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Thermal Performance of Aluminum Oxide based Nanofluids in Flat Plate Solar Collector

Ramalingam Senthil

Abstract*: *A flat plate solar collector is investigated using nanofluid as heat transfer fluid in this work. Collector aperture area is 0.135 m^2. Nanofluid is a mixture of alumina-oxide and distilled water. Size of the nanoparticle is 20 -30 nm size. Experiments carried out using distilled water and 5.0% of the mass of Al_2O_3 nanoparticles at single flow rates of 0.051 kg/s and different radiation intensity 600, 800, 1000 W/m^2. Indoor experiments are conducted with the solar sun simulator. The promising results are obtained around 21% improved heat gain as well as around 20% reduction in the heat input required to provide the same heat requirements. Further, the addition of nanoparticles to the working fluid improves the productivity of the solar collectors with more heat gain.

Index Terms*: *Flat plate collector, thermal efficiency, nanofluid, solar thermal collector.

I. INTRODUCTION

Solar energy is one of the renewable energy sources used by many countries for their thermal and electrical requirements. Solar energy is a preferable resource for its eco-friendliness. Flat plate solar collector (FPC) is the most commonly used because of their effectiveness of conversation and low manufacturing costs. Further, FPC is the simplest form and requires almost zero maintenance. The salient points from the literature and the objective and methodology of this study are discussed in this section. The low temperature operation necessitates a good conducting material for FPC. Several researches have been conducted to analyze the functioning of the collector with improved efficiency [1-2].

Potable water is one of the major concerns in several countries. The cost involved in the conversion of saline water into portable water is higher. Solar stills (SS) are one of the options for the small to medium scale installations. Flat plate collectors are used in such thermal systems. SS is used to the process of removal of salt and impurities from the water. Several researchers were worked on performance enhancement methods and techniques for SS. Coupling of FPC with SS showed improved productivity. SS with different solar collectors and mode of operations are carried out in recent years [3-5].

Addition of reflectors or booster mirrors to FPC increased the incident solar radiation and consequently improved the thermal performance. The effect of reflectors showed reduced return time on investment costs [6].

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***** Correspondence Author (s)
Ramalingam Senthil*, Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai, India.

Heat transfer improvement methods in phase change materials (PCM) and the effect of PCM in the concentrated and non-concentrated solar collectors are investigated by Senthil et al. [7]. Thermal storage enhances the productivity of the FPC. Various nanofluids are prepared and investigated for thermal performance enhancement like aluminum oxide, copper oxide, zinc oxide and selenium oxides [8]. Improvement of thermal performance was studied through energy and exergy analyses. From literature, FPCs were investigated for improvement of thermal performance through booster mirrors, secondary reflectors, thermal storage-based absorbers, nanofluid utilization. The effect of Demineralized water (DM) water with and without nanoparticles was not investigated much using experiment methods. The objective of this work is to study the effect of nanoparticles in the working fluid DM water. In this paper, experimental investigation is mainly focusing the thermal performance of FPC with copper tube and the effect of nanoparticles dispersion in the DM water. The comparison study of the thermal performance of the FPC with and without Al_2O_3 nanofluid is reported here.

II. EXPERIMENTAL WORK

FPC is fabricated for testing nanofluid at indoor experimental setup with the solar simulator. Fabrication of FPC with a required absorber plate and absorber tubes, pump and piping for the selected heat transfer fluid. Piping was insulated to avoid the heat losses between the FPC and the storage tank. Synthesis of nanofluid using DM water and Al_2O_3 nanoparticles of 5% mass concentration. The piping is minimized as short as to reduce the heat losses between the collector and tank. A hot water pump is used to supply the fluid. A flow meter and flow regulating valve are used to control the flow rate. Thermal performance study of the fabricated solar collector conducted with different simulated solar radiation. Halogen lamps are used to provide the required constant radiation. Three levels of light intensity are provided as 600, 800 and 1000 W/m^2. Measurements are mainly temperature of the collector and radiation flux on the collector. Lux meter is used to record the radiation. K-type thermocouples are used to observe the temperature of the working fluid. The schematic of experimental setup is shown in Figure 1. Specifications of the collector components used in Table 1. Thermal performance study of the fabricated solar collector is carried out at the indoor testing of DM water based nanofluid with the different solar radiation conditions. Determination of the heat gain of the DM water and DM water with nanofluid are compared for the improved thermal performance. The schematic diagram of FPC is shown in Figure 1.

