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Numerical Investigation of Flat Plate Solar Collector by Using Various Types of Mono and Hybrid Nanofluids

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Abstract*:* The performance of traditional fluids in heat transmission might be greatly enhanced by using nanofluid, a cutting-edge fluid. Improving the design elements and the convection heat transfer coefficient between the fluid and absorber tubes are the most important ways to raise the solar collector's overall efficiency. In solar collectors, water nanofluids such as MWCNT, Al_2O_3, TiO_2, SiO_2, and CuO are most commonly used nanofluids. This study used controlled conditions to numerically examine the thermal efficiency of flat plate solar collectors using Al_2O_3, MWCNT, and hybrid Al_2O_3+MWCNT (80:20%) as a working fluid. The efficiency is examined in relation to a number of characteristics, such as the volumetric flow rate and the volume percentage of nanoparticles, and the intensity of solar radiation. Six concentrations ratio of different nanoparticles were used (0, 0.01, 0.02, 0.03, 0.04, and 0.05) during this numerical investigation, with each of these concentrations six different mass flow rate were used (0.004167, 0.08334, 0.0125, 0.01667, 0.03334, and 0.05) kg/s. The results showed that the highest efficiency was obtained from using MWCNT/water as a nanofluid (76.8%, 78.3%, and 80.4%) at mass flowrate 0.05 kg/s for concentration ratios (0.03,0.04, and 0.05) respectively. While the base fluid (water) at the same mass flow achieved lower efficiency 53.4%. Al_2O_3/water achieved median efficiency (59.1%, 60.1%, and 61.1%) at mass flowrate 0.05 kg/s for concentration ratios (0.03,0.04, and 0.05), respectively. The efficiency of hybrid Al_2O_3+MWCNT (80:20%) at mass flowrate 0.05kg/s were 75.2%, 76.5%, and 78.3% for concentration ratios (0.03,0.04, and 0.05) respectively.

Keywords: *Flat Plate Solar Collectors, Solar Water Heater, Nanofluid, Hybrid Nanofluid, Stability, Thermophysical properties, Heat transfer enhancement*

1. Introduction

The global economy's expansion and population rise have significantly increased the importance of energy [1]. Conversely, the use of fossil fuels leads to numerous environmental issues, including CO_2 emissions [2]. To address these issues, experts have therefore suggested clean energy sources, like solar, geothermal, wind etc. [3]. FPSCs are one type of solar energy device that has been created using a variety of materials and configurations, and among the most crucial elements in estimating their thermal performance is their configuration [4], [5].

To improve solar systems' performance, including FPSCs, numerous researchers have used a variety of settings [6]. One useful method for accelerating the rate of heat transfer in FPSCs is the use of nanofluids [7], [8]. For example, [9] investigated how SWCNT nanofluid affected flat plate solar collectors and found that, when compared to pure water, the coefficient of heat transfer increased by 15.33%. By analysing various nanofluid types on flat plate solar collectors, [10] came to the conclusion that, in the same circumstances, using carbon-based nanofluids rather than another type of nanofluids increases the flat plate solar collectors' energy and operational efficiency. By altering the flow path's geometry into spiral, U-shaped, and wavy tubes. Using mass flow rates of 0.004 kg/s and 0.06 kg/s, respectively, and alumina-water nanofluid fractions of 1%, 2%, and 3% Investigated solar water heaters with flat plates (FPSWH) numerically. The finding suggests that FPSWH may achieve a maximum thermal efficiency of 83.9% at a mass flow rate of 0.06 kg/s. A 3% fraction raised the exit temperature by 7.2% at a lower mass flow rate [11]. [12] Discovered that using Al_2O_3 nanofluid with a volume fraction of 0.1% at mass flow rates of 1, 2, and 4 L/m increased the collector's efficiency by 23.6% at the perfect flow rate of 2 L/m. Found that using 0.1 vol percent Al_2O_3 nanofluid as a heat transfer fluid (HTF) increased efficiency by 21.9% in comparison to water. When utilizing 0.1 vol percent Al_2O_3/water and 0.5 vol percent CuO/water nanofluids, energy efficiency rose by 56.9% and 49.6%, respectively. [13]. Examined the benefits of employing a CeO_2/water nanofluid at flow rates of 1-3 L/m and volume fractions of 0.01-0.01% in term of energy, cost, and the environment. At a 0.05% volume fraction and 2 L/m mass flow rate, the efficiency rose by 20.07% and the collector area shrank by 24.52%, resulting in 175 kg less CO_2 and a longer pack return time [14]. Multiwall Carbon Nanotubes (MWCNT) with distilled water perform on thermosiphon FPSWH than forced circulation FPSWH. Using 0.1 weight percent and 0.05 weight percent MWCNT at 3.5 L/m, the thermosiphon FPSWH showed the highest energy efficiency increases of 34.13% and 23.35% [15]. Single-walled carbon nanotube (SWCNT)/water nanofluid at a volume concentration of 0.2% improved the solar collector's efficiency by 10% [16]. Concluded that the MWCNT/water nanofluid offers the greatest gain in energy efficiency when compared to Al_2O_3/water, TiO_2/water, Graphene/water, CuO/water, and SiO_2/water nanofluids [17]. Analysing the effects of various turbulence-inducing components on solar collectors, [18] found that the thermal efficiency of various shapes might rise by as much as 27.6% when compared to the simple condition. [19] investigated passive techniques for enhancing heat transmission. The results showed that, in comparison to a smooth wall pipe, using coiled square wire can significantly increase heat

