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Influence of Nanofluid Types on the Enhancements of Solar Collector Performance

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ABSTRACT

Nowadays, solar energy is attracting a great deal of research interest. Optimizing solar collectors by incorporating nanoparticles into the base fluid is one area of current research focus. This study investigates how the types of nanoparticles affect the performance of solar collector. We investigated the effects of various nanoparticles types on performance of solar collector. Nanofluid 1 (alumina nanoparticles; Al_2O_3) and nanofluid 2 (silicon dioxide nanoparticles; SiO_2) were combined with water. Nanofluids are made with a constant nanoparticle concentration of 0.5 vol. %. Data collection was conducted under Iraqi environments during the three-month study period (January, February, and March) from 9 a.m. to 3 p.m. In particular, the data for every two-hour period is displayed. The results demonstrated the collector's efficiency significantly influenced by nanoparticles' type. At 1 p.m. in February, nanofluid 1 was 4.8% in front of nanofluid 2. The significance of nanoparticle materials in enhancing solar collector efficiency is highlighted by this outcome. When water-based fluid in the solar collector was compared to nanofluids 2 and 1, the latter demonstrated a typically better efficiency. Nanoparticle owns higher thermal conductivity which is one of the reasons behind the increments of the nanofluid's overall conductivity.

1. Introduction

As a cost-effective response to the growing demand for electricity, renewable energy has emerged as the world's primary source of electricity. Solar energy is unique among these renewable energy sources because of its wide availability and capacity to meet the world's energy needs. Beyond the production of conventional electricity, solar applications are essential for energy conservation, especially in operations where significant energy savings can be realized, like desalination and water boiling (Azeez et. al., 2022; Hussein et. al., 2017; Yu et. al., 2021). Regarding the field of solar energy application, solar collectors are of two main types: concentrating and non-concentrating (Mathew et. al., 2021). Flat plate solar collectors (FPSC) and evacuated tube collectors (ETC) are two prominent non-concentrating collector types; FPSC is becoming more and more popular due to its low cost and simplicity of installation (Said, et. al., 2015). FPSC directly transfers heat from reflected sunlight to the working fluid, usually water, making it especially ideal for residential water heating systems. This direct heat transfer mechanism is attractive for wider adoption since it reduces

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maintenance requirements, requires less cleaning work, and does away with the need for intricate sunlight tracking devices.

Despite its benefits, FPSC has drawbacks like lower thermal efficiency due to convection and radiation heat losses. A significant amount of literature conducted the enhancement parameter of FPSC in order to meet these limitations (Duffie & Beckman, 2013). One significant development in this field is the incorporation of nanofluids. Dispersing nanoparticles in heat transfer fluids creates nanofluids, which offer a potential path in thermal sciences. The cornerstone of improved heat transfer efficiency is greater thermal conductivity, which is derived from the theoretical groundwork established by Maxwell for the prediction of suspension conductivity (Gupta et. al., 2017). In 1995, Choi and Eastman conducted groundbreaking research that showed that a mere 1% increase in nanoparticle volume concentration could double the thermal conductivity of nanofluids (Choi, & Eastman, 1995). It appears that adding nanofluids to FPSC will increase its effectiveness.

By introducing nanoparticles to nanofluids, forced conventional heat transfer systems can change their viscosity, pressure drop, and power needs (Said, et. al., 2013). Said et al.'s studied effects of TiO_2-water nanofluids on FPSC at volume percentages ranging from 0.1% to 0.3%. Stabilizing agents such as ethylene glycol and poly (PEG 400) were used in the study to ensure nanofluid stability throughout 0.5 to 1.5 kg/min. At 0.1 vol% and 0.5 kg/min, the results showed the maximum energy efficiency (16.9%), with no discernible changes in pressure drop or pumping power in comparison to the base fluid. Nanofluid with 0.3% shows an improvements in thermal conductivity by 6%. Depending on the literature, nanofluid enhance the efficiency of FPSC (Gupta et. al., 2017; Sundar et. al., 2020). In fact, nanoparticles own higher surface area, thermal properties which result increments in heat transfer of the nanofluid (Zhang et. al., 2007; Xie et. al., 2003; Javadi et. al., 2013; Ramachandran et. al., 2017). Furthermore, effect of different types of nanoparticles (SiO_2 and Al_2O_3) had been conducted (Khalid et. al., 2019). The results show that conductivity of nanofluid had been increased by 4.39% of Al_2O_3 nanofluid in comparison to base fluid without any additives (Khalid et. al., 2019).

