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# Computational analysis of SWCNH nanofluid-based direct absorption solar collector with a metal sheet

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ABSTRACT

In the current study, thermal efficiency of a direct absorption solar collector, using single-walled carbon nanohorn (SWCNH)-water nanofluid as the working fluid, is numerically investigated. An in-house, parallel, multi-relaxation time, lattice Boltzmann method (MRT-LBM) code is developed, and the effects of nanofluid concentration, presence of aluminum absorber sheet and its position on design parameters of the collector are discussed. Results are discussed for two cases: with and without the absorber plate, and the effects of nanoparticles concentration ($\varphi$), nanofluid's mass flow rate ($\dot{m}$), collector height (H), absorber plat position (Y) and radiation heat flux () on efficiency and maximum temperature of the collector are studied. The importance of these parameters have been proven and it was shown that, in some cases, optimal working conditions exist. It has been demonstrated that low concentrations of nanoparticles can improve the collector efficiency, while its larger amounts can lead to negative performance. The absorber plate highly improved the collector performance especially when the working fluid is the pure water. Simultaneous use of nanofluid with the absorber plate is not recommended except for low mass flow rates. Also, the bottom of the collector is the best position for the absorber plate in order to gain the maximum efficiency.

## 1. Introduction

Solar collector is a kind of heater using solar radiation, as a renewable energy resource, to heat a working fluid (usually water) without the use of fossil fuels. These solar heating systems are attractive due to their high efficiency and low cost beside their renewable features. The heated working fluid of solar collectors can be used for power generation in a power plant or be implemented directly for heating applications such as a swimming pool, residential buildings, solar still (Mahian et al., 2017) or even in cooling applications such as an adsorption refrigeration system (Kalogirou, 2004). Different designs of solar collectors are commonly used in the field of renewable energy, where flat-plate collector (Sun et al., 2016), parabolic trough collector (Mahian et al., 2013), evacuated tube collector (Ersöz, 2016) and bowl collector are some kinds of them.

For the first time, the concept of direct absorption solar collectors (DASC) used in 1980s to enhance thermal efficiency of a flat-plat direct absorption receiver as a solar radiation absorber (Bohn and Green, 1989; Arai et al., 1984). After that, continuous research studies have been conducted to design more efficient DASCs with different geometries and various working fluids. The conventional fluids used in solar collectors have relatively weak solar absorption characteristics over the solar spectrum and water could only absorb approximately 13% of the solar energy (Otanicar et al., 2010). Nanofluids including nanoparticles can enhance the absorption characteristics of the working fluid by scattering of the incident solar radiations and improving the absorption coefficient of the fluid. In addition, nanofluids, in comparison with the base fluid, have higher thermal conductivity and larger surface area to volume ratio and increase the heat transfer between nanoparticles and the base fluid. Nanofluids as the absorber fluid are commonly implemented in solar collectors (Karami et al., 2016), and can enhance the thermal and optical properties of conventional fluids with subsequent enhancement in performance of solar collectors. Hence, more compact design of collectors is possible. As a result, study of different nanofluids and their effects on solar collectors' performance have been the subject of many studies in this area (Mahian et al., 2013; Mahian et al., 2014; Mahian et al., 2015; Bazdidi-Tehrani et al., 2018; Sarsam et al., 2017; Sarsam et al., 2016). There are also many review articles about applications of nanofluids in solar energy systems and among them, (Khanafer and Vafai, 2018; Elsheikh et al., 2018; Bhalla and Tyagi, 2018; Muhammad et al., 2016; Raj and Subudhi, 2018; Ahmad et al., 2017; Gorji and Ranjbar, 2017; Verma and Tiwari, 2015; Leong et al.,

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**Nomenclature**

| | |
|---|---|
| c | lattice speed |
| $C_1$ | constant, $0.59552138 \times 10^{-8}$ W. μ m$^4$/m$^2$·sr |
| $C_2$ | constant, 14387.752 μ m·K |
| $c_s$ | sound speed |
| $c_p$ | specific heat at constant pressure |
| D | Diameter (nm) |
| DASC | direct absorption solar collector |
| f | density distribution functions |
| $f^{eq}$ | equilibrium density distribution functions |
| g | internal energy distribution functions |
| $g^{eq}$ | equilibrium internal distribution functions |
| $h_{con}$ | convection coefficient, 12.15 (W/m·k) |
| $h_{rad}$ | radiation coefficient, 5.85 (W/m·k) |
| H | characteristic length in y direction (mm) |
| I | radiation intensity (W/m$^2$ μm) |
| k | thermal conductivity (W/m·k) |
| $K_{e\lambda}$ | extinction coefficient (cm$^{-1}$) |
| $K_{a\lambda}$ | absorption coefficient (cm$^{-1}$) |
| $K_{s\lambda}$ | scattering coefficient (cm$^{-1}$) |
| L | characteristic length in x direction (cm) |
| m | refractive index |
| $\dot{m}$ | mass flow rate (kg/s) |
| M | transform matrix |
| MRT-LBM | multi-relaxation time lattice Boltzmann method |
| n | real component of refractive index |
| p | pressure (Pascal) |
| q″ | heat flux (W/m$^2$) |
| S | relaxation matrix |
| SWCNH | single-walled carbon nanohorn |
| T | temperature (°C) |
| u | x-direction velocity (m/s) |
| v | y-direction velocity (m/s) |
| W | characteristic length in z direction (cm) |
| Y | absorber plat position from collector wall (mm) |
| x, y, z | cartesian coordinates |

