FEATURE OF SiO_2 CONCENTRATION ON SOLAR THERMAL FUNCTIONAL CHARACTERISTICS OF FLAT PLATE SOLAR COLLECTOR

by

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Solar collectors configured with flat plate innovation pushed to drive the prime role in research in solar renewable energy due to economic, sustainable, and eco-friendly. Besides, the low thermal efficiency and heat loss are the major drawbacks of using flat plate-type solar collectors. The current research adopts the 2% volume fractions of SiO_2 nanofluid as the working fluid. Their effects on solar thermal functional characteristics of solar collectors made with the flat plate are experimentally analyzed with the mass-flow rate of 2 Lpm, 2.5 Lpm, 3 Lpm, and 3.5 Lpm, respectively, for air dryer applications. A flat plate solar collector's investigational thermal performance is compared with water fluid. The significance of a 2% volume fraction of SiO_2 nanofluid is operating at 3.5 Lpm recorded higher temperature (71 °C), optimum thermal efficiency of 84.1%, and better drying efficiency of 83.4%. The optimum results of the present investigation utilized for air dryer applications.

Key words: *air dryer, flat plate solar collector, SiO_2, thermal performance*

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Introduction

Economic spread with huge populations, energy consumption is significantly improved, and demandgrows steadily [1], compensated by utilizing renewable energy [2]. The trend for solar renewable energy research is to expose better alternative energy sources for the future and play a vital role in solar thermal applications [3, 4]. Flat plate and parabolic trough solar collectors have recentlygathered importance in water heating, solar drying, heat exchangers and solar heating and cooling applications [5, 6]. Besides, the heat loss due to the wide area of the flat plate and decreased thermal efficiency is the problem that occurs with flat plate solar collectors operated with water fluid [7]. Using coating material and nanofluid technology reduces the unrated heat loss and increases the thermal performance of solar systems [8, 9]. However, the design of the solar collector, operating parameters, and thermal management system is to fix the performance of the solar collector [10].

Moravej *et al.* [11] experimentally investigated and analyzed the flat plate solar collector thermal efficiency by using water and TiO_2-water nanofluid combinations. They reported that the system operated with 1wt.% TiO_2-water blend nanofluid gained a maximum thermal efficiency of 78% compared to water fluid. Moreover, the concentration of TiO_2 nanoparticles facilitated good thermal gain. Choudhary *et al.* [12] studied the flat plate solar collector adoption with iron oxide nanofluidat different mass-flow rates (30-150 Lph). They reported that the system operated with 1 vol.% iron oxide nanofluid under a 30 Lph flow rate found a maximum thermal efficiency of 68% related to water fluid at a similar flow rate. Akram *et al.* [13] experimentally investigated and compared the thermal behaviour of flat plate solar collectors using oxide nanofluids. The experimental results showed progressive improvement in thermal properties with improved nanofluid concentration. The higher metal oxide concentration was found to have better thermal efficiency. Besides, the thermal performance of the flat plate solar collector system will be varied due to the selection of material, nanofluid, and flow conditions. They found that the system installed with a higher concentration of nanofluid offered maximum thermal conductivity and solar gain [14]. Tong *et al.* [15] studied and compared the energy and exergy performance of solar collectors installed with flat plates and operated by Al_2O_3 and CuO under varied flow rates. The 1 vol.% Al_2O_3 nanofluid adopted flat plate solar collector found significant improvement in thermal and exergy efficiency compared to other fluids and operated with 0.047 kg/s flow rate was found to be higher thermal efficiency of 78%. However, the solar collector installed with a flat plate operated by oxide basis nanofluid exposed good thermal behaviour compared to others. Many researchers found good thermal conductivity and maximum heat gain [16, 17].

According to the aforementioned literature, the thermal performance of flat plate solar collectors is enhanced by the action of nanofluid and SiO_2-based nanofluid, gaining advantages over other fluids [18, 19]. The present aims to enhance the solar collector configured with a flat plate via SiO_2 nanofluids of 2% volume fraction under different flow rates. Effect of nanofluid concentration on thermal properties like fluid temperature associated with solar radiation, thermal efficiency of solar collector, and dryer efficiency. Output results of the present research found higher temperature gain improved thermal efficiency with better drying efficiency on 3.5 Lpm flow rate compared to others. With this, the best result of a solar collector is connected toa solar dryer and used for air dryer applications.

