Effect of Al_2O_3 Nanofluid on the Performance of Direct Absorption Solar Collector

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Abstract: Due to the growing demand of energy and lesser availability of fossil fuels, it shifts our concern towards Renewable energy sources. From all of the sources available to us solar energy is the best option with minimum environmental impact. But the problem lies in efficiently collecting and converting this energy into something useful form. The present study has been carried out to increase the efficiency of the solar collector by using new type of solar collector (DASC-Direct absorption solar collector) and different class of fluids called (Nanofluids). In conventional type of flat plate solar collectors we get three resistances whereas in DASC these three resistances are reduced to one. In the present work we have evaluated the collector efficiency using water and Al2O3nanofluid with volume concentration .005% and .05% at different mass flow rates 6, 8 and 10lit/hr. Also the variation of temperature difference with time is also plotted. By performing the experiment it has been found that the efficiency of the flat plate DASC using Al2O3 nanofluid is 3-4% more than using the water. If we compare two concentrations of Nanofluides at higher concentrations the tendency of the nanoparticles to settle down is higher. By varying the mass flow rate and varying the volume concentration of nanoparticles in nanofluids the variation in collector efficiency and temperature difference are studied.

Keywords: *Solar energy, Nanoparticle, Heat transfer, Nanofluides*

I. INTRODUCTION

Solar thermal energy is one of the most popular renewable sources of sustainable energy with least environmental impact, no requirement of transportation and free availability for every human being all over the world [1–3]. Solar thermal collector is a widely used system for collection and conversion of solar energy into thermal energy. Among these different types of solar collectors, the conventional ‘tube in plate’ type flat plate collector absorbs incident solar radiation through a black solid surface, and transfers heat to working fluid flowing in tubes called risers, brazed onto the surface of the absorber plate. The efficiency of a solar thermal collector relies on the effectiveness of absorbing incident solar radiant energy and heat transfer from the absorber to the carrier, which is normally fluid. Due to surface heat absorption and in direct transfer of heat to working fluid, the conversion of sun light into thermal energy suffers from relatively low efficiencies [4].

In order to improve the efficiency of solar thermal collector, researchers proposed the concept of directly absorbing the solar energy within the fluid volume in the 1970s called Direct Absorption Solar Collector (DASC) [5, 6]. However, the efficiency of direct absorption collector is limited by the absorption properties of the conventional working fluid, which is very poor over the range of wavelength in solar spectrum [7]. In the beginning, black liquids containing millimetre to micrometre sized particles were also used as working fluid in direct absorption solar collectors to enhance the absorption of solar radiation that had showed efficiency improvement. The applications of micron sized particles in to the base fluid for DASCs lead to pipe blockage, erosion, abrasion and poor stability. Particle sedimentation from the suspensions resulted in clogged channels [5].

Advance material synthesis technologies provide us an opportunity to produce the nanosized materials (nanoparticles), when suspended in conventional fluids considered as nanofluids [8]. The use of nanofluid has a dramatic improvement on the liquid thermophysical properties such as thermal conductivity [9, 10]. Studies suggested the thermal conductivity enhancement due to dispersion of nanoparticles [11], intensification of turbulence [12], Brownian motion [13, 14] and thermohoresis [15].

Masuda *et al*. [16] dispersed Al2O3 and TiO2 nanoparticles in water and found thermal conductivity improvement by 32% and 11%, respectively. Grimm [17] dispersed aluminium metal particles (1–80 nm) into water and claimed100% increase in thermal conductivity of the nanofluid for 0.5–10wt%.

Natarajanand Sathish [18] investigated the thermal conductivity enhancement of base fluid sussing carbon nanotube (CNT) and suggested efficiency enhancement of the conventional solar water heater by using CNT based nanofluides as a heat transport medium. Nanoparticles also offer the potential of improving the radiative properties of liquids, leading enhanced efficiency of direct absorption solar collectors [19]. Recently Sheikholeslami *et al.* [20–24] used nanofluid and simulated nanofluid flow and heat transfer by different methods for different kind of problems to enhance the heat transfer rate.

