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Experimental study on roll-bond collector/evaporator with optimized-channel used in direct expansion solar assisted heat pump water heating system

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HIGHLIGHTS

- Roll-bond panel is used as the collector/evaporator.
- Flow channel structure of the roll-bond panel is optimized.
- The optimized channel pattern enhances the performance of the roll-bond panel.
- The honeycomb shaped channel pattern shows best performance.

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ABSTRACT

In this investigation, a direct expansion solar assisted heat pump (DX-SAHP) water heating system using an optimized-channel roll-bond collector/evaporator was designed, fabricated and tested. Optimized fractal T-shape and honeycomb shaped channel patterns were adopted to improve the thermal performance of the roll-bond panel, which acts as both the evaporator for the heat pump system and the collector for solar thermal utilization. The performance of the studied water heating system using the south-faced, wall-mounted roll-bond panel with the new composite channel patterns was investigated experimentally. Results show that, under the experimental conditions, the roll-bond panel with optimized channel pattern shows better thermal properties, and the performance the DX-SAHP system is significantly enhanced by using the roll-bond panel with optimized channel pattern. Compared to the conventional parallel channel pattern, fractal T-shaped channel pattern enhanced COP of the system by 14.6%, and heating capacity by 17.3%. And the honeycomb shaped channel pattern further enhanced COP and heating capacity of the system by 5.9% and 6.2%.

1. Introduction

The direct expansion solar assisted heat pump (DX-SAHP) is a kind of hybrid system that combines solar collector and heat pump together. For a heat pump system, one of the key factors that affect the coefficient of performance (COP) is the evaporating temperature. So, besides outdoor air, other types of energy such as water and ground source, which are all indirect solar energy, have been used to get higher evaporating temperature, thus to improve the performance of the heat pump system. While in a DX-SAHP system, solar radiation is used directly as the heat source, which can provide a higher evaporating temperature than the indirect solar sources [1–5].

The idea of DX-SAHP was first proposed by Sporn and Ambrose in 1955 [1], and more studies began since the late 1970s. In the years following, other different types of DX-SAHP have been proposed. Performances of various prototypes were tested and analyzed [2–13], and reviews on this topic can also be found [3–5]. In a DX-SAHP system, solar collector and evaporator of the heat pump are combined into one single unit. The working fluid evaporates in the collector/evaporator and absorbs heat from solar thermal conversion and ambient air. Compared with the conventional solar water heating system with flat plate or evacuated glass tube solar collector, the temperature of working fluid in collector/evaporator of DX-SAHP is much lower and consequently can exploit solar radiation more efficiently. While compared with the air

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Nomenclature

A_{evap}	area of the evaporator
c_w	specific heat of water
$F_{e\text{-}g}$	evaporator-ground view factor
$F_{e\text{-}s}$	evaporator-sky view factor
f_s	solar fraction
K_{evap}	heat transfer coefficient between the evaporator and the ambient air
m_w	mass of the water in the tank
N_{in}	input power of the compressor
Q_c	convectional heating exchanging capacity of the evaporator
Q_{evap}	heat gain of the evaporator
Q_h	water heating capacity
Q_r	radiant heating exchanging capacity of the evaporator
R	solar radiation intensity
t	time
T_{air}	ambient air temperature
T_e	surface temperature of the evaporator
T_{em}	average surface temperature of the evaporator
T_g	equivalent ground temperature
T_e	evaporating temperature
T_{sky}	equivalent sky temperature
T_w	water temperature in the tank
T_{w0}	initial water temperature
T_{wh}	water temperature at the end of the heating process
T_{wl}	water temperature at the beginning of the heating process
α	absorptivity of the collector/evaporator
ΔT_e	difference between the mean surface temperature and the evaporating temperature
ε	emissivity of the collector/evaporator
η_s	solar collector efficiency

source heat pump system, solar radiation can provide a higher evaporating temperature in collector/evaporator of DX-SAHP, resulting in an improved COP.