Materials and methods

Selection of nanofluid

Comparable, the (SiO_2) nanofluid has superior thermal conductivity, better stability, enhanced heat transfer rate and compatibility (mixing with water, glycol, and oil) [18]. For this reason, the SiO_2 nanofluid is chosen as a working fluid with a concentration of 2% volume fraction. Table 1 illustrates the properties of working fluids.

Table 1. Behaviour of working fluids

Working medium	Density [kgm^{-3}]	Specific heat capacity [Jkg^{-1}K^{-1}]	Thermal conductivity [Wm^{-1}K^{-1}]
Water	997.72	4178	0.598
SiO_2 nanofluid	2200	745	1.4

Solar collector installed with flat plat set-up

Figure 1 illustrates the solar collector set-up configured with a flat plate and contains a symmetric flat plate collector, absorber plate covered with a glass plate, nanofluid storage tank, pump, air duct, and dryer assembly. The specification of a flat plate solar collector is shown in tab. 2.

Here, the nanofluidis stored in the storage tank and circulated with the help of a pump assembly. With the help of a pressure gauge and flowmeter, the pressure and fluid-flow are controlled. The nanofluid is forced to circulate the flat plate solar collector assembly based on designated flow rates. Its inlet and out temperature of nanofluid, temperature gain, and hot air temperature of air-dryer are noted by *K*-type thermo couple set-up. This investigation utilized water and a 2% volume of SiO_2 nanofluid as a working medium. Its performance was measured by the flow conditions of 2 Lpm, 2.5 Lpm, 3 Lpm, and 3.5 Lpm. The experiments were conducted between 8.00 a. m. and 17.00 p. m: mm for five days, and the average is considered for investigation analysis.

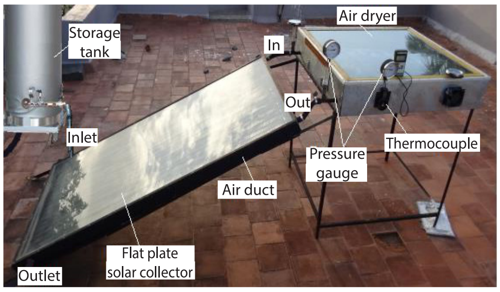

Figure 1. Flat plate solar collector with air dryer set-up

Table 2. Specification of flat plate solar collector

Particulars	Specification details
Working fluid	H_2O and SiO_2
Absorber	Cu
Backplate	Al
Thickness of plate	4 cm
Length of pipe	1885 mm
Area of collector	2.1 sq.m
Angle for collector	30°
Transmissivity	0.765

Uncertainty analysis

According to the present investigation, every instrument hada minimum percentage calibration error during the evaluation and data collection. Besides, the uncertainty of investigation measured results deviated from the basics and was considered an error value [5]. In the present investigation, the thermocouple, pressure gauges, flow meter, and solar analyzer are utilized, and their permissible range and percentage of uncertaintyare addressed in tab. 3.

Table 3. Uncertainty analysis for measuring instruments

Measuring parameters	Permissible range	Uncertainty percentage
Pressure	±0.5 bar	±1
Flow rate	±1 Lpm	±3
Temperature	±1 °C	±2.5
Solar radiation	±0.1 K	0.05%

Results and discussions

Variations of temperature

Figures 2 and 3 represents the temperature variations during the evaluation of a flat plat installed solar collector operated with water and SiO_2 nanofluid under different fluid-flow rate.