Yousefi *et al*. [25] reported the experimental results on a tube in plate type conventional solar collector (size 2 m2) using Al2O3–H2O nanofluid of 0.2wt% and 0.4wt% concentrations for three different mass flow rates and found 28.3% improvement in efficiency with 0.2wt% of nanofluid in comparison to water. Yousefi *et al*. [26] also examined the effects of multiwall CNT-water nanofluid and observed remarkable efficiency increase with 0.4wt% nanofluid.

Tyagi *et al.* [27] numerically studied a direct absorption solar collector using aluminium nanoparticles in water for performance evaluation and reported efficiency improvement upto 10% than that of a flat-plate collector. Otanicar *et al.* [28] experimentally studied the role of different nanofluides as the absorption medium on the efficiency of horizontal micro size (3 cm × 5 cm) direct absorption collector in indoor environment and reported efficiency improvement upto5%.

Very few studies on the thermal performance evaluation of flat plate solar collector with nanofluides are available. As such no study on full size (1.4 m2) tilted DASC under actual outdoor condition is available. An attempt has been made in the present paper, to experimentally study the effect of Al2O3-H2O nanofluid flowing as thin film over the glass absorber plate as a direct absorbing medium on the efficiency of a tilted direct absorption solar collector under outdoor condition. Effect of three different nanofluid flow rate i.e.6 lph, 8 lph and 10 lph were considered on the DASC efficiency and the collector performance was also compared with base fluid distilled water.

II. DASC EXPERIMENTAL SETUP

Schematic diagram explaining the working of direct absorption collector is shown in Fig. 1.

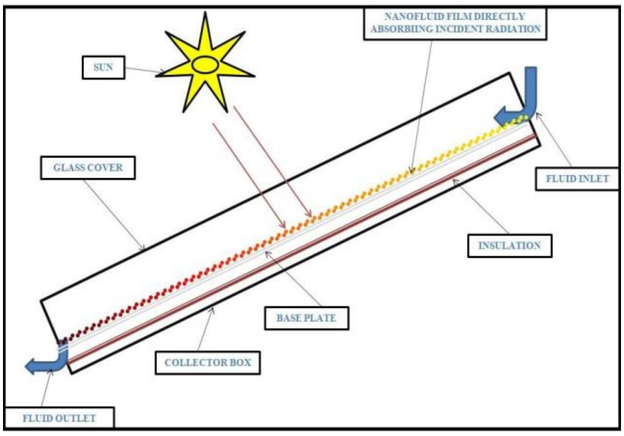

Figure 1: The schematic of direct absorption solar collector (DASC)

An experimental setup of direct absorption solar collector of size 1.54 m × 0.9 m (gross area of 1.4 m2) has been developed as shown in Fig. 2.

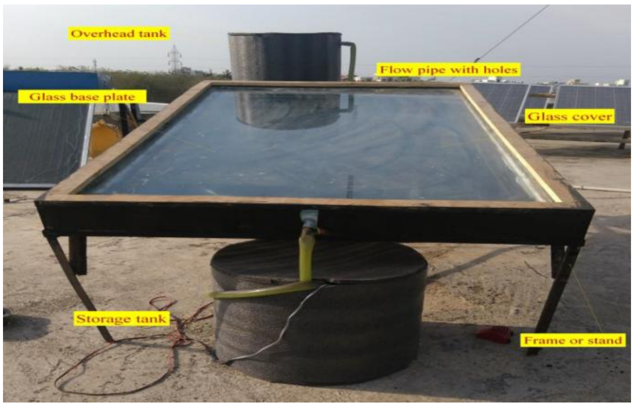

Figure 2: Experimental setup of Direct Absorption Solar Collector

For experimental study, a setup of DASC was developed and erected at the roof top of Renewable Energy Lab, Government College of Engineering, Amravati (20°57’42” latitude and77°45’34” longitudes). The collector was oriented due south with a tilt angle of 26°. Photograph of experimental setup (Fig. 2) showing direct absorption collector, two tanks and instruments used along specification of the collector components used in Table1. It mainly consists of a glass base plate (1.5m long, 0.9m wide, 0.006m thick), mounted on a wooden box with inner glass wall on all four sides and equipped with a spray system for film formation over the glass base plate. In DASC no tubes are used for carrying fluid and nanofluid flows directly over the glass plate, which is used in place of black absorber plate.

