HEAT TRANSFER INTENSIFICATION IN FLAT PLATE SOLAR COLLECTOR BY USING AL2O3-H2O NANOFLUID

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A B S T R A C T

Nanofluids are embryonic fluids that exhibit thermal properties superior than that of the conventional fluid. The application of nanofluids is to achieve the highest possible thermal properties at the smallest possible concentrations, by homogeneous dispersion and stable suspension of nanoparticles in the host fluids. Nanofluids plays vital role in various thermal applications such as automotive industries, heat exchangers, solar power generation etc. Mostly heat transfer augmentation in solar collectors is one of the key issues in energy saving, compact designs and different operational temperatures.

Solar energy is one the most popular renewable energy sources that can be used in a thermal or photovoltaic system. Solar collectors play a key role in solar thermal systems. They convert solar radiation into heat and transfer the heat to working fluids such as water or air. Flat-plate collectors are the most common type of solar collector and are typically used as a water heater or air heater. These collectors have a low efficiency and low outlet temperature. Recently, many researchers have attempted to enhance the efficiency and performance of flat-plate collectors via different methods. One of the methods for improving the performance of flat-plate collectors involves using nanofluids instead of common fluids in solar collectors. Nanofluids are suspensions comprising base fluids such as water and nanoparticles 1–100 nm in size. These types of working fluids have more thermal properties than their base fluids. Numerous studies have been performed across the world concerning the use of nanofluids in solar thermal systems.

Keywords: Heat Transfer, Solar Flat Plate Collector, Al_2O_3-H_2O

Nomenclature
CNT carbon nanotube
DASC Direct Absorption solar collector

1.Introduction

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). 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. In the beginning, black liquids containing millimeter to micrometer 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 into the base fluid for DASCs lead to pipe blockage, erosion, abrasion and poor stability. Particle sedimentation from the suspensions resulted in clogged channels. Advance material synthesis technologies provide us an opportunity to produce the nano-size materials (nanoparticles), when suspended in conventional fluids considered as nanofluids. The use of nanofluid has a dramatic improvement on the liquid thermo physical properties such as thermal conductivity. Studies suggested the thermal conductivity enhancement due to dispersion of nanoparticles, intensification of turbulence, Brownian motion and thermophoresis.

2. Experimental

The experimental set-up, shown in Figure 1.For project, a setup of DASC was developed and erected at the saswad, Pune (18.52° latitude and 73.86° longitudes). The collector was oriented due south with a tilt angle of 88° (from vertical) in the month of may. The above setup 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 (30 in long, 26.5 in wide), mounted on a steel collector and equipped with a spray system for film formation over the base. 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 (100 holes of 1 mm diameter with 1mm pitch) is used to obtain a uniform nanofluid film on the glass plate. Project 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. A diaphragm pump circulates the collected fluid in the system. Three J-type thermocouples were installed to measure collect or inlet and outlet fluid temperatures and the ambient temperature. These readings were used for further calculation. Intensity of total solar radiation was taken from handbook published by India meteorological department. The project was performed at different inlet temperatures of working fluid

Table 1 : Thermo physical properties of Al_2O_3 Nanoparticles

Sr. no.	Parameter	Specification
1	Size of particles	20-30 nm
2	Shape of particles	Spherical particles
3	Density	3700 kg/m^3
4	Surface area per unit weight	15–20 m^2/g
5	Al_2O_3 content	99.99%
6	Heat Capacity	773 J/kg K

Al_2O_3 nanoparticles are mixed in base fluid distilled water to get nanofluid of 0.005 volume fraction concentration and investigations are performed to determine the effect of different flow rates at 1.5, 2 and 2.5 lpm. Nanofluid is collectedin the bottom tank and then pumped to overhead tank. At each flow rate experiments with several test periods at different inlet fluid temperature in quasi steady state conditions were conducted from 11.30 AM to time when stagnation temperature is achieved on a day. The experimental results are plotted in graph