It is easy to be inferred that the performance of a DX-SAHP system is significantly affected by solar radiation, and a collector/evaporator with high solar absorptivity as well as low heat loss is a key component of the system. Thus, the study on the thermal performance of the collector/evaporator has been a focus of researches. Various types of collector/evaporator with different shapes, structures and dimensions have been proposed and investigated. Charter and Taylor outlined a DX-SAHP using a solar bare panel as collector/evaporator [2]. Chaturvedi and Shen studied DX-SAHP system using an un-glassed solar collector as the evaporator experimentally [6]. Huang et al. studied the evaporator/collector made of aluminum fin tubes arranged in parallel and directly exposed to air, which was always maintained at the ambient temperature [9]. Hawlader et al. used an unglazed copper plate fitted with copper tube brazed underneath the plate as collector evaporator in a solar assisted heat pump dryer [10]. Li et al. used an unglassed roll-bond collector/evaporator in a DX-SAHP water heater [14, 15]. Kuang et al. studied the flat plate collector/evaporator covered with single glass [12]. Ji et al. studied the PV evaporator that consisted of PV cells and evaporating-collector plate made of aluminum alloy [7]. Tagliafico et al. introduced dynamic thermal models and CFD analysis of different types of flat-plate thermal solar collectors [18].

Among the various types of collector/evaporator, bare flat plats made of aluminum or copper were used most widely. Most of those bare plat panels employed simple parallel or S-shaped flow channel patterns. Researchers have made first and second law analysis on the performance of the collector/evaporator, and effects of solar radiation, ambient temperature and operating condition et al. have been investigated. While according to the constructal theory analysis of thermodynamics by Bejan and Lorente [16,17], geometrical structure (configuration) of the flow channel is also an important factor that affects the thermal performance of the collector/evaporator panel. With channel network optimization, thermal conductive performance of the collector/evaporator can be improved and thus solar energy absorbed by the panel can be transferred to the working fluid more efficiently, resulting in lower average temperature of the panel and higher efficiency of solar utilization.

In this study, the roll-bond panel is used as the collector/evaporator in the DX-SAHP system. The roll-bond panel is one kind of evaporator used a lot in Refrigerators and freezers, which is made of two aluminum sheets. During the production process, the designed channel networks are printed onto the Al sheets with graphite, and then the two Al sheets are assembled together by a rolling process. Because of the graphite, the area occupied by the channel circuit cannot be rolled together, thus the inner channel can be created by pressuring. Compared to the tube-type heat exchanger, it is easy and cheap to manufacture a roll-bond panel with complex flow channel networks. Besides, the roll-bond panel is suitable for the DX-SAHP system for the following advantages: (1) unique design flexibility for the DX-SAHP system; (2) easy to be shaped to fit different applications; (3) easy for design and fabrication; (4) low cost for design and manufacturing; (5) convenient for aluminum recycling.

In this work, a DX-SAHP water heating system using the roll-bond collector/evaporator was fabricated and investigated experimentally, and the thermal performances of the roll-bond collector/evaporators with various types of channel networks were tested and compared to decide an optimized flow channel structure. The influences of the external conditions (including solar power and ambient air temperature) on the performance of the system are also discussed.

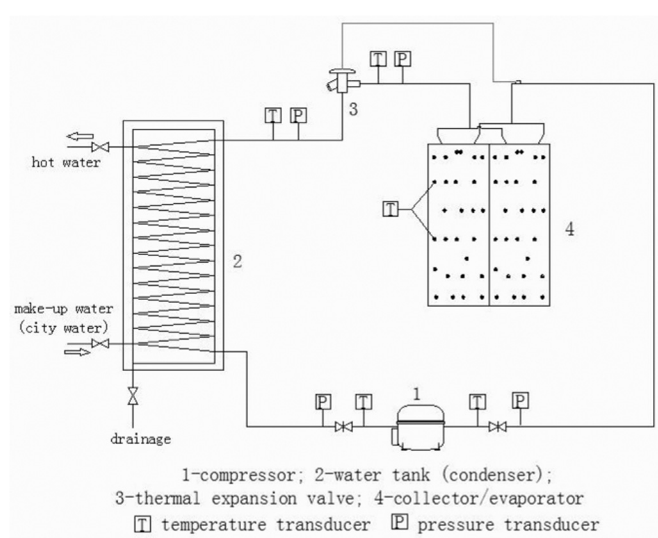

Fig. 1. Schematic of the DX-SAHP system.