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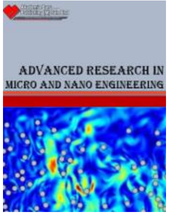

Performance of Solar Thermal Collector Using Multi-Walled Carbon Nanotubes: Simulation Study

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ABSTRACT

A flat-plate solar collector (FPSC) using multi-walled carbon nanotubes (MWCNTs) was numerically studied. Multi-walled carbon nanotubes (MWCNTs) with outside diameters of (< 8 nm) and 0.1wt.% were utilized. A three-dimensional model was built and solved via ANSYS software and the inlet parameters as 1000 W/m2, inlet temperature of 30°C and the volume flow rates in the range of 0.2-0.8 kg/min. Using DW decreased the temperature of absorber by 0.840%, 1.437%, 1.909%, 2.308%, 2.616% and 2.869% for the varied flow rates. Relative to DW, the temperature of absorber decreased by 0.874%, 0.804%, 0.756%, 0.717%, 0.685%, 0.655% and 0.633% at the same flow rate ranges. Meanwhile, the thermal efficiency of MWCNTs nanofluid was increased by 6.080%, 6.322%, 6.311%, 6.337%, 6.450% and 6.857% for volume flow rate of 0.2-0.8 kg/min.

Keywords:
Flat-plate solar collector; Thermal efficiency; Carbon-based nanofluid; MWCNTs nanoparticles

1. Introduction

Flat plate solar collectors (FPSCs) are basic devices used to deliver hot water required for usual practices. FPSC can be installed above the housing or public buildings since its mechanism is simple. The daylight passes over one or two glass layer (s) and strikes to the thin flat plate made of aluminum which with a special coating to absorb more energy. Then, the heat is transferred to the working fluid flowing through riser pipes attached to the flat plate absorber [1][2].

However, considering the low cost of maintaining flat plate collector systems and no need for sun monitoring, their low thermal performance is one of the researchers' biggest challenges. However, investigators have come up with many findings to resolve this key deficiency, such as suspension nanoparticles (1nm-1 µm) made of metallic or non-metallic within the base fluids or alteration of the geometry of the absorber to obtain an effective design [3],[4],[5].

Carbon nanostructures such as (SWCNTs, MWCNTs, GNPs, GO & Gr) were used as HTFs rather than basic fluids inside the FPSCs [6], [7], [8], [9]. Said *et al*. [6] and [10] tested SWCNTs-H_2O nanofluid through theoretical and experimental studies in terms of heat transport, pressure drop, and exergy

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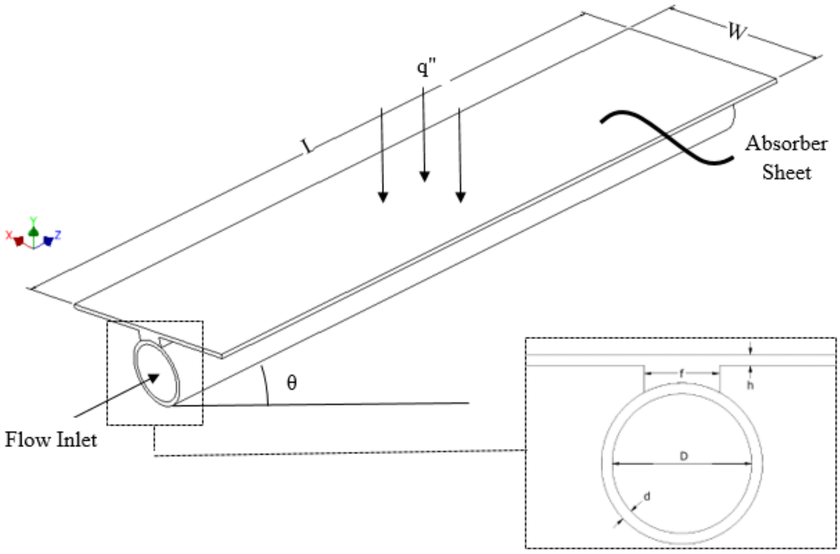
efficiency of the solar absorber. The energy and exergy performance reached about 95% and 26.25%, respectively when using 3 wt.%-SWCNT-H_2O at 0.5 kg/min. Also, the solar energy efficiency was increased by 28.6% when using 0.2 wt.%-MWCNTs-H_2O at 2 kg/min [11].Vakili *et al*. [8] increased the energy efficiency of solar collector to 13.5%, 19.7% and 23.2% for 0.0005wt.%, 0.001wt.% and 0.005wt.% of GNPs-H_2O, respectively at 0.9 kg/min. Ahmadi *et al*. [12] showed that, the thermal performance of solar collector was enhanced by 18.9% with 0.02wt.%-Gr-H_2O at 0.9 kg/min through theoretical and experimental investigations. Moreover, experimental findings showed that the highest energy efficiency was gained after using 0.1wt.%-CGNP-H_2O nanofluid with 0.026 kg/s.m^2, which was about 18.2% higher than H_2O. Triple nanofluid (MWCNTs/GNPs/h-BN) was tested as a heat transfer fluid under three different volume flow rates such as (2 L/min, 3 L/min, and 4 L/min) [14]. Therefore, the hybrid nanofluid with 4 L/min exhibited the maximum thermal-efficient solar collector up to 85%. Sarsam and his team in two different studies [15],[16] examined (TEA-GNPs) and (Ala-MWCNTs) inside indoor FPSC. Relative to DW, the thermal efficiency improved up to 10.53% for (0.1wt.%-TEA-GNPs) nanofluid with specific surface area (SSA) of 750 m^2/g. While, the FPSC's effectiveness improved up to 9.55% for 0.1-wt.% Ala-MWCNTs < 8 nm at 1.4 kg/min, compared with DW.

