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An Experimental Investigation of a Nanofluid (Al_2O_3+H_2O) Based Parabolic Trough Solar Collectors

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Authors' contributions

This work was carried out in collaboration between all authors. Author KSC is the principal author of the project, collaborated with all stages. Authors PVW and USW contributed in conducting the experiments and laboratory analysis. Author RSS contributed in writing and correction of the article. All authors read and approved the final manuscript.

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ABSTRACT

In the present work the effect of working fluid (Al_2O_3 + water nanofluid) on the efficiency of a parabolic trough solar collector was investigated experimentally. The weight fraction of nano particles was 0.1% and the particles dimension was 40 nm. Experiments were performed with and without nanofluid. The mass flow rate of nanofluid is constant at 2 Lit/min. The results shows that, nanofluid based parabolic trough collector has higher efficiency than water based parabolic trough collector. For 0.1%, the increased solar thermal efficiency was nearly 7%. From the results, it can be concluded that the nanofluid causes an enhancement in heat transfer coefficient by 32%. The paper presents the preparation of nanofluid, calculation of nanofluids properties, test result and performance evaluation of Parabolic Trough Solar Collectors with and without nanofluids.

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1. INTRODUCTION

Nanofluids are suspensions of metallic or nonmetallic nano particles in a base fluid. This term of fluid was used by Choi [1]. The thermal conductivity of metallic liquids is much larger than that of nonmetallic liquids. Thus, fluids having suspended metal particles are estimated to noticeable enhanced thermal conductivities relative to pure fluids [2]. A sufficient increase in liquid thermal conductivity, liquid viscosity, and heat transfer coefficient, are the unique characteristic of nanofluids. It is well known that metals in solid phase have higher thermal conductivities than those of fluids [3]. Recently some studies were reported about use of nanofluids in solar collectors. Tyagi et al. [3] theoretically studied the effects of various parameters on the efficiency of a low temperature nanofluid based direct absorption solar collector. They use mixture of water and aluminum nanoparticles as a working fluid. For adiabatic condition, the top surface of this collector is covered by a glass and the bottom side is well insulated. Tyagi et al. [3] discussed the effect of particle volume fraction on collector efficiency, where the volume fraction varies from 0.1% to 5%. Their results explained that the efficiency increases remarkably by increasing volume fraction of nanoparticles to the working fluid. They attributed the increase of collector efficiency to the increase in attenuation of sunlight passing through the collector due to the nanoparticles addition that leads to the increase of collector efficiency. As the efficiency remains nearly constant for a volume fraction higher than 2%, so increasing the volume fraction nanoparticles is not favorable. In this paper they also studied the effects of nanoparticles size on the collector efficiency with the volume fraction is equal to 0.8%. The results discovered that the efficiency increases to some extent with an increase in the size of nanoparticles. Yousefi et al. [4] experimentally studied the effects of Al_2O_3+water nanofluid on the efficiency of a flat-plate solar collector. They examine the effects of two different weight fractions of the nanofluid, with 0.2% and 0.4% and the diameter of particles was 15 nm. They studied the effects on effectiveness of Triton X- 100 used as a surfactant. Their results concluded that, the solar collector of 0.2% weight fraction (wt.) nanofluid has greater efficiency than water by 28.3%. The effectiveness of collector with 0.2% wt. nanofluid is higher compared to 0.4% wt. Efficiency enhance to 15.63% by using surfactant. Yousefi et al. [5], used the same experimental setup of the flat plate collector [4], to examine the effects on effectiveness of water Multi wall carbon nanotubes (MWCNT) + Water nanofluid. The experimental results shows use of 0.4 wt. % MWCNT + Water nanofluidas a working fluid improves the overall efficiency of the collector when it compares to the use of water as the working fluid. The experimental results shows use of 0.2 wt. % MWCNT + Water nanofluidas a working fluid decreases the overall efficiency of the collector when it compares to the use of water as the working fluid. The use of surfactant increases the efficiency of collector for 0.2 wt. % nanofluid compared to water. Nijmeh et al. [6] concluded that solar stills efficiency increases by 29% by adding violet dye to the water, which is remarkable. It is clear that nanofluids are more expensive than dyes. Hence this is challenge to use nanofluids in solar stills. It can be used to minimize the production of greenhouse gas emissions from the production of fresh water.

2. MATERIAL

All the chemicals used in the experiments were of reagent grade. Commercial spherical-shape Al_2O_3 powders with an average diameter of 40 nm were used. The double distilled water was used throughout the studies as a base fluid.