As shown above, that nanoparticles have been positively influence the performance of FPSC. Therefore, in this study and under the Iraqi weather conditions, we examined the influence of two different nanoparticles' types on the performance of FPSC during (January-February-March). We selected the Al_2O_3 and SiO_2 nanoparticles because these two types have been tested and they found to show an improvement of the nanofluid properties by (Khalid et. al., 2019).

2. Preparation of Materials

Without undergoing any further procedures, we implement Al2O3 and SiO2 into the base fluid. Al2O3 and SiO2 have been purchased from HiMedia Laboratories Pvt. Ltd., Mumbai, India. First of all, nanoparticles mechanically dispersed into the base fluid. Secondly, an electronic mixing applied for 90 minutes to homogeny disperse the nanofluid. Ultrasonic has been used for 90 minutes to ensure a well-disperse nanofluid. After that, nanofluid swirled inside the test section. It was observed that nanofluids are stable for 17 hours. The kinds of materials used in this work are collected in Table 1.

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Table 1: The properties for the material used in this research (Khalid et. al., 2019).

Properties	Water	Nanofluid 1 (0.5% Al_2O_3 -water)	Nanofluid 2 (0.5% SiO_2 - water)
Density (kg/m^3)	996	4000	2220
Specific heat capacity (J/kg.K)	4178	765	745
Thermal conductivity (W/m.K)	0.615	36	1.4

3. Experimental setup

This arrangement consists of one by one meter box made from aluminium and 3-layers of plastic panel, an aluminum layer within, and glass wool insulating material between. A 4 mm thick fixed glass cover minimizes heat loss while allowing sun rays to flow through. Included in the solar collector are 0.85-meter-long copper tubes with headers that have an inside diameter equals to 22.5 mm with 1 mm in thickness. The dimensions of heat-absorbing tube are inside diameter= 9.5 mm with 1.5 mm thick. To reduce heat loss, Armaflex insulation was layered twice inside the collector to act as insulation.

Heat exchangers, made in Germany, and tanks are connected together by 0.5 in plastic pipes, valves, and connections. These connections were used to control the flow rate of the working fluid. To move fluids around the system, 2-vertical pumps (0.25 HP, maximum height 2.5m) were used. Two pumps were used: one to transport the nanofluid outside container to the collection and another to circulate water. A flow-meter was used to track each fluids' respective flow rates. The experimental setup's schematic diagram is shown in Fig. 1. Type K thermocouple sensors and a controller system were used by the data recording system to gather and store the data.

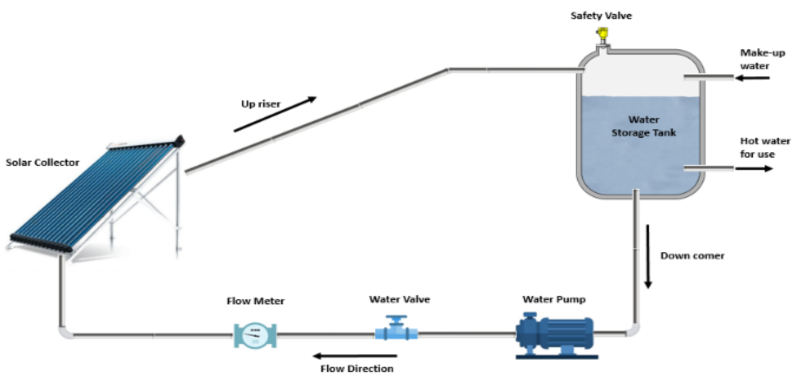

Figure 1. The schematic diagram of experimental setup.

4. Data Reduction

In a steady state flat plate solar water collector (q), the potential energy production is (Hwang et. al., 2009; Terekhov, et. al., 2010):

$$q = \dot{m} \times Cp_{nf} \times (T_{c.o} - T_{c.\ in}) \quad (1)$$

Where: $\dot{m}$= mass flow rate (kg/sec), $Cp_{n.f}$ is nanofluid specific heat (kJ/kg. K), $T_{c,\ in}$ and $T_{c,o}$ (K) inlet and outlet of the fluid into the solar collector, respectively. The efficiency, $\eta_{c.}$ (Khalid et. al., 2019):

$$\eta_c\% = \int_{t1}^{t2} q\, dt / A_c \int_{t1}^{t2} R(t)\, dt \quad (2)$$

Where: R(t) represents the instantaneous solar radiation (W/m^2), and A_c represents the collector's area (m^2).

