Performance analysis of Flat Plate Solar collector by using Al_2O_3 Nanofluid at different concentrations with different Aspect Ratios

Punnaiah Veeraboina, Dr.G.Yesuratnam

***Abstract*— The efficiency of the FPC was studied experimentally. The concentration of the Al_2O_3 Nanofluid was 5.97 grams, 11.94 grams and 17.91 grams. The SDBS is used as dispersion liquid. The experiments were performed in different mass flow rates of 0.05, 0.075, and 0.1 kg/sec. of Al_2O_3 Nanofluid. From the experimental results, the weight fraction 0.2% to 0.4%, there is a substantial increase in the efficiency of Solar Flat Plat Collector.**

***Index Terms*— Al_2O_3 Nanofluid, solar flat plate collector, heat transfer, absorption medium**

List of symbols

A Collector area (m^2)
F_R Collector heat removal factor
I Intensity of solar radiation (W/m^2)
T_c Collector average temperature (^oC)
T_i Inlet fluid temperature (^oC)
T_a Ambient temperature (^oC)
U_L Collector overall heat loss coefficient (W/m2)
Q_i Collector heat input (W)
Q_u Useful energy gain (W)
Q_o Heat loss (W)
Greek symbols
g Collector efficiency
s Transmission coefficient of glazing
a Absorption coefficient of plate

Subscript
m Mass flow rate of fluid through the collector (kg/s)

I. Introduction

Solar insolation is the amount of electromagnetic energy (Solar Radiation) incident on the surface of the earth. Basically that means how much sunlight is shining down on us. By knowing the insolation levels of a particular region we can determine the size of solar collector that is required and how much energy it can produce. An area with poor insolation levels will need a larger collector than an area with high levels.

A Solar insolation levels are generally expressed in $kWh/m^{2/}$day and is the amount of solar energy that strikes a square meter of the earth's surface in a single day. Insolation levels change throughout the year, lowest in winter and the highest in summer. Close to the equator the difference throughout the year is minimal whereas at high latitudes winter can be a fraction of summer levels. A very high summer value, as you would see in a hot desert is 7 kWh/m^2/day. The 30 % of the solar power actually reached the Earth, every 20 min the sun produces enough power to supply the earth its needs for an entire year [1].

Solar water heaters use the solar energy from the sun to generate heat (not electricity) which can then be used to heat water for showering, space heating, industrial processes or even solar cooling. Collection will drop, the amount of performance loss depending greatly on the type and quality of the collector. For this reason thermal layering is important in a solar storage tank, ensuring that solar is always heating the coldest water possible. Give that the coldest water is in the bottom of the tank, the solar heating is always in the bottom area, either direct flow or with a coil heat exchanger.

The most common hot water system involves heating and then storing hot water in a tank. When hot water is used, it is drawn from the top of the tank, where the water is the hottest, and fresh cold water is delivered into the bottom of the tank. Because hotter water is lighter and sits above colder water, it is realistic to see a tank that has bottom half cold and the top half hot, this is referred to as thermal layering, or stratification. Hot water solar heater is one of the energy efficient water heating options available which may contribute significantly to reduce the Energy Performance Index (EPI) of the home. Flat Plate Collectors (FPC) has been in service for a long time without any significant changes in their design and operational principles [2].

Solar irradiance passing through the glazing is absorbed directly onto the absorber plate. Surface coatings that have a high absorptivity value for short-wave length light are used on the absorber. Paint or plating is used and the resulting black surface will absorb almost over 95 % of the incident radiation [3]. The most commonly used solar water heating system for domestic needs is through natural circulation type that consists of a flat plate solar collection connected to an insulated storage tank. The sun's rays pass through the glass and are trapped in the space between the cover and the plate or are absorbed by the black body [4].

The Flat Plate Solar Collector (FPSC) is the main part for domestic solar hot water system (DSHWS). The main object is to improve the optimal performance of the solar collector by reducing the internal losses of the system. The circulating water through a conduit system located between the cover and

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Punnaiah Veeraboina, Electrical Engineering Department, CDFD, Hyderabad, India
Dr. Yesuratnam Guduri, Electrical Engineering Department, Osmania University, Hyderabad, India

absorber plate is heated and then carried to the storage tank. Flat plate collectors (FPC) are most suitable when a temperature below 100°C is required. The performance of the thermos siphon system depends upon the size and capacity of the storage tank, the thermal capacity of the collector and connecting pipes including fluid flow and on the pattern of hot water use [5]. The collector housing is highly insulated at the back and sides to reduce the heat losses. It is impossible to reduce 100 % of the heat losses, still the heat losses will be present due to the temperature difference between the absorber and ambient air results in convection and radiation losses. The convection losses are caused by the angle of inclination and the spacing between the glass cover and the absorber plate, while the radiation losses are caused by the exchange of heat between the absorber and environment.

