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Augmentation of thermal efficiency of the glass evacuated solar tube collector with coaxial heat pipe with different refrigerants and filling ratio

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ABSTRACT

Modified coaxial heat pipes have been designed and manufactured to improve the thermal performance of the glass evacuated solar collectors. Heat pipes were made up of two concentric copper tubes so that the annulus volume space between the concentric tubes was charged with refrigerant. In addition, the air as the working fluid at four different mass flow rates 0.0051, 0.0062, 0.007 and 0.009 kg/s flows through the inner tube of the heat pipe to the flow through the annulus between the heat pipe and glass evacuated solar tubes. The effect of the tilt angle of the evacuated tube on thermal performance of the evacuated solar tube collector was examined to obtain the optimum tilt angle during the experiments period. The influence of filling ratio for the two types of refrigerant R22 and R 134a on the thermal efficiency of the coaxial heat pipe solar collector at filing ratio range from 30% to 60% was conducted experimentally. Results show that the maximum increased in the thermal efficiency reached 67% corresponding to without heat pipes at mass flow rate 0.009 kg/s. The experiment results showed similarity between the two refrigerants.

1. Introduction

Solar energy has received wide interest globally as a promising energy source. Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to working fluid. The working fluid (usually air, water, or oil) flows through the collector [1]. The evacuated tube and the flat plate are the most commonly used solar collectors for domestic heating applications and integrated in desalination system [2–4]. Among stationary solar collectors, all-glass evacuated tube solar collectors (ETSCs) are widely used due to its easy installation, good thermal performance, reliability, transportation and cost-effectiveness [5–8].

Two different types of internal concentrator augmented solar collectors with either an evacuated or non-evacuated direct flow or heat pipe have been examined by Nkwetta et al. [9]. The results showed that the heat pipe enhancement the performance of both evacuated and non-evacuated pipe concentrators. Shukla et al. [10] stated that, the two most widely used solar collectors in domestic water heating are Heat-pipe ETCs and U-tube-glass ETCs.

Past research has focused mainly on low-temperature evacuated tube solar collectors for domestic water heating rather than moderate- and high-temperature applications [11–15]. The optimal tilt-angle of flat plate collectors was widely investigated In the past two decades by many researchers [16–19] while for all-glass evacuated tube solar collectors, such work was scarcely studied. Different types and applications of solar collectors have been studied by several authors. Kalogirou [20] presented various types of solar thermal collectors and the applications where these types can be used. His study showed the solar collectors provide significant environmental and financial benefits and should be used whenever possible.

Theoretical analysis and experimental study was performed by Liang et al. [21] investigating the performance of the filled-type evacuated tube with U-tube. The effects of the heat loss coefficient and the thermal conductivity of the filled layer on the thermal performance of the evacuated tube were studied. Their results showed that the filled-type evacuated tube with U-tube has a favorable

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Nomenclature

A	surface area of the solar collector (m^2)
C_p	specific heat capacity (J/kg K)
D	inner diameter of the evacuated tube (m)
I	solar radiation intensity (W/m^2)
m°	air mass flow rate (kg/s)
T	temperature (°C)
ΔT	temperature difference, [$T_o - T_{in}$] (°C)
Greek symbols	
η	thermal efficiency
β	tilt angle (degree)
γ	Azimuth angle (°)
φ	latitude angle (°)
δ	declination angle (°)
ω	solar hour angle (°))
ϕ	filling ratio (%
Subscripts	
a	ambient
c	condenser section
evp	evaporator section
in	tank inlet
o	tank outlet