5. Results and Discussions

Figure 2 shows the solar intensity during the hours of 9 a.m. to 5 p.m. for January, February, and March. The variations in solar radiation peak around 12 p.m. for March, February, and January, respectively, at 805 W/m^2, 800.8 W/m^2, and 792.5 W/m^2. After this high, there is a sharp fall that culminates in its lowest values in March, February, and January, which are 692 W/m^2, 688.5 W/m^2, and 682.4 W/m^2, respectively. Furthermore, as Figure 4 shows, data at March exhibits a greater solar intensity throughout time in comparison to both January and February.

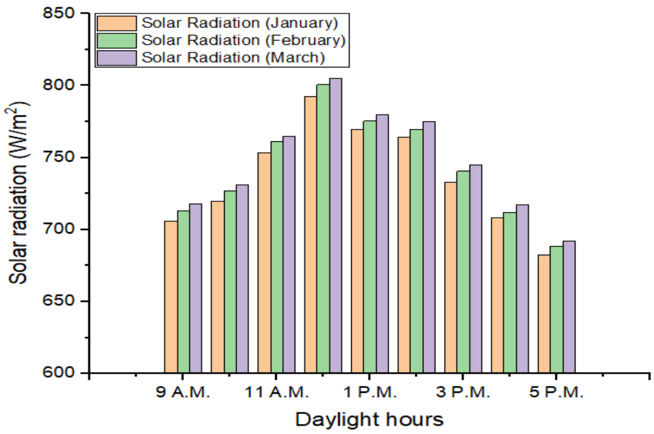

Figure 2. The solar radiations at different months (January, February, and March) vs. Daylight hours (9 a.m. – 5 p.m.)

By contrasting the study's findings with existing literature, its validity has been established (Sundar et. al., 2010; Khalid et. al., 2019). Current results were compared with data from the reference (Sundar et. al., 2010; Khalid et. al., 2019) as shown in Figure 3. A good agreement has been observed between the current work and the literature findings, Figure 3. This emphasize the reliability of current work.

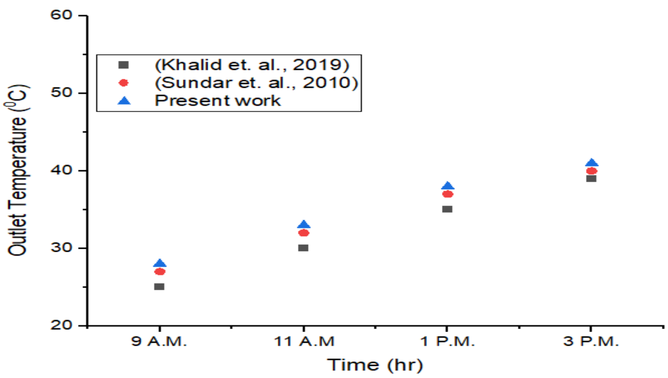

Figure 3. Comparsion between the current data and literature (Sundar et. al., 2010) and (Khalid et. al., 2019).

According to Figures (4-6), it is obvious that nanofluid outperform the base fluid. In fact, nanofluid 1 shows the higher increased in the collector efficiency than other types. For example, at 1 P.M. February, collector efficiency were 25.76%, 28.1%, 26.8% for base fluid, Nanofluid1, and Nanofluid2, respectively.

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This emphasizes the impact of nanoparticles presence and types on the collector efficiency.