A perforated header pipe (106 holes of 1 mm diameter with 1 mm pitch) is used to obtain a uniform nanofluid film on the glass plate.

Experimental test setup consists of a solar collector, working fluid loop and data acquisition system. The working fluid loop has two tanks called bottom storage reservoir and upper reservoir. A simple manual globe valve is used to control flow rate of working fluid and flow rate is measured with the help of electromagnetic digital flow meter (Make- Electronet, range 0–5 lpm, accuracy 7 1%). A centrifugal pump circulates the collected fluid in the system. Intensity of total solar radiation was recorded using digital solar meter (Range 1–1300 W/m2, accuracy ±5% of measurement). The experiments were performed at different flow rates of working fluid according to ASHRAE Standard 93-86 [29].

Table 1: The specifications of DASC components

S. no.	Component	Dimension	Remark
1	Collector	1.54 m × 0.9 m	Gross area= 1.4 m2
2	Absorber	1.44 m ×0.80 m	Effective area = 1.15 m2
3	Transparent cover	6 mm	Material toughened glass
4	Base plate	6 mm thick	Material toughened glass
5	Collector box inner glass wall	6 mm thick	Material - plain glass
6	Film formation system	¾″ Header pipe with 1 mm dia. holes	Plastic Pipe
7	Bottom insulation	50 mm thick	Glass wool
8	Side insulation	25 mm thick	Glass wool
9	Frame	200 mm height	Material- M.S.

Table 2: Physical properties of nanoparticles

Size of particles	20-30nm
Shape of particles	Spherical particles
Density	3700kg/m3
Surface area per unit weight	15–20 m2/g
Al2O3 content	99.99%

A. Preparation of Nanofluides

Nanofluid is produced by metal or metal oxide nanoparticles suspended in base fluids such as oil or water. It involves many methods such as changing the pH value of the suspension, using surfactant activators, and using ultrasonic vibration. The nanoparticles suspended in base fluids are stable for a long time. For this research, nanofluid was prepared by a sonicator for one hour.

The sonicator had a probe type, operating frequency, and power source of 20 kHz, AC100, and 120V/AC220 240V 50/60 Hz, respectively.

III. TESTING METHOD

Thermal performance of solar collectors is commonly evaluated using ASHRAE Standard 93-86. Collector thermal performance is calculated by determining collector instantaneous efficiency for different incident solar radiations, and flow rates. Intensity of incident solar radiations as well as useful heat gain by the working fluid is measured.

A. Time attempt

As per ASHRAE Standard 93-86 steady-state conditions should be maintained during the data period and also during a specified time interval prior to the data period, called the pre-data period. For attaining steady state conditions the mass flow rate must be within ±1%, irradiation must be within ±50 W/m2, the outdoor ambient temperature must not vary more than ±1.5 K, and the inlet temperature must be within ±0.1 K for the entire test period steady state conditions.

B. Governing equation for efficiency calculation

The experiments were performed at different inlet temperatures of working fluid according to ASHRAE Standard. The measurements were taken for ambient, inlet & outlet temperature, global solar intensity and the mass flow rate of working fluid. The useful heat gain by the fluid can be calculated using Eq. (1).

$$Q = m * Ceff * (T2 - T1) \quad (1)$$

Where,

A Surface area of solar collector (m2),
Ceff Heat capacity of fluid (J/kgK),
M Mass flow rate of fluid (kg/sec),
T1 Inlet temperature (K).
T2 Outlet fluid temperature (K),
Q Useful heat gain (W)

The heat capacity of nanofluid is calculated with the help of equation (2).

$$Ceff = \frac{(1 - \Phi p)\rho f * cf + \Phi p * \rho p * cp}{\rho eff} \quad (2)$$

Where,
cf Heat capacity of base fluid
cp Heat capacity of nanoparticles
ϕP Volume fraction of nanoparticles
ρeff Density of nanofluid
ρ_f Density of base fluid
ρ_p Density of nanoparticles