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transmission and friction loss. [20] investigated tubes with cone loop turbulators and twisted tape swirl generators and found that using this technique can raise the thermal efficiency by 4-8% and the Nusselt number by 4–10%, respectively. [21] found that using a Fe_3O_4/water-ethylene glycol 50:50) nanofluid instead of the basis fluid can increase an FPSC's thermal efficiency by 15.27 percent.

Solar systems are not the only places where nanofluids are used. By employing these techniques, the functionally of various energy systems, such as tubes, cavities, heat exchangers, etc., has been enhanced by numerous researchers. Here are a few of these analyses to highlight the importance of nanofluids and turbulators in thermal systems. [22] numerically investigated, the hydrothermal behaviour of a turbulent CuO/water nanofluid flow within a turbulator-equipped tube. According to the results, a variety of turbulators with varying forms have been used to give FPSCs appropriate performance, depending on the nanofluid's flow rate. [23] used nanofluids and conical turbulators to assess the HT improvement in solar collector (SC). A numerical analysis of the collection conical turbulators in a tube thermal-hydraulic performance was conducted. Conical turbulators and the use of carbon nanotubes and silicone oil instead of pure oil significantly enhanced the thermal performance. The demonstration was assessed between 0.9 to 1.82. Energy and thermal efficiency increased by 18.2% and 11.5%, respectively. PSCs with turbulators were reviewed, and hydrothermal performance was numerically evaluated by [24]. Turbulator devices' benefits and drawbacks were acknowledged. A novel PSC was demonstrated, and a quantitative evaluation of its hydrothermal performance was conducted [25], evaluated the friction factor and the resulting variations in heat transfer. According to the result, the HTC could be raised to 78.25% by altering the flow direction using 4% CuO nanofluid in wavy tubes.

One of the best strategies to raise the thermal performance of solar collectors is to employ hybrid nanofluids. In addition to enhancing efficiency, they significantly reduce the costs of nanomaterials as well as produce a more stable nanofluid [26][27]. The energy and energy efficiency of the CuO and MgO hybrid nanofluid are 71.54% an 70.63%, 70.55%, and 69.11%, respectively. According to [28] examination of MWCNT-based MgO and CuO hybrid nanofluids in conjunction with FPSWH hybrid nanofluids. Regarding the highest level of vitality and energy efficiency, MgO hybrid nanofluids performed 25.1% better than other nanofluids. CuO-MWCNT and MgO-MWCNT hybrid nanofluids' energy and exergy performance in a flat plate collector were examined by [29]. The flow rate can reach 2 L/m, and the nanoparticle concentration approach 2%. The energy and exergy efficacies of the MgO-MWCNT hybrid nanofluid were 71.56% and 70.55%, respectively, while the CuO-MWCNT hybrid nanofluid showed efficacies of 70.63% and 69.11%. Energy and energy investigations were conducted using hybrid nanofluids of Al_2O_3/Water and Al_2O_3-Fe/Water in a flat plate collector with particle loadings of 0.05 percent, 0.1%, and 0.2%. Using Al_2O_3-Fe/water hybrid nanofluid, they found that the thermal efficiency was 1.79 percent and 2.16 percent in Al_2O_3/water at 0.1% particle loading. They also reported that the hybrid nanofluids of Al_2O_3-Fe/water and Al_2O_3/water had energy efficiencies of 5.7% and 6.9%, respectively [30].

Using Al_2O_3, MWCNT, and hybrid Al_2O_3+MWCNT nanofluids, this work attempts to do numerical research (Energy, Enhancement of the Economy and Environmental Considerations) of improving flat plate solar collectors' thermal performance.

