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# Performance analysis of a minichannel-based solar collector using different nanofluids

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## ABSTRACT

In this paper, an analytical analysis has been performed to evaluate the performance of a minichannel-based solar collector using four different nanofluids including Cu/water, $Al_2O_3$/water, $TiO_2$/water, and $SiO_2$/water. The analysis of first and second laws is conducted for turbulent flow by considering the constant mass flow rate of nanofluid. The results are presented for volume fractions up to 4% and nanoparticle size of 25 nm where the inner diameter of the risers of flat plate collector is assumed to be 2 mm. Analysis of the first law of thermodynamics reveals that $Al_2O_3$/water nanofluids show the highest heat transfer coefficient in the tubes while the lowest value belongs to $SiO_2$/water nanofluids. The highest outlet temperature is provided by Cu/water nanofluids, and after that $TiO_2$/water, $Al_2O_3$/water, and $SiO_2$/water nanofluids are in ranks of second to fourth. The results of second law analysis elucidate that Cu/water nanofluid produces the lowest entropy generation among the nanofluids. It is found that although the effective thermal conductivity of $TiO_2$/water nanofluids is less than $Al_2O_3$/water nanofluids, but the entropy generation of $TiO_2$/water is lower than $Al_2O_3$/water. Finally, some recommendations are given for future studies on the applications of nanofluids in solar collectors.

## 1. Introduction

Among the solar energy technologies, flat-plate solar collectors are the most popular devices that can be used for heating of residential and public buildings. One of the aims which is considered by designers is the increase of outlet temperature of the solar collectors [1]. Using of nanofluids may be a solution to increase of outlet temperature in solar collectors. Nanofluids are mixtures of common fluids such as water and ultra-fine solid particles with the size of 1–100 nm. The application of nanofluids is developing day by day, especially in renewable energy systems. Here, a literature review is presented by focusing on the application of nanofluids in solar collectors. As one of the first studies on using of nanofluids in solar collectors, Yousefi et al. [2] conducted tests on a flat plate solar collector using $Al_2O_3$/water nanofluids with and without surfactant and in different weight fractions of nanoparticles, i.e. 0.2% and 0.4%. Their findings reveal that the weight fraction of 0.2% is the optimal weight fraction from the highest thermal efficiency viewpoint. They also found adding surfactant to the nanofluid will increase the efficiency considerably (by 15%). In the following of this work [2], Yousefi et al. [3] found that use of multi walled carbon nanotube/water nanofluids with the weight fraction of 0.4% leads to a higher efficiency compared to the concentration of 0.2%. In another work, Yousefi et al. [4] concluded that the pH of nanofluids can be an important factor in the increase of collector efficiency so that when the pH is close to the isoelectric point the efficiency is maximized. Tyagi et al. [5] investigated theoretically the potential of alumina/water nanofluids to improve the performance of non-concentrating direct absorption solar collectors. Their results show that the thermal efficiency of nanofluid-based direct absorption solar collector is about 10% higher than common flat plate collectors.

Khullar et al. [6] examined the efficiency of a nanofluid-based concentrating parabolic solar collector using aluminum nanoparticles and Therminol VP-1 as the base fluid. Their results show that the nanofluid based solar collector has higher efficiency (by 10%) compared to conventional collectors. In a numerical study, Nasrin et al. [7] solved the natural convection of $Al_2O_3$/water nanofluids in the space between the glass cover and sine-wave absorber of a flat plate collector. They concluded that the heat transfer can be enhanced by an increase in the number of waves on the absorber.