Instantaneous collector efficiency relates the useful heat gain to the incident solar energy by Eq.(3)

$$\eta = \frac{m * Ceff * (T2 - T1)}{* A} \quad (3)$$

Where,
η Efficiency of the collector
G_T Global solar radiation (W/m_2)

Figure 3: Photograph of Ultrasonicator Probe Machine Used for nanofluid Preparation

Courtesy:-Physics department, Vidhyabharti College, Amravati

IV. RESULT AND DISCUSSION

A. Water as working fluid

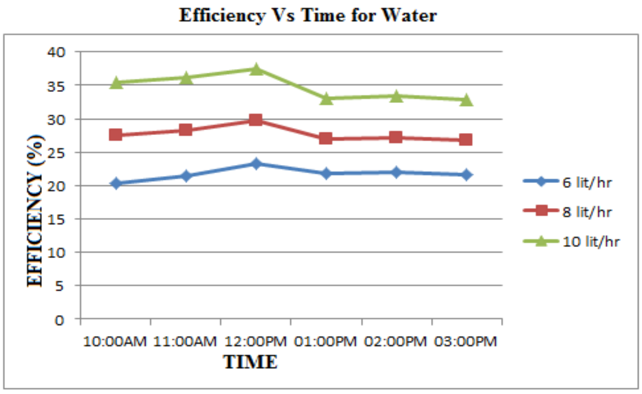

Fig. 4: Collector efficiency for water w.r.t time at different mass flow rates

From Fig. 4 If we increase the flow rate from 6lit/hr to 8lit/hr, the efficiency of the collector increases by nearly 8% and same thing happened when we increase flow rate from 8lit/hr to 10lit/hr. It is observed clearly that as the mass flow rate increases efficiency increases, this may be due to the higher value of the mass flow rate and minimum efficiency is reported at 1:00 pm, because at that time; the value of global solar irradiation is maximum.

B. Al_2O_3 –Water as working fluid with ϕ=0.05%

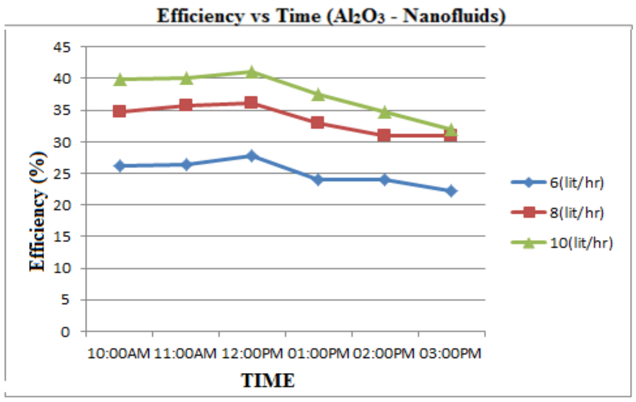

Figure 5: Variation in collector efficiency w.r.t time at different mass flow rates for nanofluid

From fig 5 shows clearly that for higher mass flow rate efficiency is higher. After 12pm efficiency decreases in all cases because the value of GT increases much faster than the heat gained by the collector.

C. Al2O3 –Water as working fluid with ϕ=0.005%

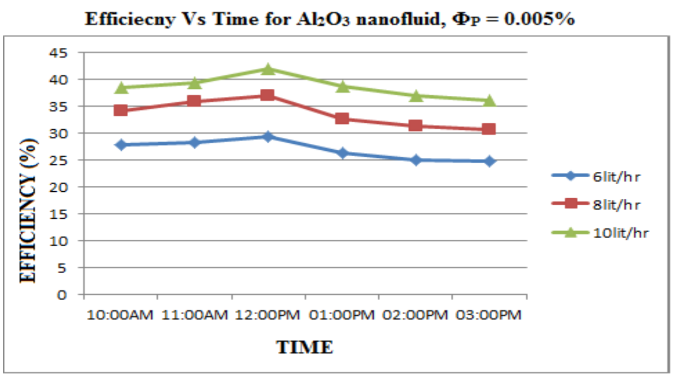

Figure 6: variation in collector efficiency w.r.t time at different mass flow rates

From Fig. 6, it is observed that at higher mass flow rates the efficiency is higher than low mass flow rates, this may be due to the higher value of mass flow rate. The value of temperature difference is also almost constant between 12 pm to 2 pm.