2. Numerical Modeling and Hybrid nanofluid

This section describes and investigates the Mathematical Modelling and Numerical simulation of the (FPSC). For hybrid nanofluid, Heat transfer and fluid dynamics' governing equations considering the three fundamentals of physics (mass, momentum of fluid, and energy) were presented. The provided numerical solution was developed using COMSOL Multiphysics 6.1. The model used in the simulation is introduced, and details about it, such as its geometry, parameters, and (FPSC) materials, are provided.

This study uses a three-dimensional numerical simulation of the FPSC geometry. Fig. 1 shows the solar system's geometry under study. Al_2O_3/water, MWCNT/water and Al_2O_3+MWCNT/water hybrid nanofluid is used as the working fluid in an FPSC in this investigation. A comparison is made between the outcomes of the base fluid and nanofluid. The two—phase mixture model, consisting of Al_2O_3+MWCNT and water, is used to model the hybrid nanofluid. Mesh creation is used to generate the computational domain's grid. We used the pressure-based method to model the continuous flow of a two-phase Al_2O_3+MWCNT/water hybrid nanofluid. The mass flow rate of hybrid varies from 0.004167 to 0.05 kg/s, while their Φ ranges from 1% to 5%.

2.1. Problem Description

The 3D FPSC with a 30° tilt angle is examined in this work; the schematic is shown in Fig. 1. Table 1 lists the dimensions and attributes. Fig. 2 shows the domain of this evaluation.

Table 1 The proposed FPSC's dimensions and material characteristics [4].

Part	Material	ρ (kg/m³)	k (W/m.K)	C_P (J/kg.K)
Cover	Glass	60	0.78	840
Cavity	Air	1.25	0.0242	1006.43
Absorber plate	Aluminum	2719	202.4	871
Pipe	Copper	8978	387.6	381

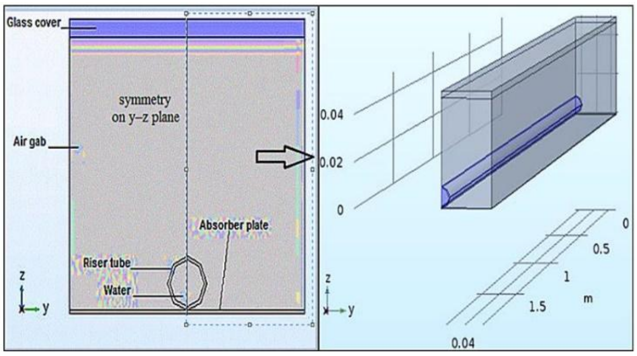
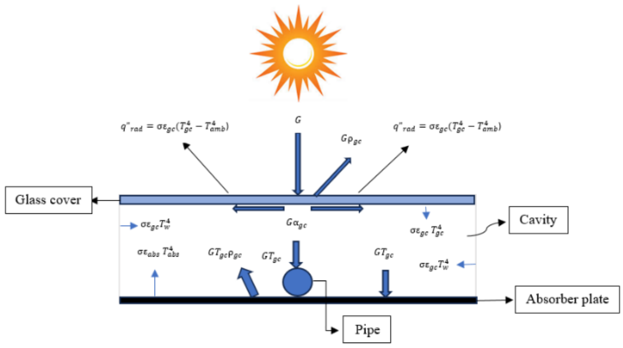


Fig 1. Schematic for the CFD model FPSC

Fig 2. Domain of investigation



2.1.1 Glass Cover

The glass cover considers both radiation and heat transfer depending on the collector's external wind flow. The coefficient of heat transfer is in equation (1), and the wind speed is change with time [31].

$$h\_ext = 5.7 + 3.8V_{wind} \quad (1)$$

2.1.2 Air Cavity

The Boussinesq approximation are used to investigate Convection and buoyancy's effects within the air cavity. Table 2 lists the air characteristics for the Boussinesq approximation. The lateral surfaces have also been considered adiabatic to prevent heat loss. It has been assumed that the lateral surfaces are diffuse and gray.

Table 2 Property of air [4].

ρ (kg/m^3)	β (1/K)	C_P (J/kg.K)	k (W/m.K)	μ (Pa.s)
1.25	0.0033	1006.43	0.0242	1.478×10^{-5}

2.1.3 Working Fluid

The absorber plate and copper tube are joined by a copper weld joint. We have considered an unsteady state condition, a 3D model, and a Newtonian fluid. For the laminar flow regime, a tube with constant flow at the inlet has been examined. Pure water, nanofluid (Al_2O_3/water and MWCNT/water) and a hybrid nanofluid of (Al_2O_3+MWCNT/water) (80:20%) are utilized as the operational fluid. The Reynolds number spans from 745 to 8940, while the inlet temperature is 293K. Nanoparticle concentrations between 1% to 5% have been chosen. The homogenous dispersion of nanoparticles has been postulated based on a low temperature gradient and a change in flow direction. Table 3 lists the conditions and specifics of irradiated surfaces.