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**Nomenclature**

| | |
|---|---|
| $A_c$ | collector surface area ($m^2$) |
| $A_e$ | surface area of edges ($m^2$) |
| $Be$ | Bejan number |
| $C$ | constant defined in Eq. (14) |
| $C_p$ | heat capacity (J/kg K) |
| $D$ | outer diameter of tube (m) |
| $D_i$ | inner diameter of tube (m) |
| $d_p$ | size of particle (m) |
| $\dot{E}_d$ | destroyed exergy rate (W) |
| $\dot{E}_l$ | leakage exergy rate (W) |
| $\dot{E}_{d,\Delta T_s}$ | destroyed exergy rate due to the temperature difference (W) |
| $\dot{E}_{d,\Delta P}$ | destroyed exergy rate due to pressure drop (W) |
| $\dot{E}_{d,\Delta T_f}$ | destroyed exergy rate due to the flow of nanofluid in the collector (W) |
| $F$ | standard fin efficiency |
| $F'$ | collector efficiency factor |
| $F_R$ | removal heat factor |
| $f$ | friction factor |
| $g$ | gravity acceleration ($m^2/s$) |
| $G_t$ | solar radiation on solar collector ($W/m^2$) |
| $h_{fi}$ | heat transfer coefficient of fluid ($W/m^2$ K) |
| $h_L$ | total head loss (m) |
| $h_W$ | heat transfer coefficient of wind ($W/m^2$ K) |
| $k$ | thermal conductivity (W/m K) |
| $K_L$ | loss coefficient |
| $L_r$ | length of riser (m) |
| $\dot{m}$ | total mass flow rate (kg/s) |
| $\dot{m}_r$ | mass flow rate in riser (kg/s) |
| $n$ | number of risers |
| $N$ | Avogadro number |
| Ng | number of glass covers |
| Nu | Nusselt number |
| $N_g$ | number of glass covers |
| $P$ | pressure (Pa) |
| Pr | Prandtl number |
| $Q_u$ | absorbed heat by plate (W) |
| Re | Reynolds number |
| $S$ | received solar radiation to plate ($W/m^2$) |
| $\dot{S}_{gen}$ | entropy generation rate (W/K) |
| $T_a$ | ambient temperature (K) |
| $T_p$ | mean temperature of plate (K) |
| $U_b$ | heat loss coefficient of bottom ($W/m^2$ K) |
| $U_e$ | heat loss coefficient of edges ($W/m^2$ K) |
| $U_L$ | overall heat loss coefficient ($W/m^2$ K) |
| $U_t$ | heat loss coefficient of top ($W/m^2$ K) |
| $V_w$ | wind velocity (m/s) |
| $W$ | tube spacing (m) |
| $\beta$ | tilt angle of solar collector |
| $\mu$ | viscosity (kg/m s) |
| $\rho$ | density ($kg/m^3$) |
| $\tau$ | constant defined in Eq. (13) |
| $\delta_c$ | thickness of absorber plate (m) |
| $\kappa_B$ | Boltzmann constant ($m^2$ $kg/s^2$ K) |
| $\varepsilon/D_i$ | relative roughness |

*Subscripts*

| | |
|---|---|
| *ave* | average |
| *p* | nanoparticles |
| *f* | base fluid |
| *nf* | nanofluid |
| *in* | inlet |
| *out* | outlet |

The results of experiments conducted by Jamal-Abad et al. [8] show that using Cu/water nanofluids with weight fraction of 0.05 wt% instead of pure water leads to a higher efficiency as much as 24%. Faizal et al. [9] evaluated the potential of four different water based nanofluids, including CuO/water, $SiO_2$/water, $TiO_2$/water and $Al_2O_3$/water to reduce the size of solar collectors, and therefore economic and environmental benefits. They concluded that CuO/water nanofluids are the best option to reduce the size of solar collectors. In another work, Faizal et al. [10] studied the potential of $Al_2O_3$/water nanofluids to reduce the size of solar collectors using the data available in the literature. Nasrin and Alim [11] simulated the natural convection of two nanoparticles, including Ag and CuO suspended in water for application in solar collectors.

To solve the problem of sedimentation of nanofluids in the solar collectors, Colangelo et al. [12] designed a new flat plate collector. They stated that the heat transfer coefficient increases by 25% using $Al_2O_3$/water nanofluid and the new design. Rahman et al. [13] simulated the natural convection in a triangular shaped collector using three different nanofluids, including Cu/water, $Al_2O_3$/water, and $TiO_2$/water. The study shows that the heat transfer rate is enhanced by 24% by using Cu/water nanofluid with volume concentration of 10% in comparison with water. Parvin et al. [14] analyzed the natural convection and entropy generation due to Cu/water and Ag/water nanofluids in a direct absorption solar collector. They found that with an increase in the volume fraction of nanoparticles and the Reynolds number the entropy generation increases. They offered correlations for Nusselt number and collector efficiency where the Reynolds number is less than 1000, and volume fraction of nanoparticles is less than 3%. Alim et al. [15] investigated the entropy generation due to the flow of four different nanofluids i.e. $Al_2O_3$/water, CuO/water, $SiO_2$/water, $TiO_2$/water with volume fractions up to 4% in a solar collector. Their results disclose that by using CuO/water nanofluid instead of water, the heat transfer coefficient rises up to 22.15% while the entropy generation is reduced by 4.34%. In this work, the pressure drop contribution to entropy generation is neglected. The readers also can refer to two review papers on the application of nanofluids in solar energy and solar collectors [16,17]. Also, a review is conducted by Mahian et al. [18] on the entropy generation in thermal systems. The channels can be classified based on the size into three groups including conventional channels, minichannels, and microchannels. The channels with hydraulic diameter between 0.2 mm and 3 mm are called minichannels [19].

The main aim of the present work is to investigate the effects of using four different nanofluids including Cu/water, $Al_2O_3$/water, $TiO_2$/water, and $SiO_2$/water on the performance of a minichannel flat plate solar collector. The first and second laws of thermodynamics are considered to assess the collector where the mass flow rate is constant and diameter of risers is 2 mm. The contribution of pressure drop is taken into account in the entropy generation analysis. The results of this work elucidate that which type of nanofluids can be used to have the best performance and output in a minichannel based solar collector.

## 2. Problem description

A minichannel based solar collector is considered in this study. The specifications of the collector are given in Table 1. It is assumed that the risers are parallel and the centerlines of absorber