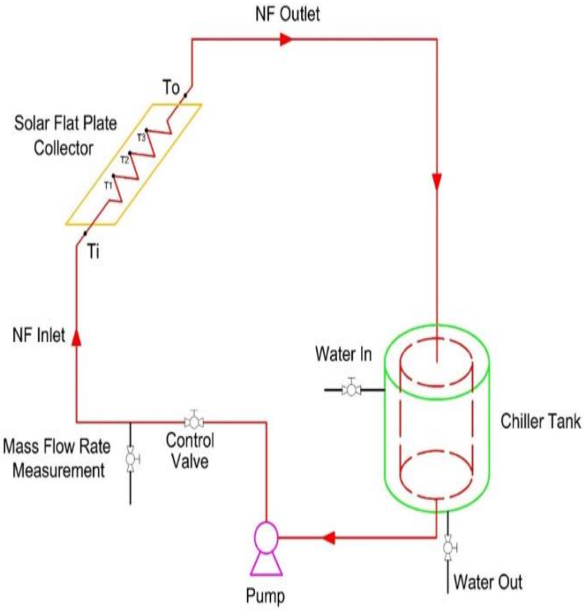

Figure 1. Schematic diagram of experimental setup.

TABLE 1. Specifications of the collector components.

Component	Dimensions	Remarks
Collector	0.450 m x 0.300 m	Gross area=0.135 m^2
Transparent cover	3 mm thick	Material: window glass
header pipes	8 mm ID, 10 mm OD	Material: copper
Bottom insulation	0.045 m thick	Material: glass wool
Tank	0.280 m x 0.092 m	Volume: 1.90 l

The mass of nanoparticles is calculated using Equ. (1),

$$m_{np} = V_t * VF_{np} * \rho_{np}$$

m_{np} - Mass of nanoparticle
V_t - Total volume of nanofluid
VF_{np} - Volume fraction of nanofluid
ρ_{np} - Density of nanofluid

Preparation of nanofluid with uniform dispersion is carried out with vibration setup at the test site. The uniformly dispersed nanofluid used to the thermal performance.

Heat gain and efficiency of the FPC is given by Equ. (2) and (3) respectively.

$$Q_u = m\ Cp\ \Delta T \qquad (2)$$

$$\eta = Q_u/A\ I \qquad (3)$$

Where,
η - Efficiency
Q_u - Useful heat gain (W)
A - Area (m^2)
I - Solar radiation (W/m^2)
m - Flow rate (kg/s)
Cp - Specific heat (kg/kJ K)
ΔT - Temperature difference of fluid (^0C)

The investigated solar radiations are 600, 800 and 1000 W/m^2 at indoor test setup. The optimum values are obtained at solar radiation of 800 W/m^2. Hence, the optimum readings are discussed in the next section to discuss the heat gain. However, the overall comparison of thermal performance of the collector was done for all the three radiation levels.

III. RESULTS AND DISCUSSION

Experimental study of FPC conducted at the indoor with a fixed flow rate and three radiation intensity values. ASHRAE standard 93-86 is followed during testing. Two important environmental parameters that affect the efficiency of solar collector are the solar intensity and ambient temperature. Solar intensity gradually increases from morning to noon and then gradually decreases from noon to evening the solar intensity is maximum at noon time.