thermal performance and good agreement was found between the modelling predictions and previous experimental data. Tang et al. [22] developed a mathematical procedure to estimate the daily collectible radiation on single tube of all-glass evacuated tube solar collectors. The effect of different parameters such as collector type, central distance between tubes, size of solar tubes, tilt and azimuth angles, use of diffuse flat reflector (DFR) on the annual collectible radiation on a tube have been studied. The results revealed that the use of DFR can significantly improve the energy collection of collectors. The results also showed that all-glass evacuated tube solar collectors should be generally mounted with a tilt-angle less than the site latitude in order to maximize the annual energy collection. Shah et al. [23] investigated numerically the heat transfer and flow structures inside glass evacuated tubular collectors. Their study covered tube lengths from 0.59 m to 1.47 m with five different inlet mass flow rates varying from 0.05 kg/min to 10 kg/min with a constant inlet temperature of 333 K. The results showed that the collector with the shortest tube length achieved the highest efficiency and the optimal flow rate was around 0.4–1 kg/min. Zambolin et al. [24] presented a comparative test on standard glazed flat plate collector and direct flow evacuated tube collector with external compound parabolic concentrator (CPC) reflectors installed in parallel and tested at the same working conditions. Zhen et al. [25] investigated experimentally the thermal performance of the evacuated tube solar air heaters with simplified compound parabolic concentrator and concentric tube heat exchanger. The results showed that the solar air collector has excellent high temperature collecting performance, even in the winter. With the increase of air temperature, thermal efficiency reaches 0.35 at an air temperature of 150 °C, and 0.21 at an air temperature of 220 °C. Few studies related to all-glass evacuated tube air heater for heat-temperature applications have been done. An experimental study and numerical simulation have been carried out by Zhen et al. [26] concerning a novel all-glass evacuated tubular solar air heater with simplified CPC. The Calculated and experimental results demonstrate that this experimental system can provide heated air exceeding 200 °C in the summer. A numerical study was carried out by Morrison et al. [27] investigating the performance of a water-in-glass evacuated tube solar pre-heater for water circulation through long single-ended thermosyphon tubes. The numerical simulations have shown the existence of inactive stagnant region near the sealed end of the tube which influences the operation of the tube inside the collector. Morrison et al. [28] developed their numerical model of the heat transfer and fluid flow inside a single-ended evacuated tube. The Flow measurement using Particle Image Velocimetry (PIV) has been undertaken to validate the numerical model. The results showed that the natural convection flow rate in the tube was high enough to disturb the tank's stratification. Also it was found that the tank temperature and the circumferential heat distribution strongly affect the circulation the flow structure and the flow rate through the tubes. Budihardjo et al. [29] investigated numerically the natural circulation flow rate through single ended water-in-glass evacuated tubes mounted over a diffuse reflector. A correlation for the circulation flow rate was developed in terms of solar input, tank temperature, collector inclination and tube aspect ratio. Hayek and Assaf [30] investigated experimentally the overall performance of two kinds of evacuated tube solar collectors, the water-in-glass tubes and the heat-pipe designs under local weather conditions along the eastern coast of the Mediterranean Sea. The results showed that the heat-pipe based collectors are better than the water-in-glass designs and their efficiency is almost 15–20% higher. Yong et al. [31] investigated numerically and experimentally the thermal performance of a glass evacuated tube solar collector consisting of a two-layered glass tube and an absorber tube by changing the shape of absorber tubes. The results showed that the performance of a solar collector is significantly affected by the shape of the absorber, incidence angle of solar irradiation, and arrangement of collector tubes. Glembin et al. [32] experimentally investigated the effect of the flow rate, diameter of the ETC and the material used on the efficiency of ETC. Nchelatebe et al. [33] experimentally tested concentrated evacuated tube heat pipe solar collectors at a tilt angle of 60° to the horizontal. Different parameters as indoor solar simulated experimental conditions temperature response, collection efficiency, heat loss coefficients and energy collection rates as well as the incident angle modifier (IAM) were recorded and compared at five different transverse angles (0–40°) at 10° increments. The concentrated double-sided absorber evacuated tube heat pipe proves better compared to the concentrated single-sided absorber evacuated tube heat pipe solar collector due to higher outlet temperature with greater temperature differential and improved thermal performance. Experimental investigations based on heat extraction of direct-flow coaxial evacuated-tube solar collectors with and without heat shields have been carried out by Xinyu et al. [34] the experimental analysis showed the evacuated-tube solar collector performed better with a heat shield, especially at higher working temperatures, it is due to the heat loss coefficient was 50.8% lower. Arturo et al. [35] investigated low water temperature in glass evacuated tube solar collector numerically based on two models. The first model was based on boussinesq equation while the other on the variation of properties with temperature. The boussinesq model showed good argument with the experimental results.

The aim of this experimental work is to enhance the thermal performance of glass evacuated tube solar collector by using modified coaxial heat pipe. The refrigerant gains heat form the solar incidence causing vaporization in evaporator section. The refrigerant releases the heat to the inlet air at condenser section. The