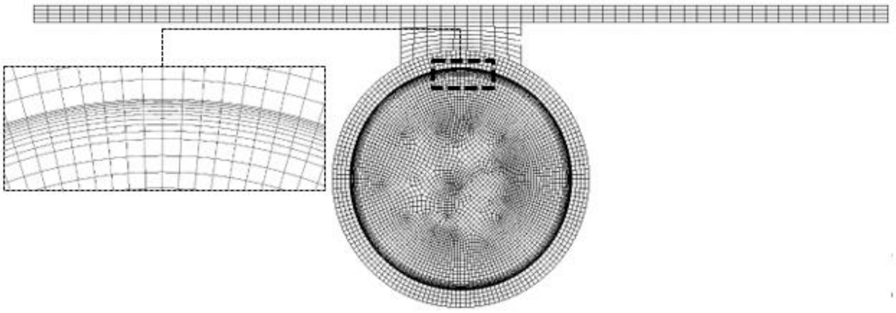
More research is needed to understand the usage of carbon based nanofluids as HTFs inside solar collectors. In this paper, a 3D numerical model was solved under conjugated laminar mixed convection heat transfer using MWCNTs-H_2O with outside diameters of (< 8 nm). Different parameters were taken into consideration such as; the mass fraction of 0.1wt.%, the heat flux of 1000 W/m^2, the inlet temperature of 30°C and the volume flow rates in the range of 0.2-0.8 kg/min.

2. Methodology

Figure 1(a) demonstrates the current model of 3D-FPSC working under conjugated laminar mixed convection and the solar radiation was applied as a constant heat flux at the absorber surface. The basic model contains a thin absorber plate made of aluminum and a riser pipe made of copper. The detailed dimensions are summarized in Table 1 as; the flat plate length (L), flat plate width (w), flat plate thickness (h), pipe thickness (d) and pipe inner diameter (D). The CFD domain is also subdivided into many simple small cells with the purpose of having better control over grid sizes and enhance the meshing efficiency. As shown in Fig. 1(b), the feature of inflation is selected near the walls of the riser pipe.



(a)



(b)

Fig. 1. (a) A schematic diagram of FPSC, (b) Grid domain

Table 1
Specifications of geometrical parameters of FPSC

Dimension	Value	Dimension	Value
L	914.4 mm	D	10.5 mm
w	128 mm	h	2 mm
d	0.5 mm	θ	30°

3. Mathematical Modelling

Conjugated laminar mixed convection of DW and MWCNTs/H_2O was examined using a 3D-FPSC with tilt angle of 30°. The fully developed condition is assumed at the inlet boundary condition, the working fluids have uniform temperature The thermophysical properties of DW and MWCNTs/H_2O nanofluid are taken from the literature review at the inlet condition of 30°C [16]. As mentioned earlier, the flow is considered to be steady-state condition, Newtonian, and laminar. The flat absorber is heated by a constant wall heat flux while non-slip and adiabatic boundary conditions are set for the lateral absorber plate walls and lower outer riser pipe. Gravitational force is applied in the normal direction of (y-axis) with a value of (-9.81 m/s^2). Furthermore, body forces, solar radiation and compressibility are neglected while DW and MWCNTs nanoparticles are assumed as a single-phase in thermal equilibrium with zero relative velocity. The continuity, momentum and energy governing equations are as follows [17], [18]:

$$\frac{\partial}{\partial x_i}(\rho\mu_i) = 0 \tag{1}$$

$$\frac{\partial}{\partial x_j}(\rho\mu_i\mu_j) = \frac{\partial p}{\partial x_i} + \frac{\partial p}{\partial x_j}\left(v\left(\frac{\partial \mu_i}{\partial x_j} + \frac{\partial \mu_j}{\partial x_i}\right) - \grave{\mu}_i\grave{\mu}_j\right) \tag{2}$$

$$\frac{\partial \rho cp\mu_j T}{\partial x_i} = \frac{\partial}{\partial x_j}\left(k\frac{\partial T}{\partial x_j} - \rho cp\overline{\mu_j T}\right) + S_T \tag{3}$$

where i = 1,2,3, u_i = (u, v, w) represent velocity vectors.