Effect of nanoparticle concentration is considered in this work is 5%. The effect of different radiation levels studied experimentally. The limits of heating considered as boiling point of water. Recirculation of nanofluid is done till the water reaches its boiling point. The vapor state is not allowed during the recirculation. Single phase fluid flow is the simplest form of determining thermal performance of FPC. However, most of the FPC are operated under natural circulation.

Figure 2 and 3 show the temperature trend for the water and water based nanofluids for the simulated solar radiations. Time taken to boil the water with nanoparticles takes 70 minutes whereas the normal fluid takes 90 minutes to reach the same test state. There are around 3-4 percent increase in the temperature of the fluid and energy efficiency with the nanofluids.

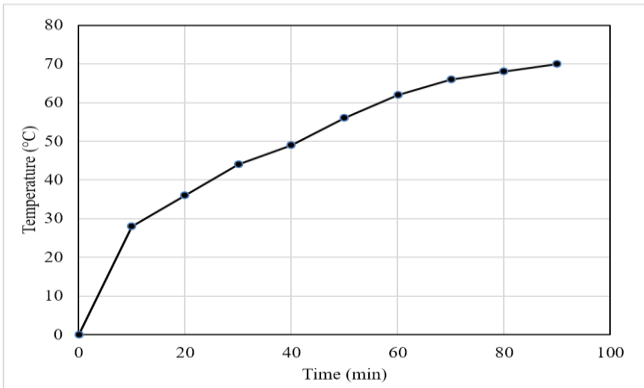

Figure 2. Temperature increase of DM water without nanoparticles flowing through the flat plate solar collector at a flow rate of 0.051 kg/s with a constant radiation intensity of 800 W/m^2.

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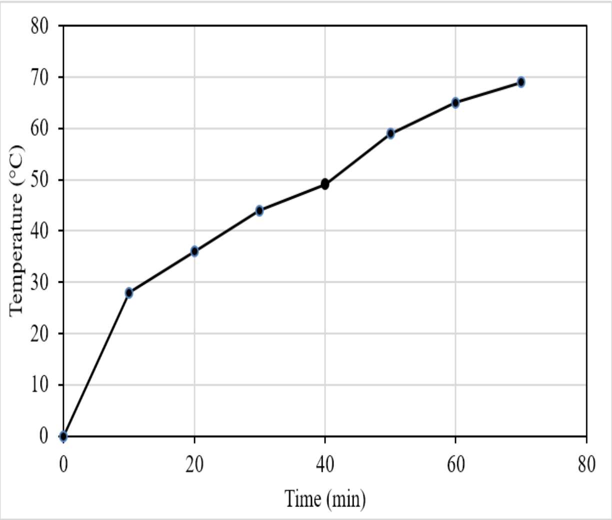

Figure 3. Temperature increase of DM water with 5% mass of nanoparticles flowing through the flat plate solar collector at a flow rate of 0.051 kg/s with a constant radiation intensity of 800 W/m².

Figure 4 shows the comparison of fluid outlet temperature and the energy efficiency for the normal fluid and nanofluid. Nanofluid usage was observed with the improved thermal performance at all the solar radiation conditions. Increased fluid outlet temperature increased the energy efficiency of FPC with nanofluid.

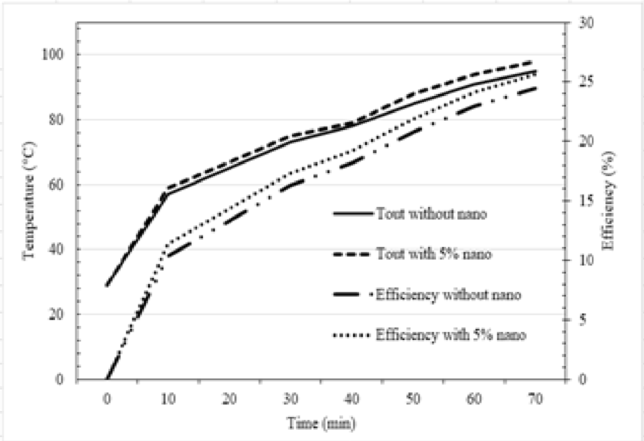

Figure 4. Comparison of water outlet temperature with and without nanofluid at a flow rate of 0.051 kg/s at constant solar radiation of 800 W/m².

