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GMDH modeling and experimental investigation of thermal performance enhancement of hemispherical cavity receiver using MWCNT/oil nanofluid

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ABSTRACT

Nowadays, nanofluids are introduced as an effective technique for enhancing the thermal efficiency in solar collectors. In this work, the MWCNT/oil nanofluid with 0.8% nanoparticle mass fraction is investigated experimentally in a solar dish concentrator coupled to a hemispherical cavity receiver. The main objective of this research is to examine the effect of the nanofluid application for improving the solar thermal performance of the hemispherical cavity receiver. The results revealed that thermal efficiency of the hemispherical cavity receiver has averagely increased equal to 12.93%, using application of the MWCNT/oil nanofluid compared to the application of the basefluid. In the steady state periods, the average thermal efficiency of 76.23% and 67.50% were calculated for the hemispherical cavity receiver using the MWCNT/oil nanofluid and pure oil, respectively. It was conducted that the receiver heats gain and the thermal efficiency of the cavity receiver has a similar trend with the working fluid difference temperature. Two experimental models were suggested based on the overall performance versus $\frac{T_{in}-T_{amb}}{I_{beam}}$ for the MWCNT/oil nanofluid and the pure oil. Finally, it is found that the use of the examined nanofluid is able to enhance the thermal performance of the examined collector about 13%. Also, in this study, group method of data handling (GMDH) artificial neural networks is applied in order to model the dependency of thermal efficiency and the cavity heat gain of the Hemispherical Cavity Receiver on the mentioned factors.

1. Introduction

In the past few years, utilization of nanofluids are significantly increasing in thermal apparatus as a working fluid, since they have favorable thermal characteristics. The first introduction of the term nanofluid goes back to 1995 presented by Choi and the nanoparticles' suspension into a base fluid like oil or water was considered with the properties of diameters between 1 and 100 mm. With the help of using nanofluids, the heat transfer coefficient and thermal conductivity increase considerably, which can be enumerated as two main benefits resulted in enhancing the rates of heat transfer.

Murshed et al. (2008) reviewed thermophysical and electrokinetic properties such as thermal diffusivity, convective heat transfer, and electrokinetic properties of nanofluids. Duangthongsuk and Wongwises (2008) summarized the most cited models for prediction of the thermophysical properties of the nanofluid. Also, they experimentally calculated the thermal heat transfer coefficient in a double-tube counter flow heat exchanger. Philip and Shima (2012) reviewed thermal properties of nanofluids especially the important material properties that affect the thermal properties of nanofluids. Maxwell (1954) presented a model for the effective thermal conductivity of nanofluids depends on the thermal conductivities of both phases and volume fraction of solid. Also, some other models were suggested for the effective thermal conductivity of nanofluids (Hamilton and Crosser, 1962; Hui et al., 1999; Xuan and Li, 2000). Zhu et al. (2007) reported that the thermal conductivity of CuO/water increased with increasing nanofluid volume fraction. Karthikeyan et al. (2008) observed thermal conductivity of CuO/water + EG nanofluid increased compared to the pure basefluid. Duangthongsuk and Wongwises (2010) compared the results of the heat transfer performance of TiO_2/water nanofluid using experimental and theoretical calculated thermophysical properties of the investigated nanofluids. Nanoparticles with average diameters of 21 nm at volume fraction in the range of 0.2–1% were considered. They reported that the results of using presented model for Nu number

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prediction are comparable with the results of the experimental data.

Rudyak and Minakov (2018) investigated the thermophysical properties of nanofluids including viscosity, thermal conductivity and heat transfer. Different kinds of nanoparticle were considered including SiO_2, Al_2O_3, ZrO_2, TiO_2, and CuO. They conducted that the viscosity increases with decreasing the particle size while the thermal conductivity increases with increasing the particle size. Eastman et al. (1996) studied thermal conductivity of different nanofluid including Al_2O_3/water, CuO/water, and Cu/oil, using transient hot-wire method for the different volume fraction of nanoparticles. Wang et al. (1999) considered thermal conductivity of different nanofluids including Al_2O_3/water + EG, and CuO/water + EG, using the steady-state method at different particle volume percentage. They suggested the microscopic motion of nanoparticles might cause improved thermal conductivity of nanofluids. He et al. (2012) experimentally considered thermophysical properties of nanofluids as the phase change materials (PCMs). They concluded that the thermal conductivity of nanofluid increased at a volume fraction of 1.130%. Also, they reported the viscosity of nanofluid increased by increasing nanofluid volume fraction. Generally, it was concluded that the thermal conductivity of common working fluids increases by adding nanoparticles.

Lu and Fan (2008) numerically investigated the effect of nanoparticle size and volume fraction on the thermophysical properties of nanofluid including thermal conductivity, and viscosity using a new method. Results reveal that the thermal conductivity of nanofluid increased by decreasing nanoparticle size and increasing nanofluid volume fraction. Also, they concluded that the increasing viscosity can improve heat transfer capability of the nanofluids. Anoop et al. (2009) experimentally investigated the effect of the nanoparticle size in a developing region of tube flow with constant heat flux. Al_2O_3/water was used as the nanofluid. They concluded that the nanofluid has higher thermal properties compared to the basefluid, while nanofluid with 45 nm particles showed higher heat transfer coefficient than that with 150 nm particles. Safaei et al. (2014) numerically modeled a 90∘ elbow using the two-phase model with Cu/water as the working fluid. The evaluation into the effects of various parameters including shear forces, turbulence, and the concentration and size of micro and nanoparticles on fluid erosion behavior was presented. It was concluded that the erosion rate has a direct relation with the nanoparticle size and concentration as well as nanofluid velocity. Safaei et al. (2014) numerically studied a forward-facing step using MWCNT/ water as the working fluid in the turbulent flow condition. The evaluation into the effects of various parameters including heat fluxes, Reynolds numbers, and nanoparticles volume fractions on the hydraulic heat transfer behavior of the nanofluid was presented. According to the results, the nanoparticle volume fraction and the Reynolds number have a direct relation with the heat transfer coefficient of the nanofluids.