The boundary conditions (BCs) of the problem can be explained as follows [19],[20],[21]:
Inlet pipe section:

$$u = v = 0, \tag{4}$$

$$w = U_{in,} T = T_{in} \tag{5}$$

Upper surface of the absorber:

$$u = v = w = 0 \tag{6}$$

$$q''_w = I(\lambda k) - h(T_{col} - T_{amb}) \tag{7}$$

Adiabatic walls:

$$u = v = w = 0 \tag{8}$$

$$\frac{\partial T}{\partial y} = 0 \tag{9}$$

Outlet pipe section:

$$\frac{\partial u}{\partial z} = \frac{\partial v}{\partial z} = \frac{\partial w}{\partial z} = 0 \tag{10}$$

$$\frac{\partial T}{\partial z} = 0 \tag{11}$$

Solid-liquid interfaces:

$$k\frac{\partial T}{\partial x} = k_s\frac{\partial T_s}{\partial x} \tag{12}$$

The solar collector efficiency can be written as by:

$$\eta = \frac{Q_u}{A_a I} = \frac{\dot{m}cp(T_{out} - T_{in})}{A_a I} \tag{13}$$

4. Results and discussion

Figure 2 presents the values of flat plate absorber temperature using DW and MWCNTs/H_2O at different volume flow rates. It can be seen from the presented data; the value of absorber temperature decreases as volume flow rates increases for both cases (water and nanofluid). The temperature of the absorber using water was also higher than that of nanofluid, which is characteristic of the convective mode of heat transfer under constant heat flux [15]. Figures (3-4) show the results of gain energy and thermal efficiency using water and nanofluids for varied flow rates. It is evident from this that the efficiency of the collector improves as the flow rate increases, which can be due to the decreased flat plate temperature (Fig. 3), resulting in lower collector heat losses, i.e., improved collector efficiency. Using DW decreased the temperature of absorber by 0.840%, 1.437%, 1.909%, 2.308%, 2.616% and 2.869% for the varied flow rates. Relative to DW, the temperature of absorber decreased by 0.874%, 0.804%, 0.756%, 0.717%, 0.685%, 0.655% and 0.633% at the same flow rate ranges. Meanwhile, the thermal efficiency of MWCNTs nanofluid was increased by 6.080%, 6.322%, 6.311%, 6.337%, 6.450% and 6.857% for volume flow rate of 0.2-0.8 kg/min.

Figure 5 discusses the effect of volume flow rates on the thermal field for both working fluids (water and nanofluid) in terms of temperature contours. The surface temperature of flat plate using DW decreases as the volume flow rate increases. Meanwhile, the surface temperature of flat plate using DW is higher than the nanofluid. It can be firmly accepted that nanofluid is the most powerful alternative working fluid that can be used instead of traditional working fluids for higher energy efficiency in solar collectors or any other comparable thermal equipment or engineering process.