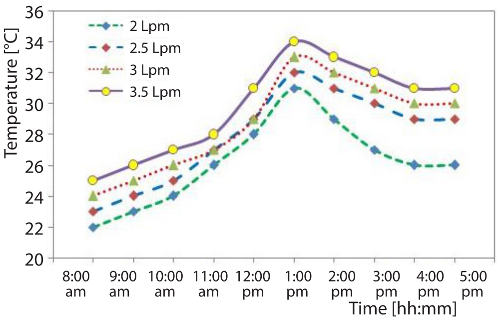

Figure 2. Temperature variations during water fluid

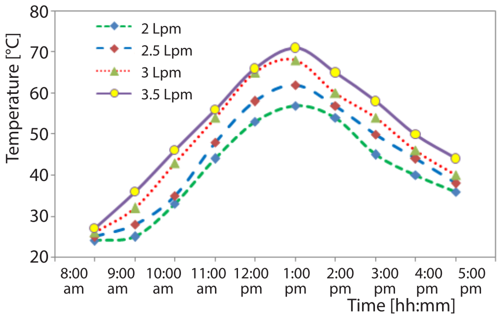

Figure 3. Temperature variations during SiO_2 nanofluid

Compared to water fluid, the temperature performance of SiO_2 nanofluid found higher temperature gain due to the appearance of a 2% volume fraction of SiO_2. It has better stability and enhanced thermal conductivity related to water fluid [6].

Here, fig. 2 depicts the experimental temperature results for a flat plate configured solar collector operating with water fluid. It was noted by 8.00 a. m. to 5.00 p. m., and its output temperature recorded progressive enhancement in temperature concerningan improved flow rate of 2-3.5 Lpm under 0.5 Lpm intervals. Besides, the temperature of water fluid steadily rises from 22 °C at 8.00 a. m. to 31 °C at 1.00 p. m. under 2 Lpm, then falls to 26 °C at 5.00 p. m. Likewise, other flow rates are shown, and the maximum temperature gain of 34 °C is noted by 3.5 Lpm flow rate at 1.00 p. m. The enhanced temperature gain is due to variations in solar radiations [7] and copper absorber plate utilization [8]. The higher flow rate offered a better temperature rise than gravitational action [10].

Figure 3 indicates the scatter plot curve for variation in nanofluid temperature measured by different flow rates under a constant volume fraction (2%) of SiO_2. Comparable to water fluid, it significantly enhanced fluid temperature due to high specific heat capacity behaviour. As earlier, the researchers utilized a 1% volume fraction of SiO_2 while evaluating flat plate solar collectorsand found better solar radiation effect on nanofluid results and better thermal properties [19].

The temperature curve showed the uptrend on improved flow rate up to peak sunlight and partially decreased. Here, the flat plat installed solar collector operated with a 2% volume fraction of SiO_2 under a high flow rate found a maximum nanofluid temperature of 71 °C at

1.00 p. m., higher than all others. The enhancement of nanofluid temperature was due to the presence of SiO_2 (2%), which offered good thermal conductivity rather than water. Besides, the nanofluidhas good fluidity characteristics and better thermal properties [18]. While compared to water fluid, the temperature of SiO_2 was recorded as 1.08 times higher than the value of water fluid under a high flow rate at peak sunlight.

Thermal efficiency

According to experimental results, the fig. 4 bar chart displays the thermal efficiency of flat plat installed solar collector efficiency measured with water and 2% volume fraction of SiO_2 nanofluid under 2-3.5 Lpm flow rate with 0.5 Lpm interval. Comparable to a water fluid-operated flat plate installed solar collector system, the SiO_2-operated flat plate configured solar collector's thermal efficiency showed better. Previously, the researchers reported that the conventional solar collector system modified with flat plat using nanofluid has better thermal performance [9, 10].

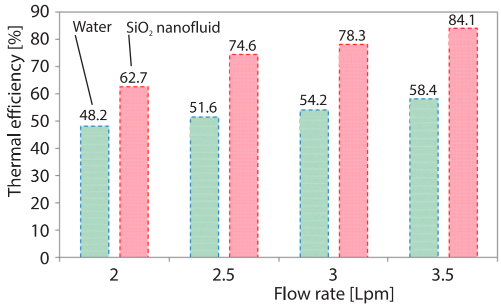

Figure 4. Thermal efficiency *vs.* flow rate

Here, the thermal efficiency of water-operated solar collectors with flat plate arrangement was found to be 48.2%, 51.6%, 54.2%, and 58.4% on improved flow rates of 2 Lpm, 2.5 Lpm, 3 Lpm, and 3.5 Lpm, respectively, when replacing the SiO_2 nanofluid instead of water fluid recorded better thermal efficiency. The thermal efficiency of the SiO_2 nanofluid-operated solar collector system showed a significant improvement due to the nanofluid. It showed 62.7%, 74.6%, 78.3%, and 84.1% on an increased flow rate of 2-3.5 Lpm. The enhancement of thermal efficiency was mainly attributed to the configuration of flat plate, copped absorber, andnanofluid. The researchers reported a maximum thermal efficiency of 83.9% on a 1% volume fraction of SiO_2 fluid [19].