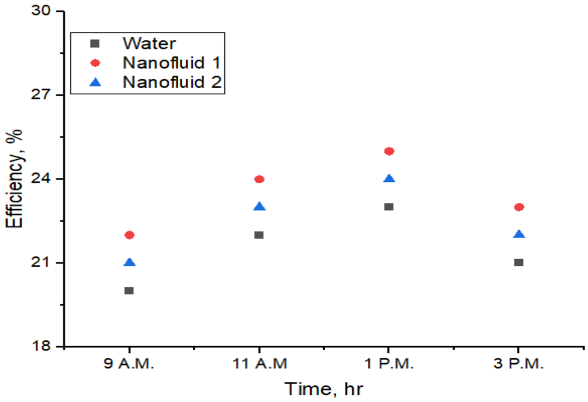

Figure 4. Efficiency of FPSC for three different fluid vs time, January data

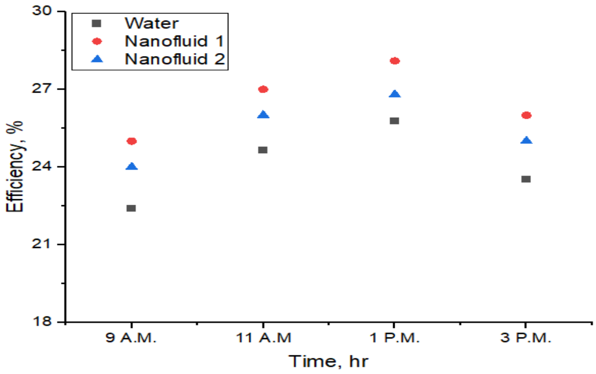

Figure 5. Efficiency of FPSC for three different fluid vs time, February data

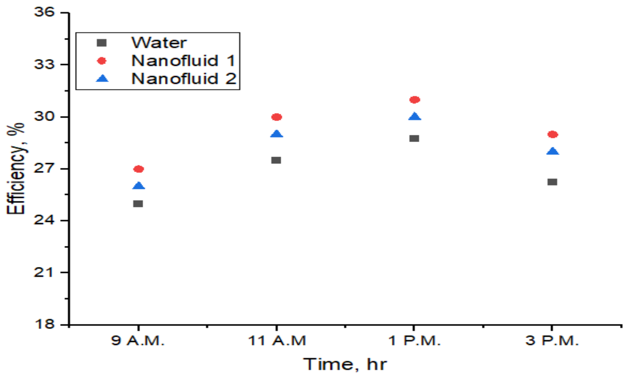

Figure 6. Efficiency of FPSC for three different fluid vs time, March data.

Moreover, date during March month showed higher increments in the efficiency than January and February months. This is obvious due to higher intensity of solar radiation in March month in comparison to both of January and February months.

On the other hand, output power data sensitivity affected by the different types of nanoparticles. Nanofluid 1 owns a higher readings of the output power.

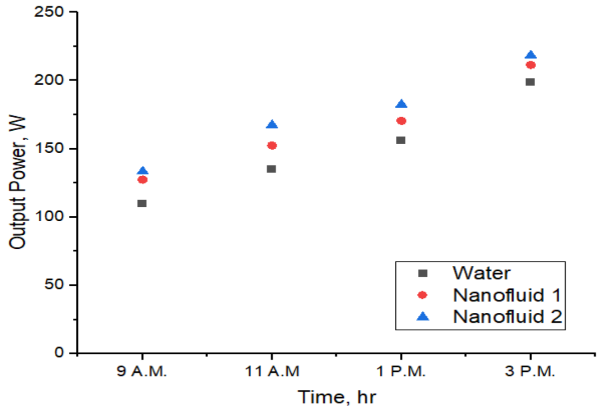

Figure 7. The output power vs. time

It is clear that Al_2O_3 nanoparticles outperform the SiO2, this could be due to the higher thermal properties as shown in Table 1. Nanofluid 1 owns thermal conductivity= 36 W/m. K while nanofluid 2 has thermal conductivity= 1.4 W/m. K in comparison to base fluid of thermal conductivity= 0.615 W/m. K. This could be one of the reason behind the improvements in the collector's efficiency. Furthermore, collector efficiency increases due to higher surface area of nanoparticles that help nanofluid to capture more of the sunlight. Additionally, the different types of nanoparticles play a virtual role in the improvements of the collector performance. At 1 P.M. in February data, Nanofluid 1 showed a higher performance of collector up to 5% in comparison to Nanofluid 2.

6. Conclusion

In this work, experimental investigation of different types of nanoparticles on the flat plate solar collector were conducted. Concentration of nanoparticles in Nanofluid 1 and Nanofluid 2 fixed to 0.5 vol.% to examine carefully the effect of type of nanoparticles. The data collected at 3-months [January, February, and March] in Kirkuk city- Iraq during the 9 a.m.-3 p.m. It was found that Al_2O_3-nanofluid (Nanofluid 1) better than SiO_2-nanofluid (Nanofluid 2).

The higher thermal properties of nanoparticles helps them to improve the collector performance. Moreover, higher surface area of these nanoparticles would improve the capture of sunlight by the nanofluid. In summary, nanofluid can develop an efficient solar collectors.

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