*Greek letters*

| | |
|---|---|
| α | absorptance ratio |
| κ | complex component of refractive index |
| φ | nanoparticles volume fraction |
| μ | dynamic viscosity (kg/m·s) |
| ν | kinematic viscosity (m$^2$/s) |
| ρ | density (kg/m$^3$) |
| τ | transmittance |
| ω | weight factor |
| Δt | time increment (s) |

*Subscripts*

| | |
|---|---|
| amb | ambient |
| bot | bottom |
| f | based fluid |
| g | glass |
| in | inlet |
| nf | nanofluid |
| np | nanoparticle |
| pl | plate |
| s | solar |
| T | integral over wavelength |

2016; Sarsam et al., 2015) can be cited.

In a review done by Khanafer and Vafai (2018), applications of nanofluid in solar collectors and some other solar systems such as thermal energy storage systems and photovoltaic/thermal systems have been investigated. They concluded that nanofluids could substantially improve efficiency and performance of solar collectors, however, higher values of nanoparticles concentration do not continuously improve the efficiency. Elsheikh et al. (2018) also presented a review of recent advances in applications of nanofluids in solar energy systems with similar outcomes. In addition to solar collectors, photovoltaic/thermal systems and thermoelectric devices, they extended their review to solar-geothermal, combined cooling-heating and power systems, and water desalination.

Different nanoparticles are commonly used in solar collectors and many research studies have been performed to compare the performance of these particles in solar energy systems. Qin et al. (2017) studied the solar collector optimization with blended plasmonic nanofluids. Mahian et al. (2014) analyzed different nanofluids as a working fluid of mini-channel solar collectors. They demonstrated that among different nanofluids used in their study, Cu-water leads to the highest outlet temperature. Hatami and Jing (2017) compared the performance of CuO, $TiO_2$, and $Al_2O_3$-water nanofluids in a DASC with wavy walls, and indicated that $TiO_2$-water nanofluid exhibits the best heat transfer performance in comparison with the other investigated nanofluids in the same concentration.

Bhalla and Tyagi (2018) wrote a review article and investigated the parameters affecting the performance of nanofluid-based solar collectors, with a special attention to the optical properties of nanoparticles, as well as, the other parameters such as volume fraction, material and shape of nanoparticles. They provided an overview of optical properties of nanofluids and concluded that five factors affect them, including the base fluid, volume fraction of nanoparticles, material, shape of nanoparticles, and stability of them in the base fluid. After review of the most recently published research studies, they summarized that the volume fraction of nanoparticles plays an important role to determine the overall optical properties of nanofluids. In addition, an optimal volume fraction for each nanofluid exists to meet the highest overall efficiency of the solar collector. They also concluded that carbon nanostructures like graphite, graphene and CNT have strong absorption wavelength range and are very effective to absorb solar irradiation. Otanicar et al. (2009), Otanicar et al. (2013) also provided the optical properties for liquids and nanoparticle suspensions.

Another review paper on thermal performance enhancement of flat-plate and evacuated tube solar collectors by using nanofluids was written by Muhammad et al. (2016). Karami et al. (2014) used carbon nanohorn nanoparticles in a solar collector and observed that implementation of nanofluid can increase the collector performance about 17%. Delfani and Karami (2016) conducted experimental and numerical investigations on a residential type solar collector – as a low cost and useful energy system which is used in buildings – by using MWCNT-water nanofluid. MWCNT nanoparticles have a high thermal conductivity and a small volume fraction of them, in the order of 0.01%, can significantly affect the thermal properties of the nanofluid. They showed this kind of nanofluid improves the collector efficiency by 10–29% with respect to the pure base fluid. Liu et al. (2015) studied a combined numerical and experimental DASC with the graphene/ionic nanofluid. They illustrated the effects of graphene concentration, solar concentration and nanoparticle size on the receiver efficiency. The graphene nanofluid-based DASC also experimentally investigated by Khosrojerdi et al. (2017) and the stability of graphene oxide nanoplatelets demonstrated in different conditions. According to their results, graphene oxide nanoplatelet nanofluid is a suitable absorber to be used in DASC. Raj and Subudhi (2018) presented a comprehensive literature review in their review paper with the focus on effects of application of