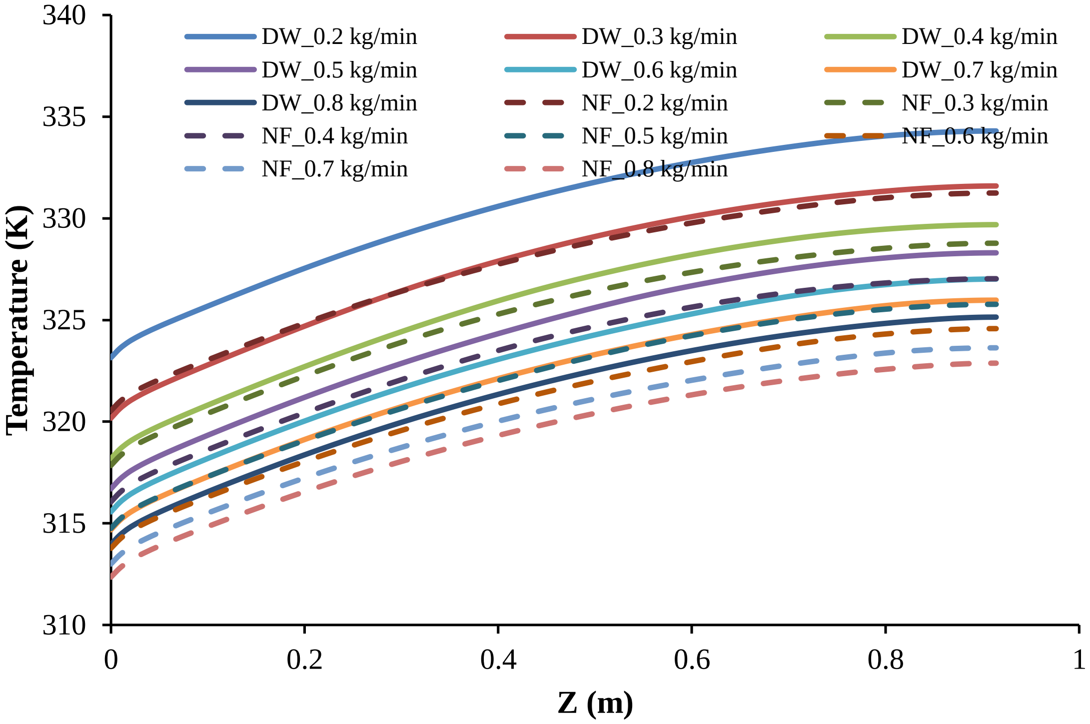


Fig. 2. Temperature of flat plate absorber using water and nanofluid at different flow rates

