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Experimental investigation of thermal performance of an evacuated U-Tube solar collector with ZnO/Etylene glycol-pure water nanofluids

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ABSTRACT

In this paper, the efficiency of an evacuated U-tube solar collector (EUSC) with ZnO/Etylene Glycol-Pure Water (ZnO/EG-PW) as a working fluid was experimentally investigated. 50%–50% EG-PW was used as a base fluid. To prepare the nanofluids ZnO nanoparticles were added to the EG-PW base fluid at different volume concentrations (1.0%, 2.0%, 3.0% and 4.0%). The maximum collector efficiency was obtained at equal working fluid inlet temperature and ambient temperature in all experiments. Moreover, the highest collector efficiency was determined 62.87% for 3.0 vol.% and mass flow rate of 0.045 kg/s that it was 26.42% higher than EG-PW as a working fluid. Also, this value is 5.2% and 6.88% higher than the base fluid for the mass flow rates of 0.03 and 0.02 kg/s, respectively. It was determined also that the thermal conductivity of ZnO/EG-PW nanofluid increases with increasing nanoparticle volume concentration.

1. Introduction

Fossil fuels have side effects for the environment and these types of fuels will be depleted ultimately. For this reason, solar energy is becoming more important day by day. Therefore, many researchers have attributed great importance on developing the thermal performance of solar energy systems. Solar energy is one of the most important and abundant renewable and clear resource for the earth. Solar collectors are also very significant devices that convert the radiation energy absorbed from the sun into usable energy. Today, solar collectors are used to heat water and generate electricity for heating and cooling applications [1]. Evacuated tube solar collectors (ETSC) show better performance at higher temperatures (above 80 °C) and cold climates compared to flat plate ones. Moreover, higher thermal performance can be obtained by selective coating and vacuum insulation which prevent convective heat losses and cylindrical shape of the absorber part [2,3]. Hence, the evacuated tube solar collectors are commonly used for solar thermal utilizations in order to provide either hot water or space heating especially in residential applications including heat pipe and evacuated U-tube solar collectors.

In recent years, the developments in nanotechnology have enabled increased synthesis of nanofluids which are obtained by suspending of nanoparticles having sizes smaller than 100 nm into the conventional heat transfer fluids such as water, oil and ethylene glycol. In this way, improvement of thermophysical properties of heat transfer fluid, enhances the heat transfer characteristics. It was seen from the past studies that conduction heat transfer characteristics of nanofluids were in high quantities [4–7]. Therefore, recent studies concentrate on usability of nanofluids on different engineering applications. Because of the higher heat transfer performance, it has been suggested to use nanofluids as a working fluid in solar collectors which are important in engineering applications. Thus, the most important way of improving the efficiency of the evacuated tube solar collectors is to increase the solar radiation absorption capacity of the working fluid in the collectors [8–12].

Recently, there are numerous studies which propose nanofluids as a collector working fluids in flat plate collectors. Yousefi et al. [8] experimentally analyzed the thermal efficiency of a flat plate solar collector (FPSC) with Al_2O_3/water nanofluid with 0.2% and 0.4% weight concentrations. A great enhancement was obtained in thermal efficiency (28.3%) at a rate of 0.2% nanofluid weight concentration. In addition, another experimental study was conducted by Yousefi et al. [9] about using MWCNT/water nanofluid in a flat plate solar collector; the highest efficiency was obtained for 0.4 wt%

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instead of 0.2%wt. Colangelo et al. [13] indicated that the heat transfer performance of a flat plate collector enhanced by 25% due to the reduction of sedimentation of Al_2O_3/water nanofluid. Moghadam et al. [14] carried out an experimental study for determining the effects of CuO/water nanofluid on flat plate collector efficiency. 21.8% increment in collector efficiency was obtained at a rate of 0.4% volume concentrations and 1 kg/min mass flow rate with 40 nm nanoparticle size. Faizal et al. [15] made an analysis about size reduction of a flat plate solar collector when using MWCNT nanofluids. They reported that 37% size reduction took place in the original size of the collector. Mahian et al. [16] performed an analytical analysis for a mini-channel based flat plate solar collector for Cu/water, Al_2O_3/water, TiO_2/water, and SiO_2/water nanofluids. Calculations were carried out for up to 4% volume concentrations and 25 nm nanoparticle size. The highest outlet temperature and lowest entropy generation were determined with Cu/water nanofluid. Said et al. [10] performed experiments about the performance of the collector by using Al_2O_3/water and Al_2O_3/EG-Pure Water nanofluids as working fluids. It was indicated that the increase in the viscosity and density of the nanofluids were negligible. An experimental investigation made by Michael et al. [17] about CuO/water nanofluid in a FPSC with different mass flow rates. The maximum augmentation obtained in thermal efficiency was 6.3% at a low volumetric concentration that is 0.05%.

Several studies have been conducted about thermal performance of different types of evacuated tube solar collectors. All glass, heat pipe and U-tube ETSC were numerically and experimentally investigated by many researchers [18–25]. The thermal conductivity of the working fluid in solar collector plays vital role on the thermal efficiency. To improve the performance of a solar collector, it is very advantageous to utilize the outstanding thermal conductivity of nanofluids. Hence, the nanoscience is very important for energy conversion technology and systems.