II. LITERATURE SURVEY

The schematic diagram of the thermosiphon flat plate solar water heating system is shown in fig.1.

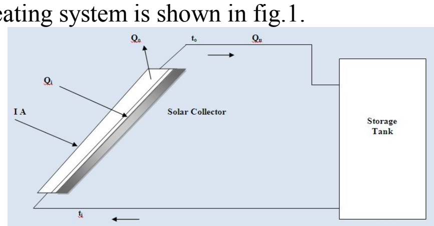


Figure 1. Schematic of SWHS.

If 'I' is the intensity of solar radiation, in W/m^2, incident on the aperture plane of the solar collector having a collector surface area of A, m^2, then the amount of solar radiation received by the collector is: $Q_i = I.A$ (1)

A part of the radiation is reflected back to the sky, another component is absorbed by glazing and the rest is transmitted through the glazing and reaches the absorber plate as short wave radiation.

Therefore the conversion factor indicates the percentage of the solar rays penetrating the transparent cover of the collector (transmission) and the percentage being absorbed.

Basically, it is the product of the rate of transmission of the cover and the absorption rate of the absorber.

Thus,

$$Q_i = I(\tau\alpha).A \quad (2)$$

As the collector absorbs heat its temperature is getting higher than that of the surrounding and heat is lost to the atmosphere by convection and radiation. The rate of the heat loss (Q_o) depends on the collector overall heat transfer coefficient (U_L) and the collector temperature.

$$Q_o = U_L A(T_c - T_a) \quad (3)$$

Thus, the rate of useful energy extracted by the collector (Q_u), expressed as a rate of extraction under steady state conditions, is proportional to the rate of useful energy absorbed by the collector, less the amount lost by the collector to its surroundings [7].

This is expressed as follows:

$$Q_u = Q_i - Q_o = I\tau\alpha.A - U_L A(T_c - T_a) \quad (4)$$

It is also known that the rate of extraction of heat from the collector may be measured by means of the amount of heat carried away in the fluid passed through it, that is:

$$Q_u = mc_p(T_o - T_i) \quad (5)$$

Eq. 4 proves to be somewhat inconvenient because of the difficulty in defining the collector average temperature. It is convenient to define a quantity that relates the actual useful energy gain of a collector to the useful gain if the whole collector surface were at the fluid inlet temperature. This quantity is known as "the collector heat removal factor (F_R)" and is expressed as:

$$F_R = \frac{mc_p(T_o - T_i)}{A[I\tau\alpha - U_L(T_i - T_a)]} \quad (6)$$

The maximum possible useful energy gain in a solar collector occurs when the whole collector is at inlet fluid temperature. The useful energy gain (Q_u), is found by multiplying the collector heat removal factor (F_R) by the maximum possible useful energy gain. This allows the rewriting of equation (4):

$$Q_u = F_R A[I\tau\alpha - U_L(T_i - T_a))] \quad (7)$$

Eq (7) is a widely used relationship for measuring collector energy gain and is generally known as the "Hottel-Whillier-Bliss equation".

A measure of a flat plate collector performance is the collector efficiency (η) defined as the ration of the useful energy gain (Q_u) to be the incident solar energy over a particular time period.

$$\eta = \frac{\int Q_u dt}{A\int I dt} \quad (8)$$

The instantaneous thermal efficiency of the collector is:

$$\eta = \frac{Q_u}{A.I} \quad (9)$$

$$\eta = \frac{F_R A[I\tau\alpha - U_L(T_i - T_a)]}{A.I} \quad (10)$$

$$\eta = F_R\tau\alpha - F_R U_L\left(\frac{T_i - T_a}{I}\right) \quad (11)$$

The system consists of flat place collector, storage tank, connecting pipes, thermocouples and data logger.

The actual photograph of closed loop thermosyphon water heating system is shown in figure 2.