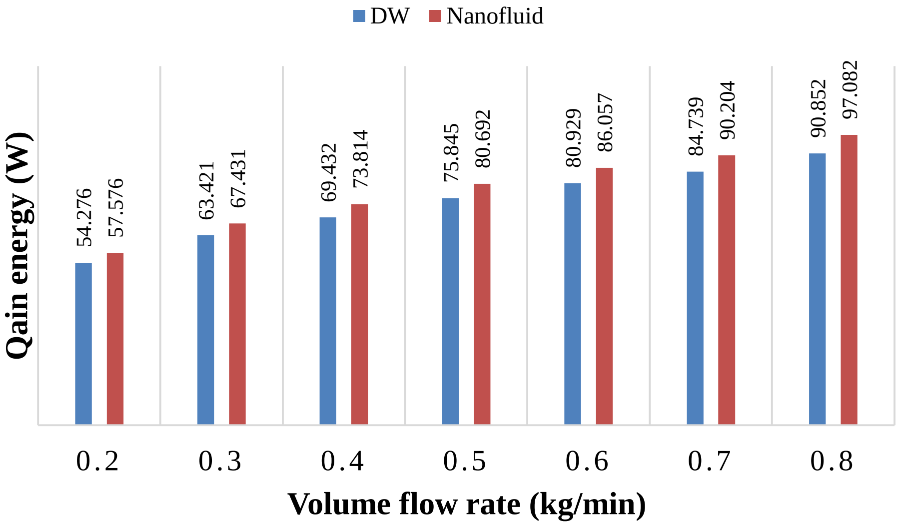


Fig. 3. Qain energy for water and MWCNTs/H_2O at different volume flow rates

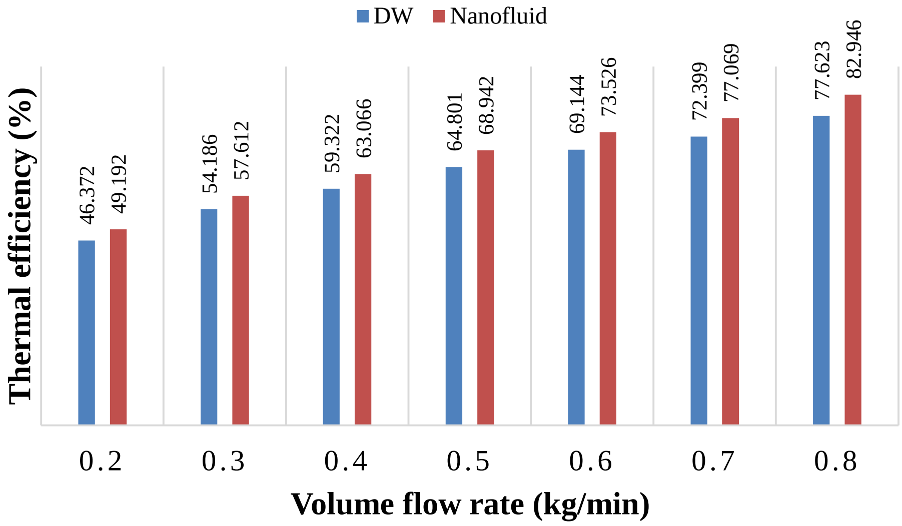
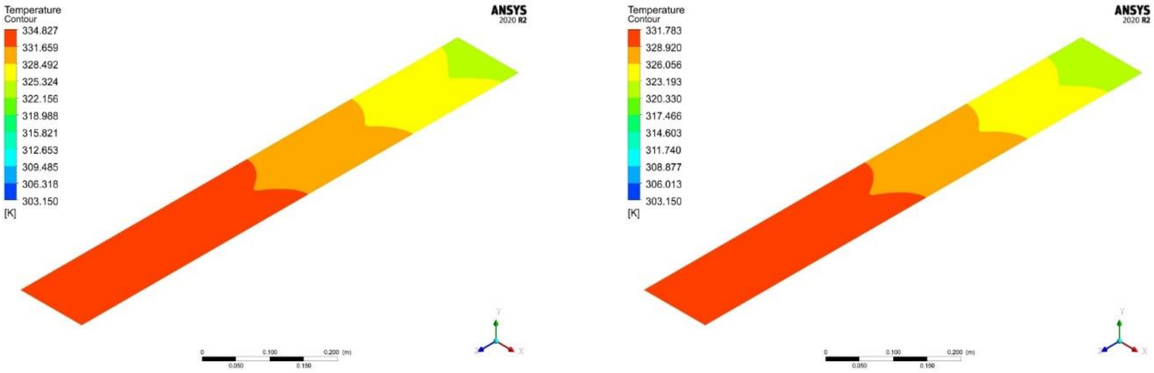
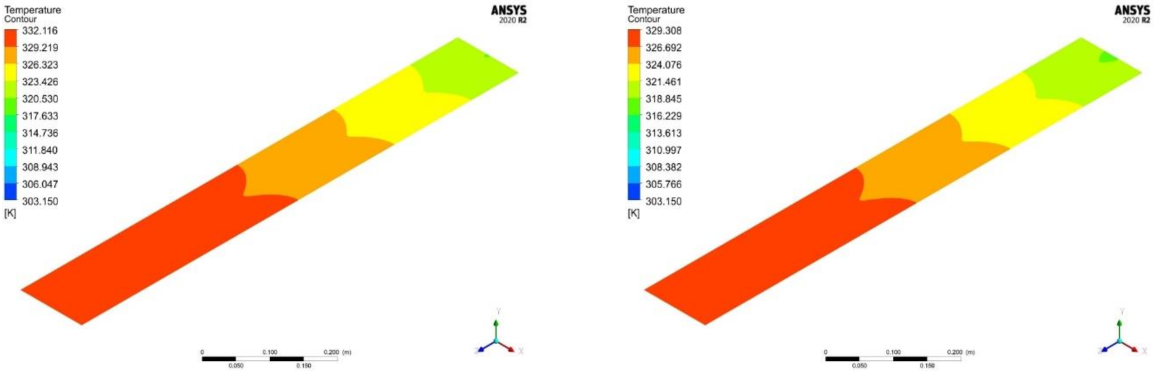


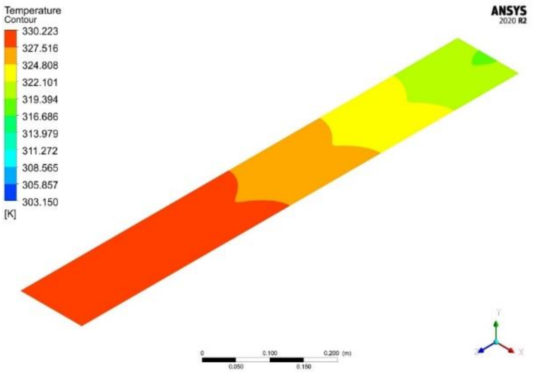
Fig. 4. Thermal efficiency for water and MWCNTs/H_2O at different volume flow rates



