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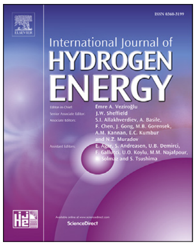

Effect of using nanofluids on efficiency of parabolic trough collectors in solar thermal electric power plants

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ABSTRACT

In this paper, forced convection heat transfer nanofluid flow inside the receiver tube of solar parabolic trough collector is numerically simulated. Computational Fluid Dynamics (CFD) simulations are carried out to study the influence of using nanofluid as heat transfer fluid on thermal efficiency of the solar system. The three-dimensional steady, turbulent flow and heat transfer governing equations are solved using Finite Volume Method (FVM) with the SIMPLEC algorithm. The results show that the numerical simulation are in good agreement with the experimental data. Also, the effect of various nanoparticle volume fraction on thermal and hydrodynamic characteristics of the solar parabolic collector is discussed in details. The results indicate that, using of nanofluid instead of base fluid as a working fluid leads to enhanced heat transfer performance. Furthermore, the results reveal that by increasing of the nanoparticle volume fraction, the average Nusselt number increases.

Introduction

Energy production and management are essential problems of our society because of the existence of many environmental problems as air pollution, global warming, climate change and water pollution [1,2]. The conventional energy sources, as fossil fuels (oil, coal and natural gas), will be depleted in some decades and also creates high carbon dioxide emissions [3,4]. Thus, the use of renewable energy sources seems to be one of the most promising solutions in order to produce clean energy. Use of renewable energy resources, on the other hand, can lead to reduction in fossil fuel consumption and in turn protection of the environment. Solar energy is one of the largest renewable energy resources. The greatest advantage of the solar energy over alternative forms of fossil energy resources is that it is clean and abundant. Solar energy is able to be converted into thermal energy using trough collector system and solar concentrators, and then to electrical energy using a steam turbine [5,6]. Power generation systems based on parabolic solar collectors is well established and commercialized all over the world in the past two decades [7]. Parabolic trough collector is considered as a suitable device to derive power generation systems with operating temperatures up to 400 °C [8]. An integrated approach for the production of hydrogen and methane by catalytic hydrothermal glycerol reforming coupled with parabolic trough solar thermal collectors was proposed by Azadi [9]. Bouhal et al. [10] investigated the influence of the domestic hot water load profiles and the collector's technology (Flat Plate FPC,

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Evacuated Tube ETC and Compound Parabolic CPC) on the performance of forced circulation solar water heaters operating under various climatic conditions. An integrated model system which is consisted of a solar pond, flat-plate collectors and an organic Rankine cycle (ORC) was designed by Erden et al. [11] to determine the thermal, electricity and hydrogen generation performances. The flat-plate collectors assisted by a solar pond to enhanced the thermal performance of the system in order to generate electrical energy with ORC. Direct steam generation in parabolic troughs or linear fresnel solar collectors for replacing thermal oils and molten salts as heat transfer fluids in concentrated solar power plants was studied by Coco-Enríquez et al. [12]. Hamed et al. [13] evaluated the energy and the exergy performance of an integrated phase change material (PCM) solar collector with latent heat storage in transient conditions numerically. They developed a theoretical model based on the first and the second laws of thermodynamics to predict the thermal behavior of the solar system. Lu et al. [14] studied the nonuniform heat transfer model and performance of solar parabolic trough receiver theoretically due to the energy balances between the heat transfer fluid, absorber tube, glass envelope and surroundings. A detailed numerical model based on Large Eddy Simulations (LES) models for simulating the fluid flow and heat transfer around a solar parabolic trough collector and its receiver tube was presented by Hachicha et al. [15]. Ghasemi et al. [16,17] proposed segmental rings for heat transfer enhancement of solar parabolic trough collector. The effects of segmental rings layouts on the heat transfer and system performance for non-uniform heat flux were discussed. The heat transfer and pressure drop characteristics of parabolic solar collector with solid rings and porous rings were numerically studied using finite volume method by Ghasemi and Ranjbar [18,19]. Water, ethylene glycol, and engine oil are the commonly used as working fluids in heat exchangers. However, the heat transfer performance is limited due to the thermal conductivity and specific heat of the fluids. Hence, to improve heat transfer performance, it is necessary to increase the thermal conductivity and/or specific heat of the fluids. This can be achieved by adding an appropriate amount of solid nanoparticles having high thermal conductivity to a base fluid for use as a heat transfer fluid. Nanofluids were first proposed by Choi [20] who found that nanoparticles raise the thermal conductivity of the coolant, thus improving the heat transfer performance. The effect of using nanofluid as working fluid on thermal performance of solar parabolic trough collector was investigated numerically [21,22]. Heat transfer characteristics of R600a with nanoparticles in smooth and flattened tubes were studied experimentally [23-25]. The effect of CuO nanoparticles in distilled water on heat dissipation from electronic components was investigated numerically by Ghasemi et al. [26]. They used Computational Fluid Dynamics (CFD) simulations to study the rectangular and circular cross-sectional shaped heat sinks. Also, Ghasemi et al. [27] investigated the cooling performance of heat sinks with different hydraulic diameter of channel experimentally. The thermal performance of a triangular shaped minichannel heat sink heat sink using alumina-water nanofluid as a coolant with different volume fractions was examined by Ghasemi et al. [28]. They concluded that when the volume fraction of nanoparticles increases under the extreme heat flux, the thermal resistance of the heat sink reduces. Recently, an experimental investigation on cooling performance of using nanofluid to replace the pure water as the coolant in a minichannel heat sink was conducted by Ghasemi et al. [29]. The experimental results showed that the nanofluid cooled heat sink outperforms the water-cooled one, having significantly higher average heat transfer coefficient.