Table 3. Conditions of the irradiated surfaces' boundaries [32].

Surface	ε	α	τ
Cavity layer	0.05	-	-
Glass cover	0.88	0.05	0.93
Absorber plate	0.05	0.95	-

2.2. Mathematical Model

The current effort rewrites the solar system's governing equations as follows: [33], [34]:

Continuity:

$$\frac{\partial}{\partial x_j}\left(\rho_{hnf} u_j\right) = 0 \quad (2)$$

Momentum

$$\rho_{hnf}\left(\frac{\partial u_i u_j}{\partial x_j}\right) = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu_{hnf}\frac{\partial u_i}{\partial x_j}\right) \quad (3)$$

Energy

$$\frac{\partial}{\partial x_j}\left(u_j T\right) = \frac{k_{hnf}}{\rho_{hnf} Cp_{hnf}}\left(\frac{\partial^2 T}{\partial^2 x_j}\right) \quad (4)$$

Equations (5-12) [31], [35], [36], [37] are used to evaluate the thermophysical characteristics of working fluids, and temperature-dependent fluid physics properties are used to look into how buoyancy affects things. Furthermore, table 4 lists the thermophysical characteristics of working fluid.

Density:

$$\rho(T) = 9.9018 * 10^{6}\, T^3 - 0.012\, T^2 + 4.9694\, T + 424.4761 \quad (5)$$

$$\rho_{hnf} = \rho_1\phi_1 + \rho_2\phi_2 + \rho_f(1 - \phi_1 - \phi_2) \quad (6)$$

Specific heat capacity:

$$Cp(T) = 1.2677 * 10^{6} T4 - 0.0018\, T^3 + 0.9363\, T^2 - 220.4437\, T + 23648.34 \quad (7)$$

$$(C_p)_{hnf} = C_{p_1}\phi_1 + C_{p_2}\phi_2 + (C_p)_f(1 - \phi_1 - \phi_2) \quad (8)$$

Viscosity:

$$\mu(T) = 1.511 * 10^{-11}\, T^4 - 2.2057 * 10^{-8}\, T^3 + 1.2075 * 10^{-5}\, T^2 - 0.0029\, T + 0.2699 \quad (9)$$

$$\mu_{hnf} = \frac{\mu_f}{\left(1 - \phi_{np1} - \phi_{np2}\right)^{2.5}} \quad (10)$$

Thermal conductivity:

$$k(T) = 1.7804 * 10^{-8} T^3 - 2.8801 * 10^{-5}\, T^2 + 0.0142T - 1.5495 \quad (11)$$

$$k_{hnf} = \frac{(k_1 + k_2) + 2k_f - 2\phi_1(k_f - k_1) - 2\phi_2(k_f - k_2)}{(k_1 + k_2) + 2k_f + \phi_1(k_f - k_1) + \phi_2(k_f - k_2)} \quad (12)$$

Table 4. Working fluids thermophysical properties [2], [38], [39], [40].

Nanoparticle & Base fluid	ρ (kg//m^3)	k (W/m.k)	C_P (J/kg.k)
Water	998	0.613	4180
Al_2O_3	3970	40	765
MWCNT	2600	3000	730

Equations (13) to (15) are used to get the collector efficiency (η), friction factor (f), and Reynolds number (Re) correspondingly [31], [38].

$$\eta = \frac{Q_{out}}{GA_c} \quad (13)$$

$$f = \frac{64}{Re} \quad (14)$$

$$Re = \frac{\rho U_{in} D_h}{\mu} \quad (15)$$

2.3. Boundary Conditions

A fraction of the radiant energy from the sun travels through the glass cover, while another portion is reflected back to the environment around region. Radiation and convection also spread a further quantity to the surrounding area. A portion of this energy's radiation hits the tubes, while another portion is absorbed by the absorber plate. Convection and radiation from the top of absorber plate distribute some of the energy in the immediate surroundings, while the collection cavity allows additional energy to enter. The following are the appropriate boundary conditions based on the explanations:

portion of the intake pipe:

$$u = v = 0, w = U_{in}, T = T_{in} \quad (16)$$

The absorber's bottom:

$$u = v = w = 0, \frac{\partial T}{\partial y} \quad (17)$$

Lateral surfaces:

$$u = v = w = 0, \frac{\partial T}{\partial x} \quad (18)$$

Upon the glass cover:

$$u = v = w = 0, q_w = G \quad (19)$$

3. Model Validation Verification

Investigations were conducted into the thermal efficiency of flat plate solar collector with straight pipes. by [10], [25], [41]. The findings of the current investigation are confirmed with them at the identical water situation at the boundary.