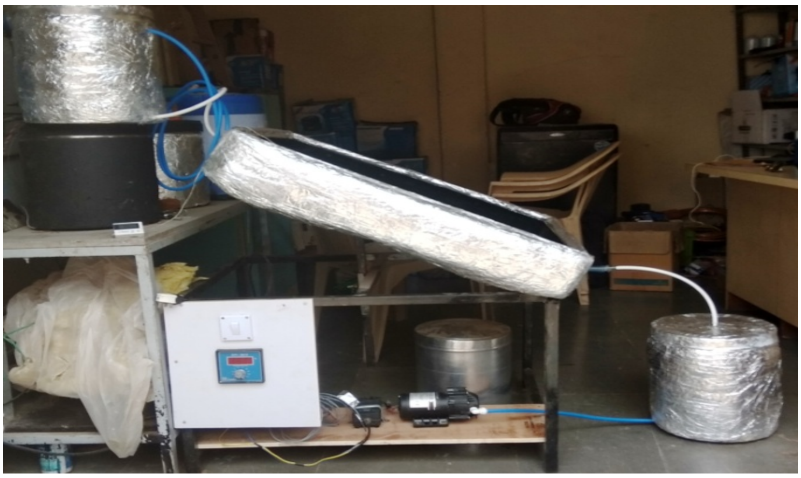
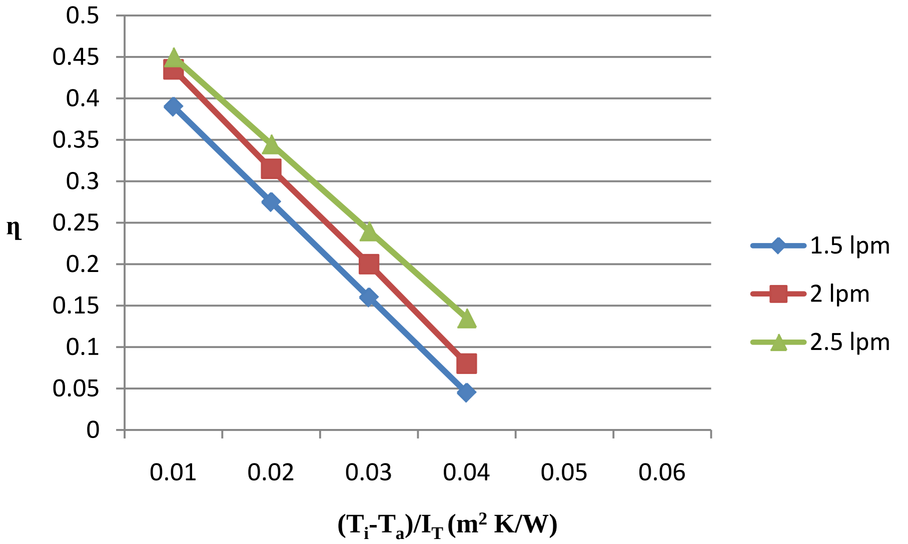


Fig.1. Experimental set-up

3. Results & Discussion

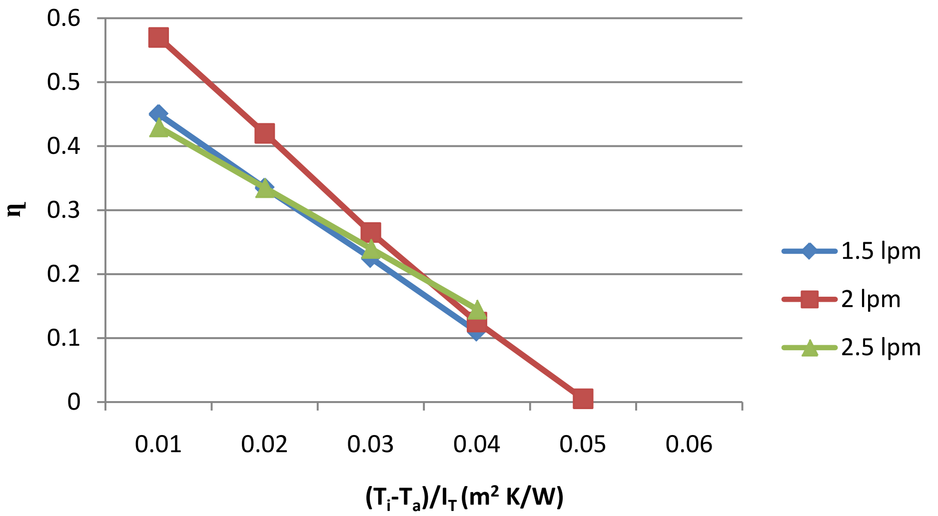
Graph is plotted between variation of collector efficiency versus the reduced temperature parameter for each flow rate. Three flow rates are in consideration 1.5, 2 & 2.5 lpm. Taking variation of collector efficiency on X-axis & reduced temperature parameter on Y- axis comparison done between flow rates for water andnanofluid