Figure 5 shows the time taken for the water and nanofluid to reach its boiling point. The time taken to boiling decreases with an increase in the solar radiation intensity. However, the radiation is maintained same for the indoor testing. The outdoor testing undergoes the Gaussian distribution of solar radiation. The instruments are calibrated, the measurement errors are below 3%. The measurement uncertainty is determined, the uncertainty values of calculated parameters are within the permissible limits.

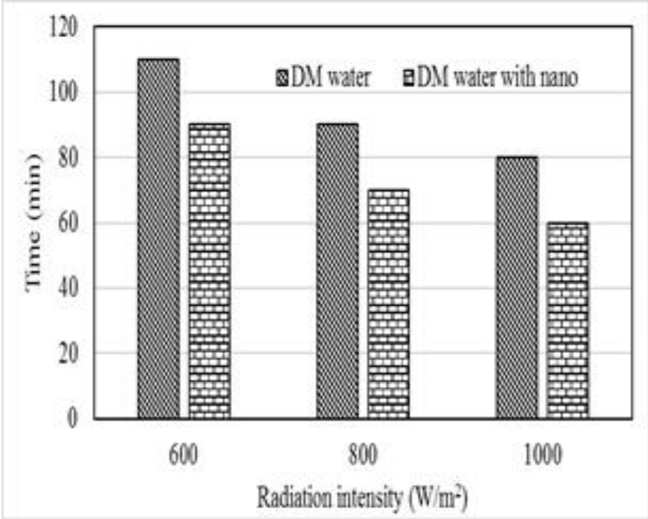

Figure 5. Comparison of time taken to reach the boiling point of DM water with and without nanofluid of Al_2O_3 through the FPC at the laboratory environment with the radiation intensity of 600, 800 and 1000 W/m².

Now, FPC efficiency for Al_2O_3-water nanofluid and water with the time was investigated by single mass flow rate of 0.051 kg/s for 2 liters of water. The variation of efficiency was studied over time at the selected mass flow rate of 1 liter per minute.

Thus, the improved heat gain was observed through nanofluids. The less operational duration for the same heat output was demonstrated in this work. The applications of nanofluids are beneficial not only to the low temperature applications but also to the high temperature fluid systems.

IV. CONCLUSION

The effect of nanofluids in the FPC is presented in this work. The experiments are conducted at the laboratory environments with the solar sun simulator. The promising results are obtained as 21% improvement in the heat gain. Further, there was a 20% reduction in the heat input required to provide the same heat output for the use of nanofluids when compared to without nanofluid. Further, the addition of nanoparticles in the low temperature solar collectors improves the productivity of the selected solar collectors through the more heat gain at the same operational duration. More heat absorption is obtained using nanofluids in such low temperature solar collectors. Outdoor experiments and different nanoparticles as well as different nanoparticles concentration will be studied in the future works.

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AUTHORS PROFILE

Ramalingam Senthil obtained B.E. from the University of Madras in 1997 and M.E. from Anna University Chennai in 2000. He received Ph.D. in Solar Energy from SRM University, Chennai, India in 2017. He has two decades of experience in teaching and industrial experience. He is working at SRM Institute of Science and Technology, Chennai from 2005. He is the author of more than 45 articles in the indexed journals. Major research area is solar thermal energy conversion and storage. He is a member of ASME, ASTFE, ISES, SESI, ISTE, etc.. He received the awards for the teaching and scientific excellence in 2018. He is the reviewer in reputed journals like ASME Journal of Solar Energy, Solar Energy, Energy Efficiency, Thermal Science.

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