With the hybrid version of the material made up of (80:20%) of each kind, Fig. 8 graphical representations compare the data from Fig. 3 utilizing the Al_2O_3 and MWCNT nanofluid compositions. This concentration was derived from previously published studies that showed that, at all volume flow rates, MgO/MWCNT hybrid nanofluid (80:20), (70:30), (60:40), and (50:50) have optimal thermal efficiency when compared to base fluid and MgO nanofluids, and MgO/MWCNT hybrid-nanofluids, although it was a little less effective than MWCNT/water nanohybrid [42].

The use of MWCNT in nanofluids gives better efficiency, but the cost of the particles is very high, so it is used in hybrid nanofluids at low mixing rates to reduce the cost as well as to avoid its significant negative effects on the solar system [43], [44]. In this study, the hybrid nanofluid Al_2O_3+MWCNT/water (80:20) is used. The results confirm that the efficiency of flat plate solar collector rises when mono nanofluids are used, depending on the kind of nanoparticles and their concentration. Also, affected by the amount of mass flow, but this increase in efficiency may be at the expense of viscosity, pumping capability and lifespan of the part of solar collector. These problems can be solved by using hybrid potty fluids that significantly enhance the thermal performance of the flat plate solar collector while maintaining fluid stability. The optimal choice of nanoparticle type depends on the balance between efficiency, stability and operational cost.

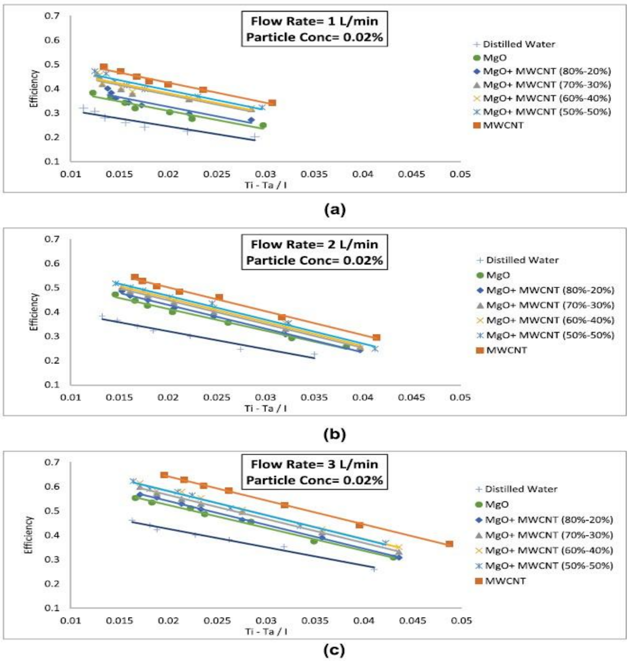


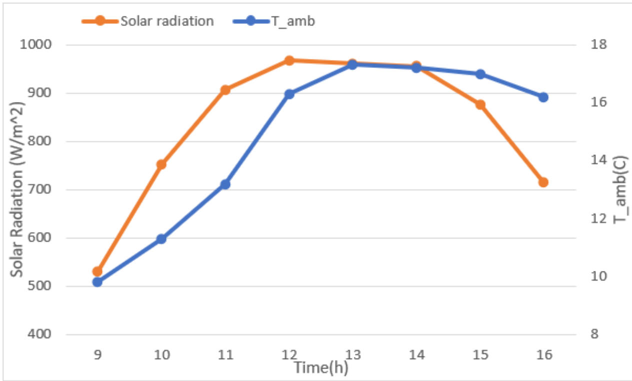
Fig. 3. At varying volume flow rates, the solar collector's thermal efficiency for nanofluids of MgO/water, MWCNT/water, and hybrid nanofluid MgO-MWCNT/water (a) 1 L/min (b) 2 L/min (c) 3 L/min [42].

4. Results and Discussions

This section presents the solution of the mixed convection flow in the pipes as well as the natural convection flow of confined air in the area between the absorber and the glass cover. To validate the numerical solution and the date reduction methodology for each phenomenon, two simplified models have been developed: the Natural Convection Validation model (NCV) for the natural convection process and the Mixed Convection Validation model (MCV) for the mixed convection process.