Thermal properties of nanofluids including thermal conductivity, specific heat capacity, density, and viscosity depend on the stability of nanofluids. Classification of nanofluids is a significant character to investigate the stability of nanofluids. Stability of nanofluid can be increased by application different mechanical techniques such as usage of ultrasonic device for nanofluid preparation, or chemical techniques such as the application of surfactant during nanofluid preparation. Ilyas et al. (2017) presented a review on the stability of nanofluids. Mukherjee and Paria (2013) reviewed preparation and stability of nanofluids. Hwang et al. (2007) investigated different types of nanoparticles such as multi-walled carbon nanotube (MWCNT), fullerene, copper oxide, and silicon dioxide for improving the thermal properties of the basefluid such as DI water, ethylene glycol, and oil. Thermal conductivities of the nanofluids and their stability were considered.

On the other hand, the renewable energy sources are the important subject for research due to the serious environmental problems such as the fossil fuel depletion, emissions of CO, CO_2, global warming, and ozone depletion. Solar energy is accounted as a favorable renewable energy. Parabolic dish concentrator is a kind of efficient solar collector for converting the radiation energy to thermal energy or power producing. There are different kinds of an absorber in the dish concentrators (Ho and Iverson, 2014; Pavlovic et al., 2017). The cavity receivers due to their special structure have the more efficiently compared to other kinds of dish absorber (Günther et al.). Some researchers have considered the dish collectors using cavity receivers (Tu et al., 2014; Stadler et al., 2017). Kaushika and Reddy (2000) optimized a dish collector using a cavity receiver. They designed and developed a dish concentrator with the modified cavity receiver. Moreover, Reddy et al. (2015) applied a numerical model in order to evaluate the performance of a solar dish concentrator with a modified receiver. They gave the emphasis in the prediction of the Nusselt number calculation under mixed convection conditions, as well as in the calculation of the cavity radiation thermal losses. In another study with the modified receiver, Chang et al. (2015) examined the use of a glass cover in the cavity opening. The used a numerical model and they found that the secondary reflections can improve the total performance of the collector. Le Roux et al. (2014) and Loni et al. (2016a, 2016b) optimized a dish collector using cavity receivers. Their results revealed the surface temperature of the cavity receiver increased by increasing diameter of the inner cavity tube. In some other studies, the researchers (Loni et al., 2016c, 2017) have investigated cavity receivers as the heat source of an electricity generation source. They optimized different operational and structural parameters of the studied solar system. Pavlovic et al. (2017) examined a cavity receiver using the smooth and corrugated tube. They observed the thermal performance increased by application of the corrugated tube. Furthermore, there are numerous papers which investigates the nanofluid-based solar cavity receivers numerically (Pavlovic et al., 2017; Loni et al., 2017). Loni et al. (2017) calculated the performance of a solar dish concentrator coupled to a cavity receiver by the application of ANN methodology. A good validation was observed for the calculated results using ANN method.

On the other hand, the application of nanofluids as the solar working fluid is researched as a reliable way of improving the thermal performance in the solar collectors (Hawwash et al., 2018; He et al., 2015). Boyaghchi et al. (2015) modeled a flat plate collector using CuO/water nanofluid. They investigated the exergy, energy, and exergy-economic analysis on the studied system. Kim et al. (2016) numerically considered the influence of the different nanofluids as the solar working fluid of a U-tube solar collector. The results indicate that the CO_2 generation reduced by application of nanofluid. Mahian et al. (2014) examined a nanofluid-based flat plate collector with alumina/ water-ethylene glycol. They finally found that the outlet temperature of the solar system is higher with the application of the nanofluid compared to the base fluid for all the examined cases with different nanofluid shapes. Otanicar et al. (2010) experimentally and numerically investigated the thermal performance of a microscale direct absorption solar collector (DASC) using the different nanofluids such as carbon nanotubes, graphite, and silver. Mwesigye et al. (2015) numerically research the application of the Al_2O_3/synthetic oil nanofluid as a solar working fluid of a parabolic trough collector. The results reveal that the thermal efficiency of the investigated collector can be increased by up to 7.6% using nanofluids. Finally, the application of nanofluid in the dish concentrator using cavity receiver is investigated only by few researchers as follows (Loni et al., 2018b; Madadi Avargani et al., 2015). Madadi Avargani et al. (2015) investigated energetically and exergetically the performance of the Al_2O_3/water nanofluid in a parabolic shape solar dish concentrator. According to their results, the use of the nanofluid enhances both the energy and the exergy performance of the system. Loni et al. (2018) performed an experimental work with the MWCNT/oil nanofluid in a solar dish concentrator coupled to a cavity receiver with a cylindrical shape. They found that there is an enhancement in the thermal performance of the solar collector with the application of the nanofluid as the heat transfer fluid in the system.

It is evident from the previous literature review that there is lack of experimental studies about the nanofluid-based solar dish concentrators

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