Liu et al. [26] experimentally analyzed an ETSC with an open thermosiphon using CuO/water nanofluid with 50 nm nanoparticle diameter and 1.2 wt%. They reported that the enhancement in maximum and mean efficiencies were 6.6% and 12.4%, respectively. Farjallah et al. [27] numerically investigated the thermal performance of an EUSC. Computational fluid dynamics (CFD) method was used to obtain the thermal efficiency at different operating conditions such as mass flow rate, absorber selectivity and different material properties. The collector efficiency was enhanced about 16% for mass flow rate 0.001 kg/s to 0.003 kg/s and also 18% enhancement obtained with graphite compared to copper fin respectively. An experimental study was carried out by Kim et al. [28] about thermal efficiency of a EUSC by using Al_2O_3/water nanofluid as a working fluid with different nanoparticle sizes and volume concentrations. The highest efficiency was obtained at 1.0% volume concentration and 20 nm nanoparticle size by comparing with pure water. They reported that maximum efficiency of the collector was 72.4%. Tong et al. [29] made an theoretical study in order to compare of EUSC and evacuated heat pipe solar collector. They indicated that the heat pipe collector shows better performance than EUSC with the rate of 8% in efficiency in sunny days. In other respect, performance of EUSC was far superior than that of heat pipe collector in terms of stability and thermal performance on cloudy days. In a subsequent work carried out by Tong et al. [30], MWCNT nanofluid as working fluid was used in a EUSC. Constant heat flux assumption was made since a copper fin was mounted in the U-tube. MWCNT provided higher thermal conductivity by filling it in the air gap of the evacuated tubes. Li et al. [31] used ZnO/distilled water nanofluids having 0.2%, 0.5% and 1.0% volume concentrations in an evacuated tubular solar collector experimental system. They stated that 0.2 vol% ZnO/pure water nanofluid effective choice due to its low viscosity.

Numerous studies have been carried out to improve the performance of solar collectors by using different types of nanofluids as working fluids as indicated above. Most of these studies are about only FPSC. There are limited number of researches about performance of evacuated U-tube solar collectors using nanofluids. Research on the effects of nanofluid and base fluid concentrations in EUSC under different operating conditions on the collector efficiency is also rare. In this regard, the main objective of this study was to experimentally investigate the efficiency of a EUSC with ZnO/EG-PW at different volumetric concentrations and base fluid (antifreeze) with percentage (EG-PW; 50:50%) under the same operating conditions. In addition, the effects of mass flow rate and heat loss on thermal efficiency were determined. The results of evaluations for thermal efficiency were compared with each nanofluid and their base fluids.

2. Experimental analysis

Evacuated tubes are composed of nested two glass tube manufactured high quality borosilicate. To reduce the heat loss from working fluid to the surrounding, vacuum is constituted between the glasses. The U-type evacuated tube solar collectors work based on direct circulation method. These types of collectors include copper pipe networks in the evacuated tubes. Copper pipe collects the heat flux coming from the sun. Therefore, there are cold inlet and hot outlet sections in each tube. The heat collector used in these types of tubes are supported with aluminum. This provides more heat collection by copper with reducing the amount of air in the collector tube and increases the conductive surface.

It is known that total incident solar radiation from the sun is not absorbed from the solar collector because of the transmissivity and reflectivity factors. Therefore, optical efficiency must be considered for thermal efficiency calculations. Optical efficiency can be defined as the ratio of absorbed solar radiation from the working fluid to received solar radiation through its surface. It is a function of the absorptivity α of the absorber, the transmissivity τ of the glass cover and the reflectivity ρ of the reflector.

Photograph of the experimental setup is given in Fig. 1. To compare the efficiency of EUSC using ZnO/EG-PW nanofluid, two collectors at same size and condition were used. The first collector is operated with EG-PW mixture, and the other one with ZnO/EG-PW nanofluid. The tilt angles of the both collectors were arranged at 45° south − facing in Karabük, Turkey having the terrestrial coordinates 41° N and 32° E. Technical data for the collectors used in this study is given in Table 1.

Schematic representation of the experimental setup and cross-sectional view of the U-tube are also given in Fig. 2. The mass flow rate of working fluid was measured with a turbine type flowmeter before entering in the solar collector. A three-way valve that is electrically controlled was placed after the pump to adjust the mass flow rate. The 100 L capacity storage tank having a heat exchanger was installed for each solar collector for the circulation of the working fluid. The inlet temperature was kept constant by using a constant temperature bath having a 1.5 HP compressor capacity for both solar collectors. Inlet and outlet temperatures of the working fluid of the solar collector was measured with T-type thermocouples having measurement range −10 to 250 °C. The thermocouples were calibrated by using a precise mercury thermometer. Frozen and boiled pure water were used in the calibration process and then calibration equations were determined for each thermocouple. Solar radiation intensity was measured with a first class pyranometer EKO-MS410 solar radiation sensor with total uncertainty 0.34%. An ambient temperature sensor NESA TA-A, sheltered from direct irradiation and wind, was installed in the experimental setup. Operating temperature range of the sensor