This study has investigated 3D FPSC functioning under conjugated laminar mixed convection. The tilt angle was 30º set for the collector. The nanofluid Al_2O_3/water and MWCNT/water using as working fluid, while Al_2O_3+MWCNT/water hybrid nanofluid (80:20%) was chosen as the working fluid. Equations (5–12) introduce water and nanofluid characteristics. Two inlet temperatures of 293 K are used to analyse the issue. A variable solar irradiance as shown in Fig., various mass flow rates, and six different volume concentration. Solar radiation and ambient temperature date were obtained experimentally for the 9th of January in Najaf city, Iraq as shown in Fig. 4. The external wind speed was also obtained as shown in Fig. 5.

Fig. 4. Variation Solar radiation and Ambient temperature with Time in



9th of January.

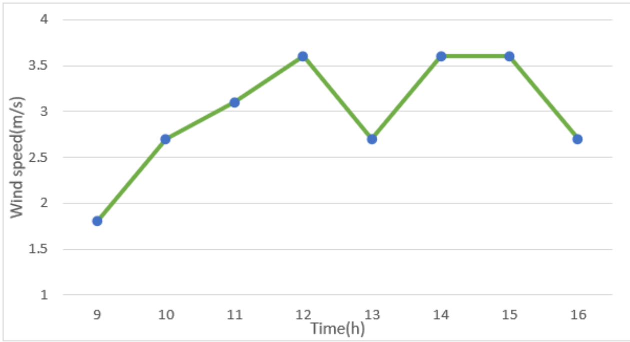


Fig. 5. Variation Wind speed with Time in 9th of January.

The concentration, mass flow rate, and type of the nanoparticles have a significant impact on thermal performance when looking at the performance of a flat plate solar collector employing mono nanofluid made of Al_2O_3/water and MWCNT/water as well as a hybrid nanofluid made of Al_2O_3+MWCNT/water.

4.1. The Effect of Volumetric Concentration

Volumetric concentration of nanoparticles being increased (Al_2O_3 and MWCNT) in the fluid leads to improve the nanofluid's thermal conductivity, which promotes heat transfer within the solar collector [8], [45], [46]. However, excessive concentration may lead to adverse effects, including the deposition of nanoparticles within the collector, which adds thermal resistance and reduces the collector's efficiency, for example, [47] using Al_2O_3, TiO_2, ZnO/water as working fluid, the nanofluid exhibited higher heat transfer coefficients and energy efficiency. Also, [48] using TiO_2, MgO, MWCNT as working nanofluid, the nanofluids enhance the collector's performance, reducing auxiliary energy consumption.

4.2. The Effect of Mass Flowrate

The temperature different between the liquid and the absorber surface increase as the mass flow rate of the liquid increases, improving heat removal from the solar collector and lowering the temperature of the liquid exiting the system. Thus, improving thermal efficiency. However, excessive flow may reduce the time the liquid stays inside the collector, reducing heat absorption. Three distinct flow rates (0.5, 1, 1.5 lpm) were employed in a study using Cu-MWCNTs/water as the working fluid. With a maximum instantaneous efficiency of 68.7% at a flow rate 1.5 lpm, the hybrid nanofluid enhanced solar collector performance [6]. [49] The usage of Al_2O_3 (0.1wt%), TiO_2 (0.1wt%), and the combination of these two nanofluids will result in an approximate 19%, 21%, and 26% increase in thermal efficiency, respectively. The mass flow rates were 1.5 lpm, 2 lpm, and 2.5 lpm.

4.3. The Effect of Nanoparticles

The thermal efficiency of the solar collector is significantly influenced by the type of nanoparticles, which is determined by how much the particles' characteristics influence the nanofluid's properties [39], [50]. Some MWCNT particles have very high thermal properties and therefore their effect in increasing thermal efficiency is significantly evident [6]. However, the use of MWCNT particles has adverse effects, as it tends to sediment, which affects the flow of fluid and therefore requires a high pumping capacity in addition to its effect on the collector equipment in case of sedimentation. Moreover, its costs are very high [39]. While the use of particles such as Al_2O_3 does not significantly improve efficiency, it has fewer negative effects compared to MWCNT, and it has a low cost [38]. This led researchers to use hybrid nanofluids such as Al_2O_3+MWCNT at different mixing ratios to achieve a balance between increasing efficiency, maintaining fluid stability and reducing the cost of nanomaterials [40].

The fluid's thermal conductivity is enhanced by nanoparticles. This enhances the solar collector's effectiveness by encouraging heat transmission from the absorbent surface to the liquid. The kind of particle employed has a big effect on how much efficiency is increased and how much performance is improved, thus when choosing nanoparticles, consideration must be given to both boosting efficiency and preserving stability within the base fluid [35].

Increasing the concentration of nanoparticles leads to increase in the viscosity of the liquid, which increases the flow resistance and may require additional energy to pump the liquid, thus reducing the solar collector's efficiency [51]. At high concentrations, nanoparticles may be deposited on the solar collector's surfaces, which adds thermal resistance and reduces heat transfer and thus reduces the solar collector's thermal performance [52].