2.1 Preparation Method

In order to minimize Al_2O_3 aggregation and improve dispersion behavior the nanofluid was prepared with magnetic stirrer. As per review, 0.1% volume fraction Al_2O_3 powder is decided for preparation of nanofluid. Exact amount of Al_2O_3 powders quantity was measured by electronic balance. Then Al_2O_3 powder with 0.1% was added to double distilled water for nanofluid preparation. For a homogenously dispersed solution, the solution was kept under magnetic stirring for about 10 hours. The solution is used for experimentation for 8 hrs. Fig. 1 shows setup for preparation of nanofluid.

2.2 Experimental Procedure

The schematic of the experimental setup is shown in Fig. 2. The solar collector was experimentally investigated at the G. H. Raisoni college of Engineering, Nagpur (21.1500° N, 79.0900° E). The relative collector position is shown in Fig. 3. The solar system is a forced convection system with an electrical pump. As shown, the solar system has a tank for absorbing the heat load from the collector cycle. The capacity of this tank is about 1 Lit. A shell and tube heat exchanger is used that transmits the heat load of the solar cycle to the cooling water. Five PT100 thermocouples were used to measure the fluid temperatures in the inlet and outlet of solar collector. Also, one PT100 thermocouple was used to measure the air temperature. The total solar radiation was recorded by a pyranometer.

3. TESTING METHOD

The thermal performance of the solar collector is determined by obtaining the values of instantaneous efficiency for different combinations of incident radiation, ambient temperature, and inlet fluid temperature. This requires experimental measurement of the rate of incident solar radiation as well as the rate of energy addition to the working fluid as it passes through the collector, all under steady state or quasi-steady-state conditions.

Fig. 1. Prepared nanofluid solution with magnetic stirrer

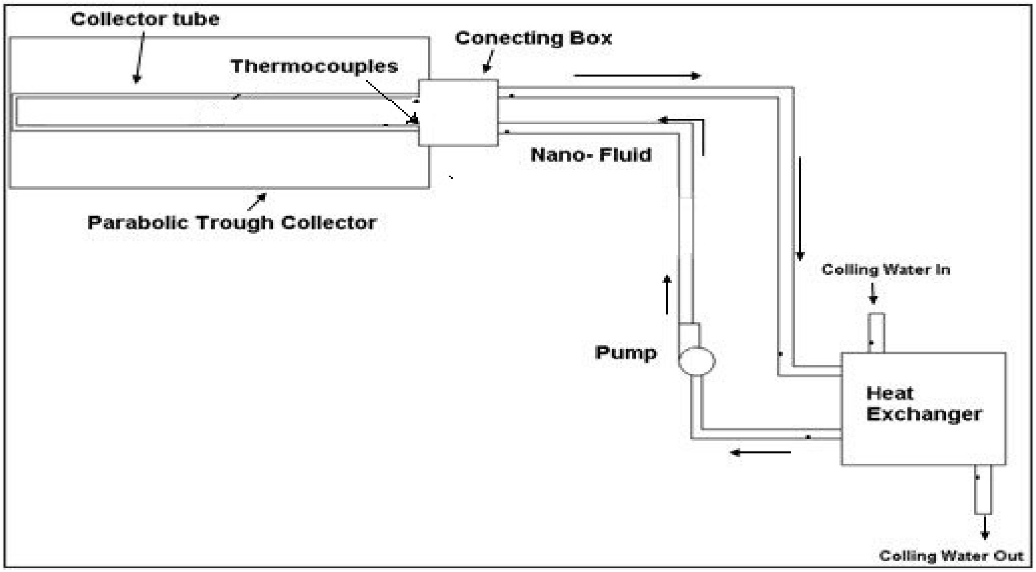

Fig. 2. Schematic diagram of experimental set up

Fig. 3. The experimental set up

3.1 Flow Rate Constant

In this study, it is considered that mass flow rate of the entire setup is constant. The previous results show that accumulation of nanoparticles in nanofluid can be minimized if the nature of flow is turbulent. Turbulent nature of flow is considered in this study. By considering overall design of setup it is recommended to use 2lit/min of flow rate. At this flow rate, Reynolds number was found greater than 5000, which is a sufficient condition for turbulent flow through pipe.

3.2 Calculation of Nanofluid Properties

The key parameters for assessing the heat transfer merits of nanofluids are their thermo physical properties. The mixture properties of nanofluids are normally expressed in volume percentage (ϕ). The density of nanoparticle(ρ_{np}) is calculated by.

$$\rho_{nf}=\phi.\rho_{np}+(1-\phi)\rho_{w} \text{....……………………………… } 1$$

Where, ρ_w is density of base fluid.

There are a few theoretical formulas that can be used to approximate nanofluid viscosities. Almost all such formulas have been derived from the original work of Einstein (1906) which is based on the assumption of a linearly viscous fluid containing a dilute, suspension of spherical particles. The energy dissipated by the fluid flow around a single particle was calculated by Einstein [8]. The viscosity of nanofluid (μ_{nf}) is obtained:

$$\mu_{nf}=\mu_{w}.\ (1+ 2.5\ \phi) \text{ ……………………………...2}$$

Where, $\mu_w$is density of base fluid.