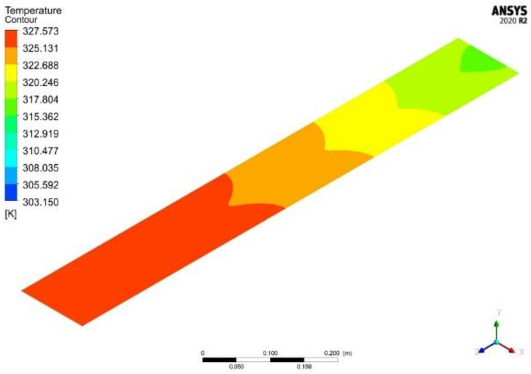
DW_0.2 kg/min NF_0.2 kg/min



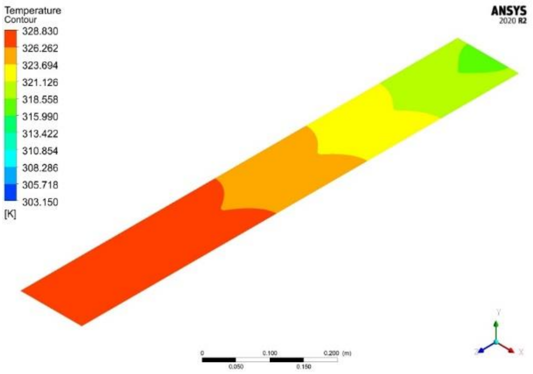
DW_0.3 kg/min NF_0.3 kg/min



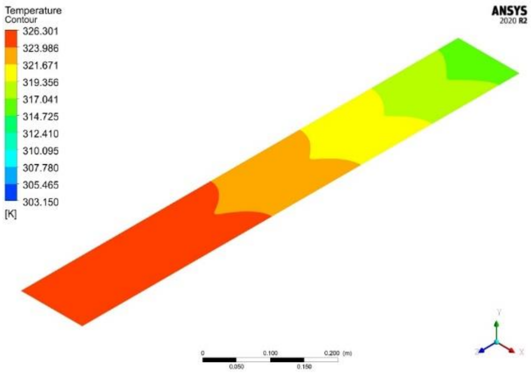
DW_0.4 kg/min



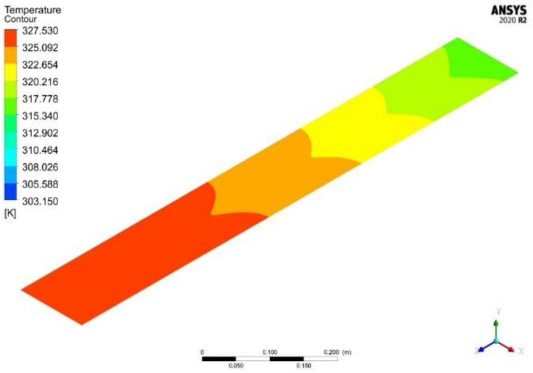
NF_0.4 kg/min



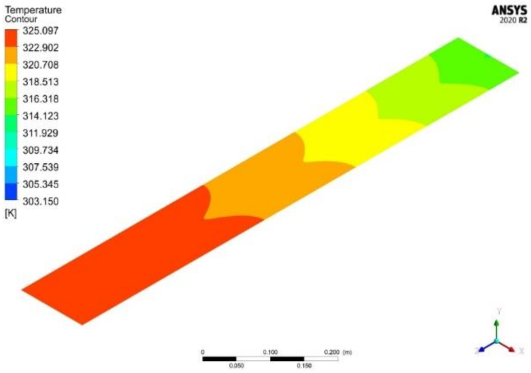
DW_0.5 kg/min



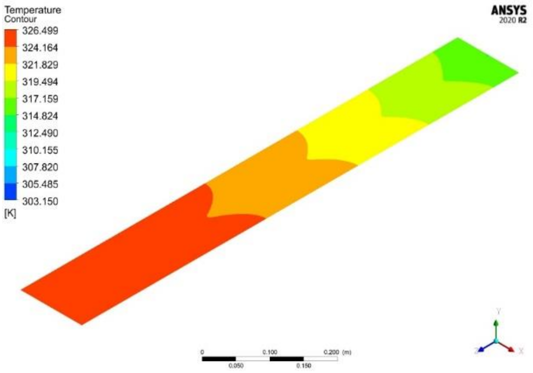
NF_0.5 kg/min



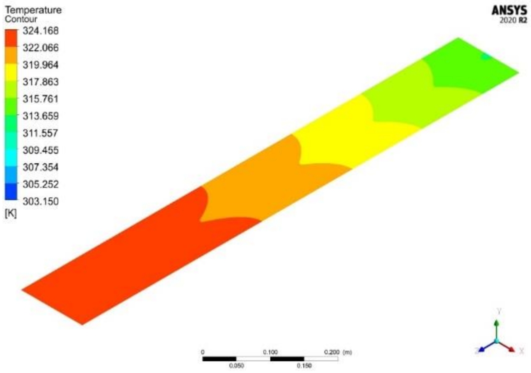
DW_0.6 kg/min



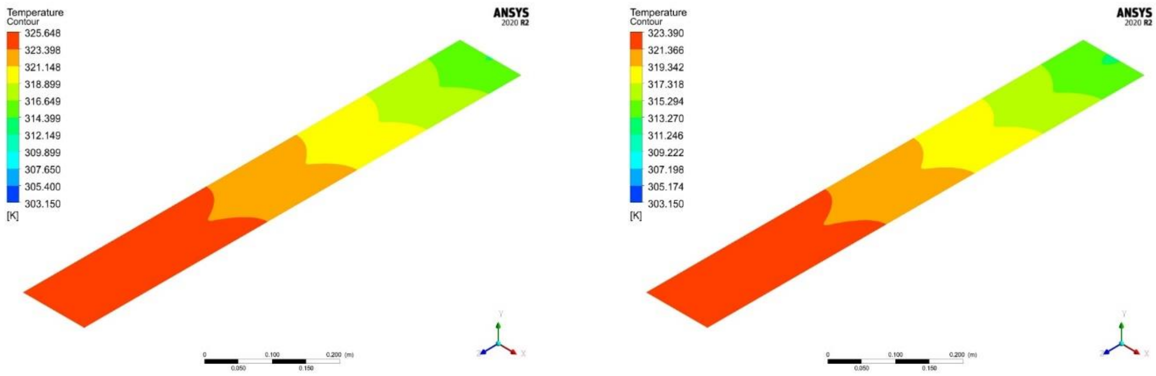
NF_0.6 kg/min



DW_0.7 kg/min



NF_0.7 kg/min



DW_0.8 kg/min

NF_0.8 kg/min

Fig. 5. Temperature contours of flat plate absorber using DW and nanofluid at different volume flow rates

5. Conclusions

Simulation studies were performed using 3D model for flat plate solar collector to examine the thermal performance of MWNCTs/H_2O nanofluid. The thermophysical properties of 0.1wt.% MWCNTs were taken from the literature review. Forced convective flow was taken into account under volume flow rate of 0.2-0.8 kg/min. Meanwhile, the inlet temperature for DW and MWNCTs/H_2O nanofluid was fixed at 30°C with a constant heat flux of 1000 W/m^2 was applied at the absorber plate as input heat. Using DW decreased the temperature of absorber by 0.840%, 1.437%, 1.909%, 2.308%, 2.616% and 2.869% for the varied flow rates. Relative to DW, the temperature of absorber decreased by 0.874%, 0.804%, 0.756%, 0.717%, 0.685%, 0.655% and 0.633% at the same flow rate ranges. Meanwhile, the thermal efficiency of MWCNTs nanofluid was increased by 6.080%, 6.322%, 6.311%, 6.337%, 6.450% and 6.857% for volume flow rate of 0.2-0.8 kg/min.

Acknowledgments

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References