III. MATERIALS FOR SOLAR ENERGY COLLECTORS

This section explains some of the requirements for and properties of the materials (Glazing, absorber plates and selective absorber) employed in solar collectors used for the transformation of solar energy into thermal energy.

A. GLAZING MATERIALS

Material description	Transmittance (τ)
Fluorinated ethylene propylene (FEP Teflon) Crystal glass Polymethyl methacrylates (acrylic) (Acryl ate, Lucite, Plexiglass) Window glass Polyvinyl fluoride (Tedlar) Polyamide (Kapton) Fiberglass-reinforced polyester (Kalwall) Polycarbonate (Lexan, Merlon) Polyethylene terephthalate	0.96 0.91 0.89 0.85 0.93 0.80 0.87 0.84 0.84

Table 1. Glazing material.

Table 1. Shows the transmittances for various glazing materials when direct solar beam is perpendicular to the glazing because the angle of the direct beams various a somewhat lower values of τ are usually used. Exact value depends also on the thickness of the glazing.

B. SELECTIVE ABSORBER

Selective absorbers often consist of a very thin black metallic oxide on a bright metal base. The oxide coating is thick enough to act as a good absorber, with α =1 and ε =0. A flat-black paint that absorbs 96% of the incoming solar energy will also reradiate much of the energy as heat, the exact amount depending on the temperature of the absorber plate and the glazing. Some of the selective absorbers and its properties are shown in the table 2.

Selective Coatings	α	ε	α/ε
Copper on nickel Copper on anodized aluminum Black Chrome Black Ni on galvanized iron CO_3O_4 on silver Black Ni on polished nickel	0.81 0.85 0.93 0.89 0.90 0.92	0.17 0.11 0.10 0.12 0.27 0.11	4.7 7.7 9.3 7.4 3.3 8.4

Table 2. Properties of selective coatings

C. ABSORBER PLATES

The primary function of the absorber plate is to absorb as much as possible of the radiation reaching through the glazing, to lose as little heat as possible upward to the atmosphere and downward through the back of the container, and to transfer the retained heat to the circulating fluid. Absorber plates are usually given a surface coating (which may be a black paint) that increases the fractions of available solar radiation absorbed by the plate. Black paints, for

Material	α	ρ	ε	α/ε
White plaster White paint White enamel Green paint Black tar paper Graphite Aluminum foil Galvanized steel Red brick Grey paint Flat black paint	0.07 0.20 0.35 0.50 0.93 0.78 0.15 0.65 0.55 0.75 0.96	0.93 0.80 0.65 0.50 0.07 0.22 0.85 0.35 0.45 0.25 0.04	0.91 0.91 0.90 0.90 0.93 0.41 0.05 0.13 0.90 0.88 0.88	0.08 0.22 0.39 0.56 1.00 1.90 3.00 5.00 0.60 0.85 1.09

which α =0.92 to 0.98[6] (Sukhatme 1984)[6].

Table 3. Solar absorptance, reflectance and IR emittance.

IV. EXPERIMENTAL SETUP

A. MATERIALS USED FOR EXPERIMENT

The tests were conducted at the roof top of A&H building of CDFD, Hyderabad (17.37°N, 78.43°E) Telangana, India.

The flat plate collector is oriented in south direction that it receives maximum solar radiation.

The detailed specifications are given in Table 1.

Parameter	**Description**
System capacity	120 LPD
Temperature output	60° C
Solar collectors	
Coating	Selectively coated
Absorber fin material	Copper
Header material	Copper
Riser material	Copper
Absorber coating	Selectively coated "NALSUN"
Box material	Aluminum extrusion, anodized
Collector insulation	Rock wool pads for side and bottom
Flanges	Brass, round with four bold holes
Glass	Spl toughened glass 4mm thick
Sealing & Gaskets	Epdm Rubber
Hardware	Stainless steel screws
Reflector Foil	Aluminum 50µ
Box Dimensions MM	2025 X 1025 X 95
Aperture size	2.00 SQ.MM.
Number of risers	9
Header size	25.4 MM
Protrusion inside the header	2 MM
Connecting nuts, bolts & washers	Stainless steel 304

Connects Gaskets	EPDM Punched
Panel boxes Nos.	1
Collector's area SQ.M.	2
Application	Bathing
Circulation	Thermosiphon
Storage tank for hot water	
Capabilities	1000 Lts
Material	Stainless steel SS 304
Thickness MM	1.2
Insulting Material Tank	BARE TANK
Insulation material density	48 KG./ M^3
Insulation thickness	100 MM.
Cladding material	Aluminium 24 SWG
System piping	Braided hose PIPE
Sacrificial anode	Yes
Tanks	SS 304 / SS 316
System	Air vent (gravity) / pressurized / heat exchanger

Table 4. Specifications of the Flat Plate Collector.