D. Temperature Difference comparisons

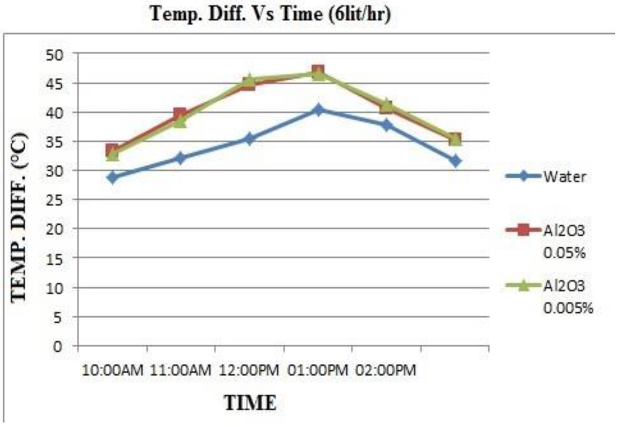

Figure 7: Variation in temp. diff. w.r.t time for water and Al2O3 nanofluid for 6lit/hr

E. Efficiency Comparison

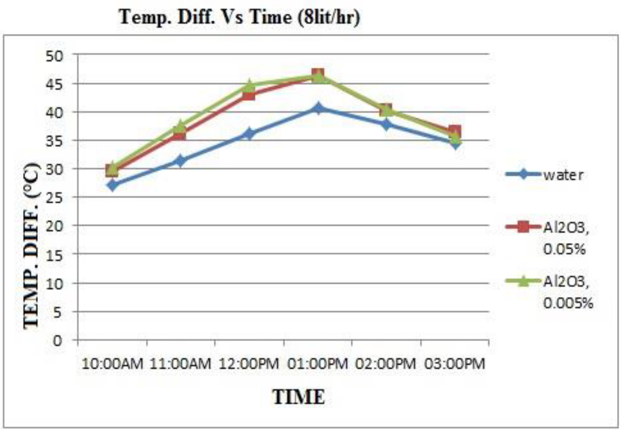

Figure 8: Variation in temp. diff. w.r.t time for water and Al_2O_3 nanofluid for 8lit/hr

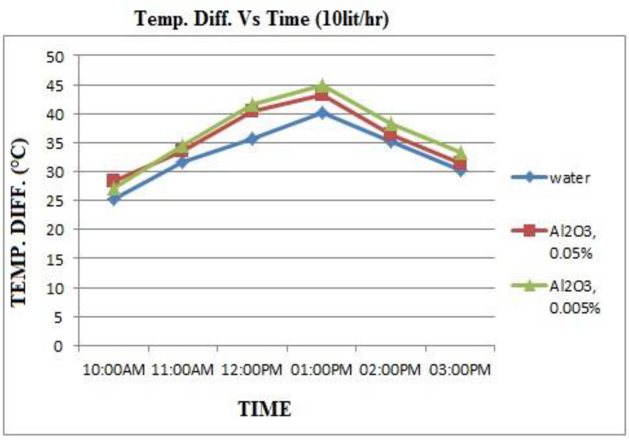

Figure 9: Variation in temp. diff. w.r.t time for water and Al_2O_3 nanofluid for 10lit/hr

Fig 7, 8, 9 shows that Al2O3 nanofluid of 0.05% volumetric concentration has higher temperature difference before 12 pm as compared to water but after 12 pm the value of water rises slightly and this may be due to the reason that the fall in temperature in case of nanofluid is more rapid as compared to water. Again for Al2O3 with 0.005% volumetric concentration, it is observed that at different time intervals the temperature difference is varying and in most of the cases the temperature difference for Al2O3 is higher than water. This is because of the higher heat absorption capacity of the nanofluids as compared to water and lastly it is clearly seen that the temperature difference in case of low volumetric concentration (ΦP = 0.005%) is slightly higher than the higher volumetric concentration (ΦP = 0.05%). This is because at higher volumetric concentration the problem of settling down of nanoparticles is more serious as compared to low volumetric concentration.