[1] Pandey, Krishna Murari, and Rajesh Chaurasiya. "A review on analysis and development of solar flat plate collector." *Renewable and Sustainable Energy Reviews* 67 (2017): 641-650. https://doi.org/10.1016/j.rser.2016.09.078

[2] Rojas, D., J. Beermann, S. A. Klein, and D. T. Reindl. "Thermal performance testing of flat-plate collectors." *Solar Energy* 82, no. 8 (2008): 746-757. https://doi.org/10.1016/j.solener.2008.02.001

[3] Sarsam, Wail Sami, S. N. Kazi, and A. Badarudin. "A review of studies on using nanofluids in flat-plate solar collectors." *Solar Energy* 122 (2015): 1245-1265. https://doi.org/10.1016/j.solener.2015.10.032

[4] Raj, Pankaj, and Sudhakar Subudhi. "A review of studies using nanofluids in flat-plate and direct absorption solar collectors." *Renewable and Sustainable Energy Reviews* 84 (2018): 54-74. https://doi.org/10.1016/j.rser.2017.10.012

[5] Akram, Naveed, Rad Sadri, S. N. Kazi, Mohd Nashrul Mohd Zubir, Mohd Ridha, Waqar Ahmed, Manzoore Elahi M. Soudagar, and Mazdak Arzpeyma. "A comprehensive review on nanofluid operated solar flat plate collectors." *Journal of Thermal Analysis and Calorimetry* 139, no. 2 (2020): 1309-1343. https://doi.org/10.1007/s10973-019-08514-z

[6] Said, Zit, Rahman Saidur, M. A. Sabiha, N. A. Rahim, and M. R. Anisur. "Thermophysical properties of Single Wall Carbon Nanotubes and its effect on exergy efficiency of a flat plate solar collector." *Solar Energy* 115 (2015): 757-769.
https://doi.org/10.1016/j.solener.2015.02.037

[7] Sadripour, Soroush. "First and second laws analysis and optimization of a solar absorber; using insulator mixers and MWCNTs nanoparticles." *Global Journal of Research In Engineering* (2017).

