includes the generator, heat exchanger, throttling valve 2, absorber, pump 2, condenser 2, throttling valve 3, and evaporator 2. In the SCS, the working fluid of water receives heat from the collector and then enters into the water tank which can also be used to store heat. By the use of pump 1, the water is cooled by evaporator 1 and re-absorbed into the collector. In order to maintain a constant evaporation temperature, we use the variable-speed pump and water tank to regulate water mass flow rate under different solar radiation intensities. This is the completion of a cycle. In the HPS, the refrigerant is cycled among the parts of the compressor, condenser 1, throttling valve 1, and evaporator 1. The water temperature of evaporator 1 is raised to a high water temperature because of condenser 1. It also means that the low-grade energy is transformed to a high-grade energy. In the ARS, the refrigerant is cycled among the units of condenser 2, throttling valve 3, evaporator 2, and the complex absorption mechanism consisting of an absorber, a solution pump, a generator, a throttling valve 2, and a heat exchanger. The heat which comes from condenser 1 is sent to the generator which ensures the normal operation of the ARS. The evaporator 2 can provide cooled water or air. The condenser 2 uses chilled water which initially comes into the absorber as the heat sink. Numbers 1–22 stands for the status points of the new type of system. In Fig. 3 there is the schematic of the original solar absorption refrigeration system.

3. Model of thermodynamic analysis

To illustrate the advantages of the new solar system, a double-layer transparent glass cover flat-plate collector is selected. R134a is a refrigerant of HPS, and lithium bromide solution is the refrigerant of ARS. Assuming there is no pressure drop in any heat exchanger or connecting piping. The steady-state thermodynamic analysis model of the new system is briefly described as follows.

3.1. SCS

The equation of energy balance is the following [25]:

$$\dot{Q}_{UC} = A_{AC} \times I_s \times \eta_{SC} = c_w \dot{m}_w \Delta t_w \quad (1)$$

where $\dot{Q}_{UC}$ is the output useful power of the collector, W; A_{SC} is the lighting area of collector, m^2; I_s is the solar intensity, W/m^2; η_{SC} is the efficiency of collector; c_w is the heat specific capacity of water, J/(kg·K); Δt_w is temperature difference, $\Delta t_w = T_2 - T_1$, °C.