Figure 2. Experimental setup.

V.EXPERIMENTAL PROCEDURE

The schematic of the experiment is shown in fig.1. The Solar FPC (shown in fig.1) was experimentally investigated at CDFD, Hyderabad, India (Latitude 17.37°N, Longitude 78.43°E). The specifications of the flat plate solar collector that used in this investigation is given in table 4. The tilt angle of the flat plate collector is 45^o. The solar system is tested with a forced convention system with an Electrical pump and thermosyphon system as shown in fig 2. The system tank for absorbing the heat load from the collector cycle. The capacity of the tank is 30 Lts. A flow sensors was connected to the system at different location (inlet temperature, outlet temperature, surface temperature, atmospheric temperature). The fluid flow control valves are connected to the water pipes at inlet and outlet to control the mass flow rates of the working fluid in the solar system. PT 100 thermocouples were used to measure the fluid temperatures in the inlet, outlet, surface and atmospheric temperatures. These PT100 thermocouples are connected to the 6-channal Data Logger through the CAT-6 cable.

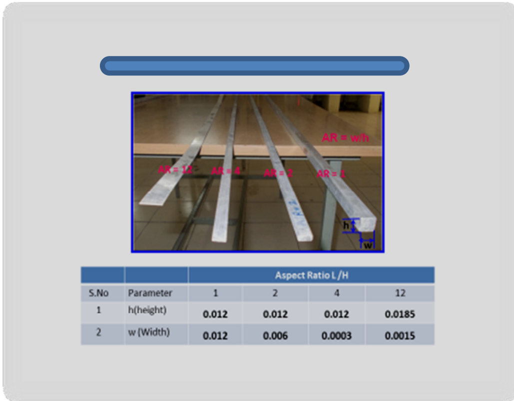
A. EXPERIMENTAL ANALYSIS ON SOLAR-FLAT PLATE COLLECTOR

The further heat transfer and flat plate collector efficiency is estimated by using water and nanofluids flow in collector by with and without twisted tape and longitudinal inserts.

The twisted tape inserts were made in the laboratory from 1mm thick and 13 mm width of aluminum strip. The clearance of 1 mm is used between inner diameter of the tube and the width of the tape, because for smooth insertion of inserts into a test tube. The twisted tapes are snug fit into the test tube and the tube fin effect is neglected. The convective heat transfer between twisted tape material and the adjacent fluid was neglected. The mass flow rate of nanofluid flowing through a tube with twisted tape inserts are estimated based on the inner diameter of the tube. The hydraulic diameter of tube with twisted tape inserts was considered as inner diameter of the tube, because the twisted tape has very negligible thickness i.e. 1 mm. The inlet, outlet, wall temperature, mass flow rate of nanofluids were recorded, once the system reaches to steady state conditions. The advantage of using the longitudinal strip inserts is to create the turbulence inside the flow and the reduction of flow area. The eventual temperature gradient along the longitudinal strip material was neglected. The mass flow rate of nanofluid flow in a tube with longitudinal strip inserts were measured in terms of hydraulic diameter ($D_h = 4A/P$) where A = cross-section area; P = perimeter. The thermal properties of nanofluids are calculated at the bulk mean temperature of the fluid.

Figure 3. Materials used for experiment.

Figure 4.Preparation of fluid for experiment.



		Aspect Ratio L /H			
S.No	Parameter	1	2	4	12
1	h(height)	0.012	0.012	0.012	0.0185
2	w (Width)	0.012	0.006	0.0003	0.0015

Figure 5. Photos of the longitudinal strip insert

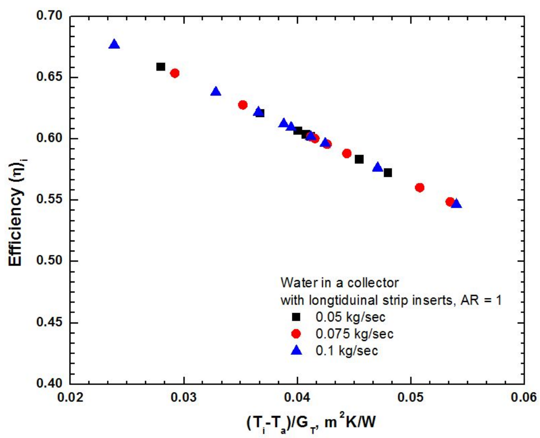


Figure 6 Efficiency of water flow in a flat plate collector with longitudinal strip inserts of aspect ratio AR=1.