The aim of the current study is to examine the thermal performance of solar parabolic trough collector with nanofluid under turbulent flow condition. The numerical simulation is implemented by using Computational Fluid Dynamics (CFD). The effect of different nanoparticles volume fraction on flow and heat transfer characteristics is investigated.

Model description

The schematic of the solar parabolic system is shown in Fig. 1. The solar radiation is concentrated onto the line circular receiver by a parabolic concentrator. The concentrated radiation is then transmitted to the working fluid by convection heat transfer in the receiver. The heat transfer characteristics of the parabolic trough collector can be improved by using nanofluid as heat transfer fluid inside the receiver of collector. Also, Fig. 2 shows the nanofluid flowing in the receiver tube of solar collector schematically.

Governing equations

The governing equations for forced convection of incompressible, steady and turbulent flow in receiver of parabolic solar collector are given as [30]:

Continuity equation:

$$\nabla \cdot (\rho \mathbf{V}) = 0 \tag{1}$$

where $\mathbf{V} = (V_R, V_\theta, V_Z)$ is the velocity vector.

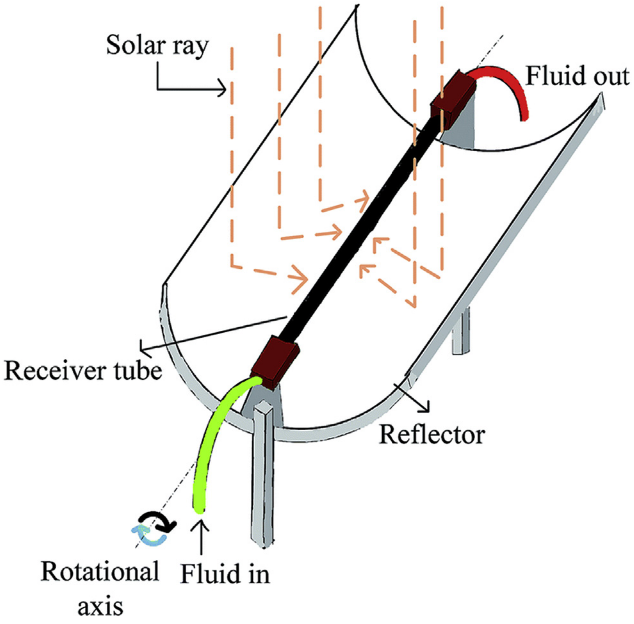

Fig 1 – Solar parabolic system.

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