Thermal conductivity studies have been the main focus of nanofluid investigations. Some investigation has also been done on the viscosity of nanofluids. The density has been reported to be consistent with the mixing theory. However, the specific heat of nanofluids C_{pnf} has received very little attention [7]. The heat capacity of the nanofluid is incorporated into the energy equation. It is, therefore, important to be able to calculate it accurately.

$$C_{pnf} = \frac{\varnothing.\rho_{np}.C_{pnP}+(1-\varnothing).\rho_{w}.C_{pw}}{\rho_{nf}} \text{……………………..3}$$

Where,C_{pw} is specific heat of base fluid and C_{pnP} is specific heat of nanoparticle.

It has been established in earlier studies that, the thermal conductivity of nanofluids increases as a function of thermal conductivities of base fluid and the nanoparticle material, the volume fraction, the surface area, and the shape of the nanoparticles suspended in the liquid. There are no theoretical formulas currently available for predicting the thermal conductivity of nanofluids. The Maxwell model, an existing traditional model for thermal conductivity, was proposed for solid–liquid mixtures with relatively large particles. Many later proposed models have been based on the Maxwell model [8]. The effective thermal conductivity of nanofluid (knf) is given by,

$$k_{nf} = \left(\frac{k_{np} + 2\,k_w + 2(k_{np} - k_w).\text{Ø}}{k_{np} + 2\,k_w - (k_{np} - k_w).\text{Ø}}\right)k_w \quad \ldots\ldots\ldots\ldots\ldots\ldots 4$$

Where, k_{np}, k_w are thermal conductivity of nanoparticle and base fluid resp.

The total heat supplied (Q) to system is

$$Q = \dot{m}.\ C_{pw}.\ (T_{b2}\text{-}T_{b1})\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

The thermal efficiency of the nanofluid based parabolic solar collector is defined as the ratio of sensible heat gain by the working fluid (nanofluid) to the normal solar radiant energy incident on the aperture as below.

$$\eta = \frac{Q}{Aa\ IbRb}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

4. RESULTS AND DISCUSSION

The tests were performed around solar noon at time 9 am to 5 pm. The experimental results are presented in the form of graphs and equations that describe the collector efficiency against a day time.

Fig. 4 shows comparison of performance of the two test set ups under same conditions. The behavior observed from curve II relates to the maximum temperature attained by the nanofluid. It is quite possible to achieve temperature more than 50°C. At mid day, when solar radiation is maximum value at that time maximum temperature is reached. As radiation intensity decreases, the outlet temperature also decreases.

Fig. 5 shows the comparison of performance on the basis of solar thermal efficiency with respect to day time. The behavior observed from curve IIis increased in performance of set up. The set up with nanofluid as working fluid provides maximum efficiency against all other setups as compared to remaining test conditions of set up. By using nanofluid, the thermal efficiency of system increases nearly by 7%.

Fig. 6 shows comparison of performance of the various test condition. The most effective results are obtained in the enhancement of heat transfer coefficient by using nanofluid. The behavior observed from curve IIis the maximum heat transfer coefficient attains by use of nanofluid. It is quite possible to achieve heat transfer coefficient more than 2100 W/m^{2}K. Figure shows that overall heat transfer coefficient of fluid is nearly constant throughout the day.

Fig. 7 shows comparison of performance of the various test set up under the same conditions. The behavior observed from curve IIis the maximum Nusselt number is attained with nanofluid. It is quite possible to achieve heat Nusselt number more than 33.

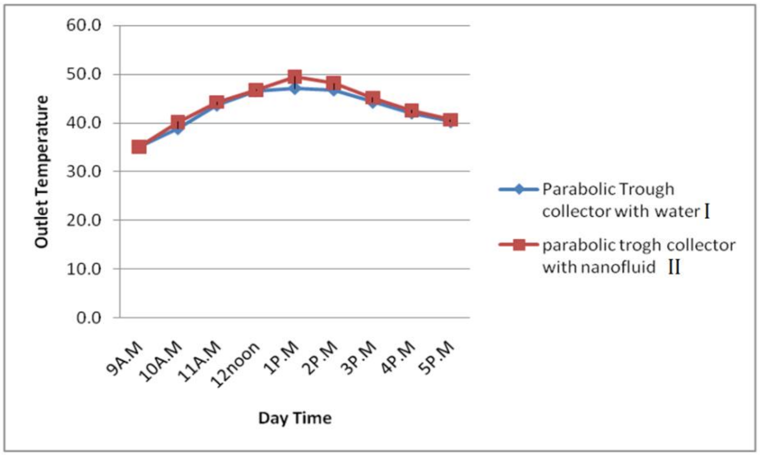

Fig. 4. Hot water outlet temperature vs Day time as per various test set ups (Full sun shine day)