- Water as working fluid shown in graph 1



Graph 1: Efficiency versus $(T_i-T_a)/I_T$ curve at three flow rates for water

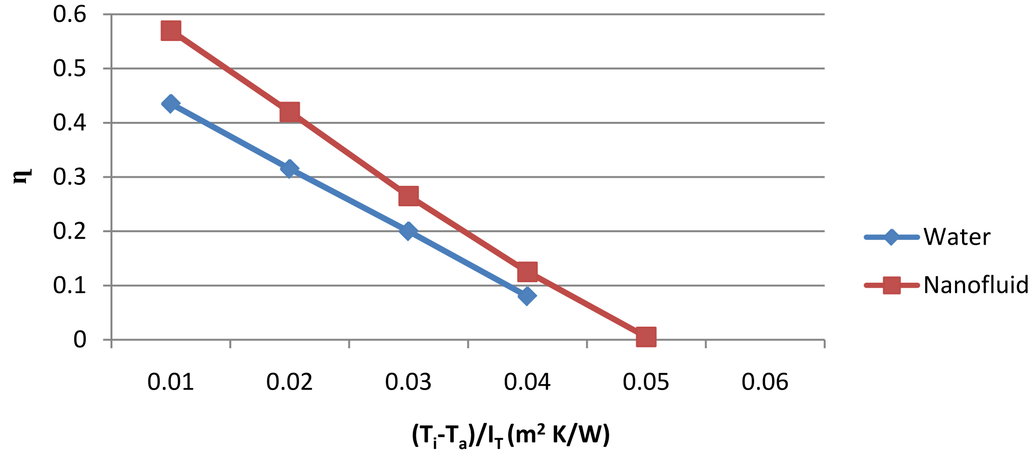
- Al_2O_3 – water as working fluid shown in graph 2



Graph 2: Efficiency versus $(T_i-T_a)/I_T$ curve at three flow rates for nanofluid

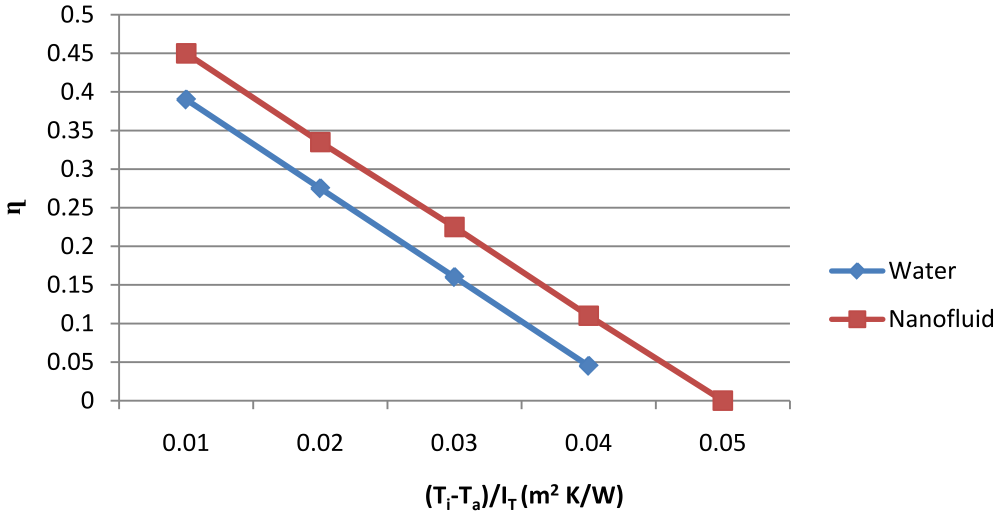
- Water & nanofluid shown in graph 3

i. At 2lpm



Graph 3: Efficiebncy versus $(T_i-T_a)/I_T$ curve at 2 lpm flow rate for water and nanofluid

ii. At 2 lpm



Graph 4: Efficiency versus $(T_i-T_a)/I_T$ curve at 1.5 lpm flow rate for water and nanofluid