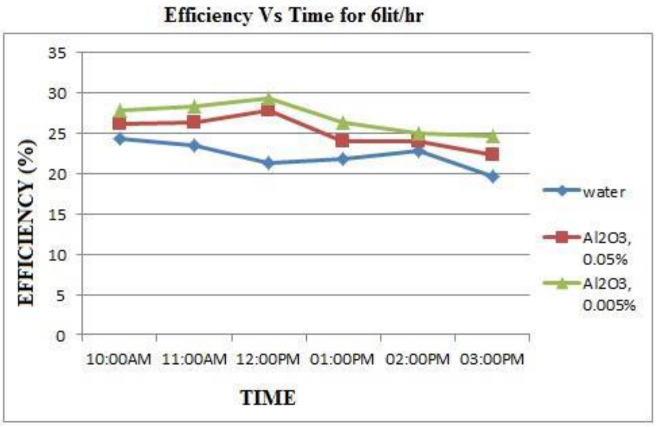

Figure 10: Variation in efficiency w.r.t. time for water and Al2O3 nanofluid for 6lit/hr

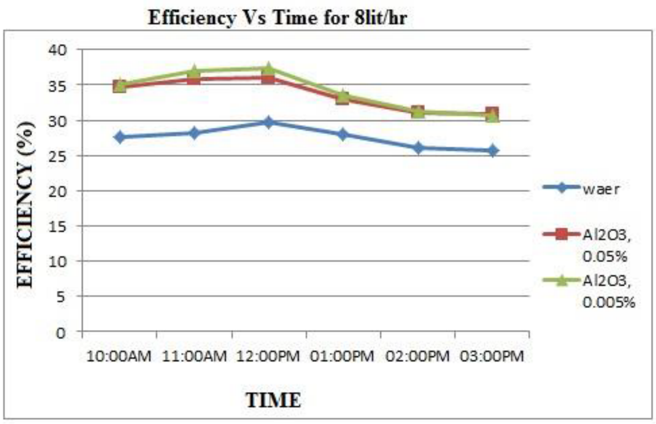

Figure 11: Variation in efficiency w.r.t. time for water and Al2O3 nanofluid for 8lit/hr

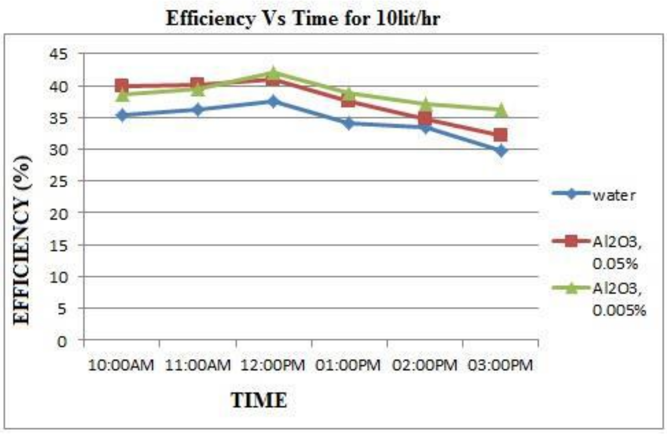

Figure 12: Variation in efficiency w.r.t. time for water and Al2O3 nanofluid for 10lit/hr

CONCLUSION

From the results obtained by performing the experiments, this can be concluded that The efficiency of the collector increases upto 4-5% on an average as compared to water. This is due to the high thermal properties of the nanofluids. At higher mass flow rate the temperature difference decreases but efficiency increases. The efficiency is found minimum near 1 pm. This is due to the higher value of global solar irradiance. When we compare two volumetric concentrations of nanofluids for same mass flow rate it is found that at higher volumetric concentration settling problems are more dominant. Hence, efficiency at lower volumetric concentration is slightly higher. Higher efficiency can be obtained in case of nanofluids if the settling of the nanoparticles in the fluid is prevented.

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