Dryer efficiency

Figure 5 indicates the dryer efficiency of a flat plate installed solar collector connected with a dryer set-up and operated using water and SiO_2 fluid at 2 Lpm, 2.5 Lpm, 3 Lpm, and 3.5 Lpm flow rates. The dryer efficiency of the present investigation operated with SiO_2 nanofluid is higher than the water fluid. The better specific heat capacity and higher temperature gain of SiO_2 nanofluid is the main reason for the enrichment of dryer efficiency. Here, the dryer efficiency of the solar collector (flat plate) functioned with water fluid showed acceptable improvements like 34.2%, 42.4%, 45.1%, and 47.1% on 2 Lpm, 2.5 Lpm, 3 Lpm, and 3.5 Lpm mass-flow rates. It was due to low thermal conductivity and specific heat [9].

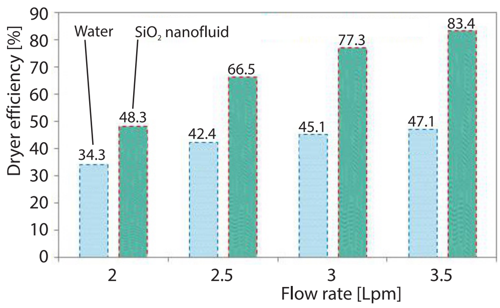

Figure 5. Dryer efficiency *vs.* flow rate

While the solar collector system adopted with a flat plate functioned dryer unit recorded a significant rise in dryer efficiency and was found to be 48.3%, 66.5%, 77.3%, and 83.4% at an improved flow rate. The maximum dryer efficiency of 83.4% is found at a higher flow rate and improved by 0.77 times higher than the water fluid in similar conditions. The optimum flow rate and 2% volume fraction of SiO_2 nanofluid utilized for flat plate installed solar collector for dryer applications.

Table 4 represents the comparative values for thermal efficiency of the present research to existing literature and found that the thermal efficiency of a 2% volume fraction of SiO_2 operated solar collector equipped with flat plate showed the higher value, and compared to recent literature, it was improved by 7.8%, 23.67%, and 0.2% compared by 1% TiO_2-water [11], 1 vol.% Fe_3O_2 [12], and 1 vol.% vol fraction SiO_2 [19] operated flat plate solar collector.

Table 4. Comparative statement for present investigation thermal efficiency results to past literature

Nanofluid	Flow rate	Thermal efficiency	Reference no.
1% TiO_2-water	0.05 Lps	78	11
1vol.% Fe_3O_2	30 Lph	68	12
1%vol. fraction SiO_2	–	83.9	19
2%vol. fraction SiO_2	3.5 Lpm	84.1	Present investigation

Conclusions

The main objective of the present investigation is to enhance the thermal properties of flat plate installed solar collector operated with a 2% volume fraction SiO_2 nanofluid, proving their significance related to dryer applications. The main key points are summarized as follows.

- Among the various working fluids and flow rates, the 2% volume fraction SiO_2 nanofluid operated with 3.5 Lpm found better thermal properties of flat plate equipped solar collector and proven better dryer efficiency compared to water working fluid.
- The solar collector with a flat plate set-up functioned by a 2% volume fraction of SiO_2,was found to be a good temperature gain and hiked by 1.08 times higher than the water fluid under a high flow rate.
- Likewise, the thermal efficiency of flat plat linked solar collector run with a 2% volume fraction of SiO_2 recorded 84.1% under 3.5 Lpm flow rate.
- With these enhancement results, the dryer performed good efficiency on a 2% volume fraction of SiO_2 functioned flat plate configured solar collector and improved by 0.77 times larger than water fluid.
- In the future, it will be utilized for agriculture seed drying and investigated by various concentrations of SiO_2.

Declarations

Funding statement: No funding was used for this study.

Conflicts of interest: Authors declare no conflicts of interest.

Data availability: All the data required are available within the manuscript.

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