4. Reading & calculations

Place: Pune

Date : 26/05/2018

Time : 11:30 AM to 3.00 PM

Readings are as fallows

- Water as working fluid

i. At 1.5 lpm

Sr. No.	Ambient temp. (Ta) (^oC)	Inlet temp. (Ti) (^oC)	Outlet temp. (To) (^oC)
1	38.9	40.4	41.6
2	38.9	41.8	43.0
3	38.9	43.6	44.4
4	38.9	45.0	45.7
5	38.9	47.4	47.9
6	38.9	49.1	49.4
7	38.9	51.7	51.7

ii. At 2 lpm

Sr. No.	Ambient temp. (Ta) (°C)	Inlet temp. (Ti) (°C)	Outlet temp. (To) (°C)
1	38.9	40.6	41.6
2	38.9	42.1	42.9
3	38.9	43.8	44.6
4	38.9	45.3	45.9
5	38.9	47.0	47.5
6	38.9	49.4	49.6
7	38.9	52.6	52.6

iii. At 2.5 lpm

Sr. No.	Ambient temp. (Ta) (°C)	Inlet temp. (Ti) (°C)	Outlet temp. (To) (°C)
1	38.9	40.4	41.2
2	38.9	41.8	42.5
3	38.9	43.6	44.2
4	38.9	45.0	45.6
5	38.9	47.4	47.8
6	38.9	49.1	49.4
7	38.9	54.35	54.35

- Al_2O_3 – water as working fluid

i. At 1.5 lpm

Sr. No.	Ambient temp. (Ta) (°C)	Inlet temp. (Ti) (°C)	Outlet temp. (To) (°C)
1	38.9	39.5	40.9
2	38.9	41.2	42.5
3	38.9	43.3	44.4
4	38.9	45.0	45.9
5	38.9	49.1	49.6
6	38.9	51.1	51.4
7	38.9	53.2	53.2

ii. At 2 lpm

Sr. No.	Ambient temp. (Ta) (°C)	Inlet temp. (Ti) (°C)	Outlet temp. (To) (°C)
1	38.9	39.5	40.9
2	38.9	41.2	42.5
3	38.9	43.3	44.3
4	38.9	45.0	45.9
5	38.9	49.1	49.5
6	38.9	51.1	51.4
7	38.9	52.6	52.6

1. Solar radiation intensity

$$I_T = \frac{25.18 \times 10^6}{24 \times 60 \times 60} = 291.44\ W/m^2$$

2. Water as working fluid

A. At 1.5 lpm

i. $\frac{T_i - T_a}{I_T} = \frac{40.4 - 38.9}{291.44} = 0.005$

ii. $\eta = \frac{m \times C_{p,bf} \times (T_o - T_i)}{I_T} = \frac{1.5 \times 4180 \times (41.6 - 40.4)}{291.44 \times 60} = 0.43$

B. At 2 lpm

i. $\frac{T_i - T_a}{I_T} = \frac{40.6 - 38.9}{291.44} = 0.006$

ii. $\eta = \frac{m \times C_{p,bf} \times (T_o - T_i)}{I_T} = \frac{2 \times 4180 \times (41.6 - 40.6)}{291.44 \times 60} = 0.48$

5. Conclusion

1. Engineering suitable nanofluids with controlled particle size and morphology for heat transfer applications is still a big challenge.
2. The effect of using Al_2O_3–water nanofluid on the direct absorption solar collector efficiency with three different flow rates 1.5, 2, 2.5 lpm have been observed. The volume fraction of nanoparticles has been selected as 0.001%. The collector efficiency increased with nanofluid than pure water for all flow rates. Collector efficiency enhancement of 6% , 22% and 3% has been observed for 1.5, 2 and 2.5 lpm flow rate of nanofluid respectively. Efficiency is maximum at 2 lpm. Efficiency first increased then decreased significantly.
3. For low temperature range, $(T_i\ T_a)/I_T<0.035$, the collector efficiency is greater at 2 lpm due to higher value of absorbed energy parameter. However for high temperature range, $(T_i\ T_a)/I_T>0.035$, the collector efficiency is greater at 2.5 lpm due to reduced heat losses. As collector is operated most of the time in the low temperature range hence, 2 lpm flow rate is observed as an optimum value of the flow rate for maximum collector efficiency.
4. At very low flow rates, the fluid residence time in the collector was high so greater absorption of solar energy allowing more temperature rise. But emission of radiation from the fluid scales with the fourth power of temperature, the fluid suffered higher emissive losses at lower velocities, which resulted in smaller collector efficiencies. Thus, the heat transfer rate is influenced by these two parameters.
5. Significant enhancement in solar radiation absorption and collector efficiency makes nano-fluids as a suitable heat transfer fluid for solar thermal applications and can also be used in solar collectors for effectively capturing and transporting thermal energy.

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