4.3.1. Effect Al_2O_3/water Nanofluid

Fig. 6 shows the relationship between thermal-efficiency and concentration ratio (Φ) with different mass flow rate when using Al_2O_3/water nanofluid as working fluid. The efficiency increases gradually with increasing volumetric concentration ratio (Φ) as well as with increasing mass flow rate. At Φ = 0 (i.e., without nanoparticles), the efficiency is lower than the rest of the values, highlighting the effect of particles in improving heat transfer. At Φ = 0.05 and with the highest mass flow rate (0.05 kg/s), the efficiency is approximately 61.5%. Heat transfer between the surface of collector and the fluid is facilitated by Al_2O_3/water nanofluid which has high thermal efficiency compared to water. Viscosity increases with increasing Φ, which can increase frictional losses, but improvement in thermal conductivity compensates for this at moderate concentrations.

4.3.2. Effect MWCNT/water Nanofluid

Fig. 7 shown using MWCNT/water nanofluid. The efficiency here is high than from all types. The maximum efficiency at Φ = 0.05 and the highest mass flow rate (0.05 kg/s) reaches approximately 80.5%. Note that performance is clearly superior to Al_2O_3, especially at low flows. MWCNT has a higher thermal conductivity than Al_2O_3, thus promoting heat transfer more effectively. However, it may cause stability and agglomeration problems at high concentrations, which explains its slightly higher performance than a hybrid fluid.

4.3.3. Effect Al_2O_3+MWCNT/water Hybrid Nanofluid

Fig. 8 shows using Al_2O_3+MWCNT/Water (80:20) hybrid nanofluid this hybrid nanofluid combines the high thermal properties of MWCNT and the uniform distribution of Al_2O_3. The thermal efficiency in this type is the highest compared to the first type. At Φ = 0.05 and with the highest mass flow (0.05 kg/s), the efficiency is approximately 78.3%. The improvement is most noticeable at concentrations as low as 0.01 compared to Al_2O_3. MWCNT possesses very high thermal conductivity (up to 3000 W/m·K) and acts as efficient thermal transfer channels. Al_2O_3 helps stabilize suspension and particle distribution. Synergy between the two materials reduces agglomeration and improves convection properties.

Particle type effect: Al_2O_3 Medium conductivity (40 W/m·K), stable performance. MWCNT is superconductive (3000 W/m·K), but a potential agglomeration. Al_2O_3+MWCNT balances high conductivity and stability.

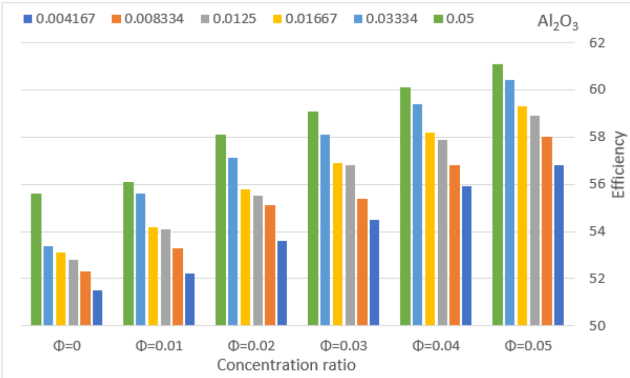


Fig. 6. Variation Thermal efficiency with Concentration ratio for Al_2O_3/water mono nanofluid in different mass flow rates (0.004167 to 0.05) kg/s.

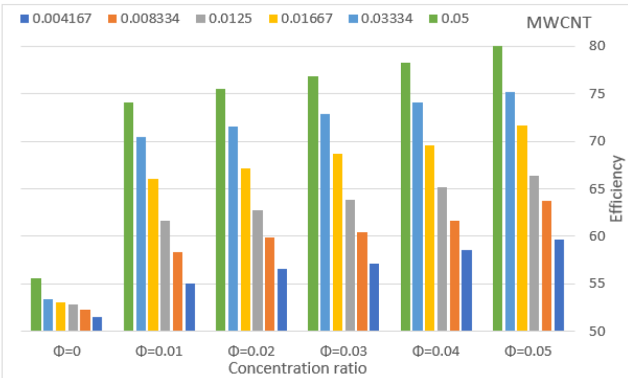


Fig. 7. Variation Thermal efficiency with Concentration ratio for MWCNT/water mono nanofluid in different mass flow rates (0.004167 to 0.05) kg/s.