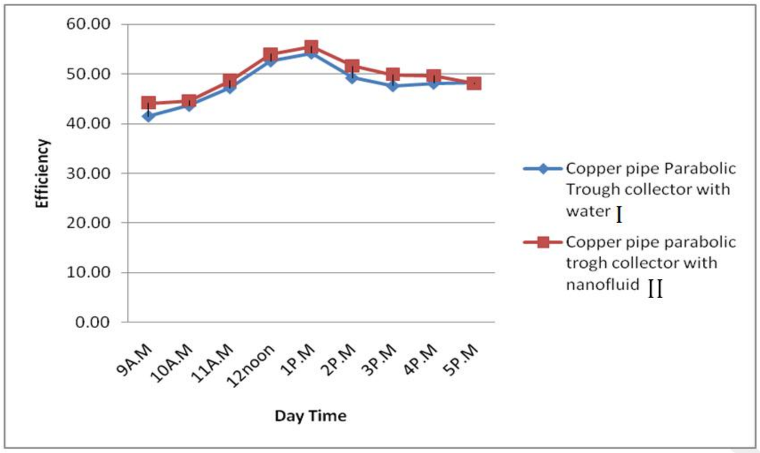

Fig. 5. Solar thermal efficiency vs day time as per various test set ups (Full sun shine day)

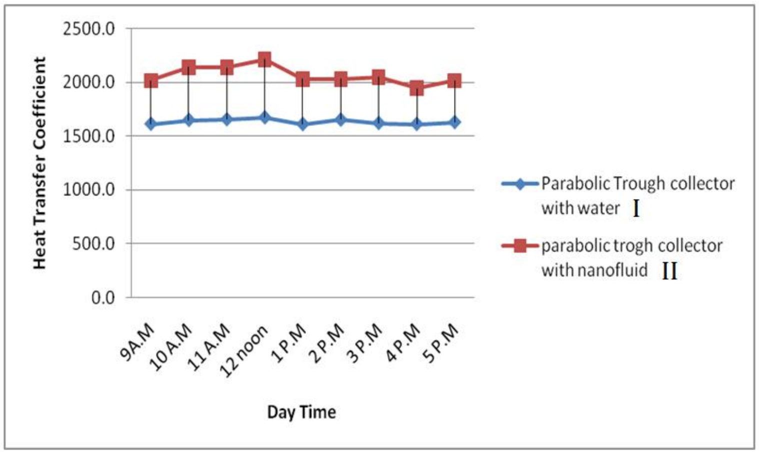

Fig. 6. Heat transfer coefficient vs Day time as per various test set up (Full sun shine day)

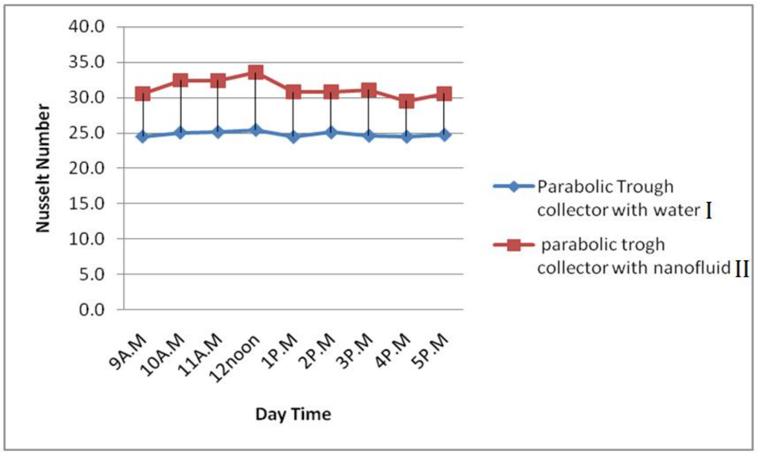

Fig. 7. Nusselt number vs Day time as per various test of set up (Full sun shine day)

5. CONCLUSION

The effect of use of Al_2O_3+ water nanofluid as absorbing medium, in a parabolic trough solar collector has been investigated and the effect of nanoparticles mass fraction on the efficiency of the collector was studied. The results show that using the 0.1 wt% Al_2O_3 nanofluid increases the efficiency of solar collector in comparison with water as working fluid by 7%. It is also seen that the use of nanofluid as a working fluid enhances the heat transfer coefficient fluid by 32% as compared to basic fluid such as water. Nusselt number also gets enhanced.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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