[8] Vakili, M., S. M. Hosseinalipour, S. Delfani, S. Khosrojerdi, and M. Karami. "Experimental investigation of graphene nanoplatelets nanofluid-based volumetric solar collector for domestic hot water systems." *Solar Energy* 131 (2016): 119-130.
https://doi.org/10.1016/j.solener.2016.02.034

[9] Vincely, D. Anin, and E. Natarajan. "Experimental investigation of the solar FPC performance using graphene oxide nanofluid under forced circulation." *Energy conversion and management* 117 (2016): 1-11.
https://doi.org/10.1016/j.enconman.2016.03.015

[10] Said, Zid, Rahman Saidur, Nasrudin A. Rahim, and Mohammad A. Alim. "Analyses of exergy efficiency and pumping power for a conventional flat plate solar collector using SWCNTs based nanofluid." *Energy and Buildings* 78 (2014): 1-9.
https://doi.org/10.1016/j.enbuild.2014.03.061

[11] Yousefi, Tooraj, Farzad Veisy, Ehsan Shojaeizadeh, and Sirus Zinadini. "An experimental investigation on the effect of MWCNT-H2O nanofluid on the efficiency of flat-plate solar collectors." *Experimental Thermal and Fluid Science* 39 (2012): 207-212.
https://doi.org/10.1016/j.expthermflusci.2012.01.025

[12] Ahmadi, Alireza, Davood Domiri Ganji, and Farzad Jafarkazemi. "Analysis of utilizing Graphene nanoplatelets to enhance thermal performance of flat plate solar collectors." *Energy Conversion and Management* 126 (2016): 1-11.
https://doi.org/10.1016/j.enconman.2016.07.061

[13] Akram, Naveed, Rad Sadri, S. N. Kazi, S. M. Ahmed, M. N. M. Zubir, Mohd Ridha, Manzoore Soudagar, Waqar Ahmed, Mazdak Arzpeyma, and Goh Boon Tong. "An experimental investigation on the performance of a flat-plate solar collector using eco-friendly treated graphene nanoplatelets–water nanofluids." *Journal of Thermal Analysis and Calorimetry* 138, no. 1 (2019): 609-621.
https://doi.org/10.1007/s10973-019-08153-4

[14] Hussein, Omar A., Khairul Habib, Ali S. Muhsan, R. Saidur, Omer A. Alawi, and Thamir K. Ibrahim. "Thermal performance enhancement of a flat plate solar collector using hybrid nanofluid." *Solar Energy* 204 (2020): 208-222.
https://doi.org/10.1016/j.solener.2020.04.034

[15] Sarsam, Wail Sami, Salim Newaz Kazi, and Ahmad Badarudin. "Thermal performance of a flat-plate solar collector using aqueous colloidal dispersions of graphene nanoplatelets with different specific surface areas." *Applied Thermal Engineering* 172 (2020): 115142.
https://doi.org/10.1016/j.applthermaleng.2020.115142

[16] Sarsam, Wail Sami, S. N. Kazi, and A. Badarudin. "Thermal performance of a flat-plate solar collector using aqueous colloidal dispersions of multi-walled carbon nanotubes with different outside diameters." *Experimental Heat Transfer* (2020): 1-24.
https://doi.org/10.1080/08916152.2020.1847215

[17] Wang, Nan, Shequan Zeng, Mi Zhou, and Shuangfeng Wang. "Numerical study of flat plate solar collector with novel heat collecting components." *International Communications in Heat and Mass Transfer* 69 (2015): 18-22.
https://doi.org/10.1016/j.icheatmasstransfer.2015.10.012

[18] Jiandong, Zhang, Tao Hanzhong, and Chen Susu. "Numerical simulation for structural parameters of flat-plate solar collector." *Solar Energy* 117 (2015): 192-202.
https://doi.org/10.1016/j.solener.2015.04.027

[19] Bianco, Vincenzo, Oronzio Manca, and Sergio Nardini. "Entropy generation analysis of turbulent convection flow of Al2O3–water nanofluid in a circular tube subjected to constant wall heat flux." *Energy Conversion and Management* 77 (2014): 306-314.
https://doi.org/10.1016/j.enconman.2013.09.049

[20] Charjouei Moghadam, Mohammad, Mojtaba Edalatpour, and Juan P. Solano. "Numerical study on conjugated laminar mixed convection of alumina/water nanofluid flow, heat transfer, and entropy generation within a tube-on-sheet flat plate solar collector." *Journal of Solar Energy Engineering* 139, no. 4 (2017).
https://doi.org/10.1115/1.4036854

[21] Edalatpour, Mojtaba, and Juan P. Solano. "Thermal-hydraulic characteristics and exergy performance in tube-on-

sheet flat plate solar collectors: Effects of nanofluids and mixed convection." *International Journal of Thermal Sciences* 118 (2017): 397-409.
https://doi.org/10.1016/j.ijthermalsci.2017.05.004