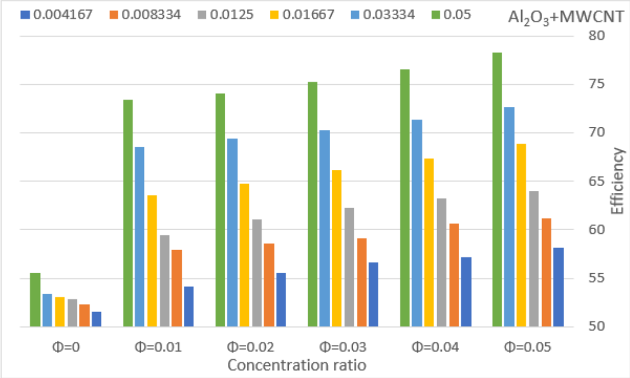


Fig. 8. Variation Thermal efficiency with Concentration ratio for Al_2O_3+MWCNT/water hybrid nanofluid in different mass flow rates (0.004167 to 0.05) kg/s

5. Conclusion

To improve the thermal performance of the flat plate solar collector, the study used a variety of nanofluid types, including Al_2O_3, MWCN, and the hybrid Al_2O_3+MWCNT (80:20%).

1. The FPSC efficiency was found to be directly influenced by the concentration nanoparticles, the fluid flow rate, and type of nanoparticles.
2. Of the three composite fluids utilized in the numerical study, MWCNT produced the most efficient results.
3. According to the results, MWCNT's highest efficiency 80.4% for 0.05 concentration ratio at the mass flow rate of 0.05 kg/s, which was around 24.8% greater than water under the same mass flowrate.
4. The efficiency of MWCNT/water higher than the Al_2O_3/water, considering the mass flow rate of 0.004167-0.05) kg/s.
5. According to this study, employing hybrid Al_2O_3+MWCNT (80:20%) increases efficiency by 19.6%, 20.9%, and 22.7% at mass flowrate 0.05 kg/s for (0.01, 0.03, 0.05), respectively.
6. This suggests that 80% of the MWCNTs be swapped out for the less expensive and dangerous Al_2O_3.

In conclusion, the findings showed that the using of Al_2O_3 and MWCNT nanofluids increases the efficiency of the flat plate solar collector relative to the base fluid. The use of MWCNT as a mono nanofluid gives the highest efficiency relative to all types, but the cost of these nanoparticles is very high, in addition to their negative effects on the system, they are unstable and tend to agglomerate faster, which requires a higher pumping capacity because they may lead to damage to the system in case of agglomeration. Using a hybrid nanofluid Al_2O_3-MWCNT is the best solution. The choice of mixing ratio (80:20) (Al_2O_3:MWCNT) gives a more stable hybrid nanofluid and less damaging to the system because the Al_2O_3 nanoparticles have higher stability compared to MWCNT.

Nomenclature

Symbol	Quantity
FPSC	Flat Plate Solar Collector
FPSWH	Flat Plate Solar Water Heating
V_{wind}	Wind Speed
T	Temperature
u	Fluid velocity
D_h	Hydraulic Diameter
ZnO	Zinc oxide
Al_2O_3	Alumina
CuO	Copper oxide
CNT	Carbon Nanotube
MWCNT	Multi Wall Carbon Nanotube
SWCNT	Single Wall Carbon Nanotube
MgO	Magnesium oxide
ND	Nanodiamond
EG	Ethylene Glycol
CeO_2	Cerium oxide
CO_2	Carbon dioxide
Fe	Iron
Cu	Copper
Ag	Silver
TiO_2	Titanium dioxide
WO_3	Tungsten trioxide
SiC	Silicon carbide
Fe_3O_4	Iron III oxide
Al	Aluminum
MCV	Mixed Convection Validation Model
NCV	Natural Convection Validation Model
Q	Useful Heat
$\dot{m}$	Mass flowrate
h	Heat transfer coefficient
Cp	Specific heat
k	Thermal Conuctivity
Symbols of Greek	
ρ	Density
μ	Dynamics Viscosity
Φ	Volumetric-Concentration Ratio
η	Thermal-Efficiency
θ	Collector Tilt Angle
β	Thermal-Expansion Coefficient
Optical parameters	
α	Absorptivity
ε	Emissivity
σ	Stefan–Boltzmann Constant
τ	Transmissivity
ρ	Reflectivity
Subscripts	
f	Fluid
nf	Nanofluid
hnf	Hybrid Nanofluid
np	Nanoparticle
ext	External
gc	Glass Cover
in	Inlet
out	Outlet
avr	Average
abs	Absorber
Dimensionless numbers	
Re	Reynolds Number
Pr	Prandtl Number
Nu	Nusselt Number

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