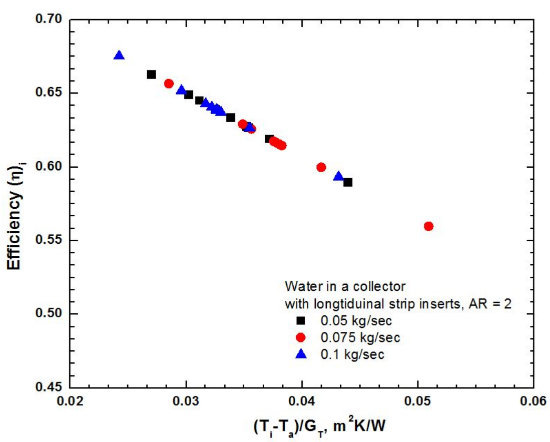


Figure. 7 Efficiency of water flow in a flat plate collector with longitudinal strip inserts of aspect ratio AR=2.

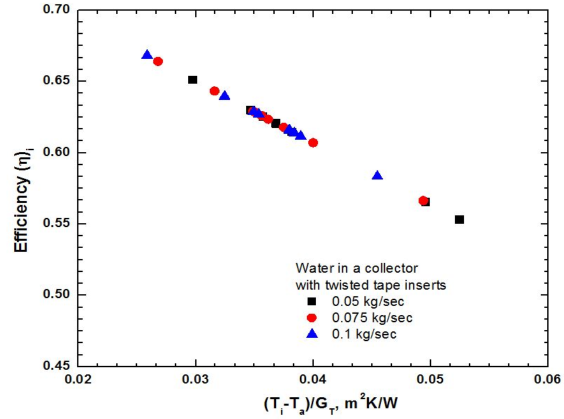


Figure 8. Efficiency of water flow in a flat plate collector with twisted tape inserts.

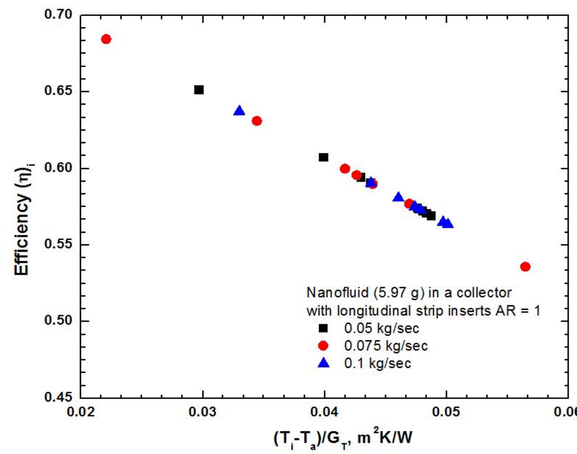


Figure 9. Efficiency of nanofluid (5.97 g) flow in a flate plate collector with longitudinal strip inserts of AR=1.

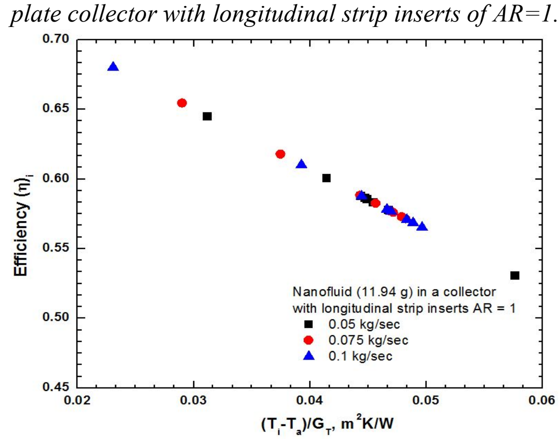


Figure. 10. Efficiency of nanofluid (11.94 g) flow in a flate plate collector with longitudinal strip inserts of AR=1.

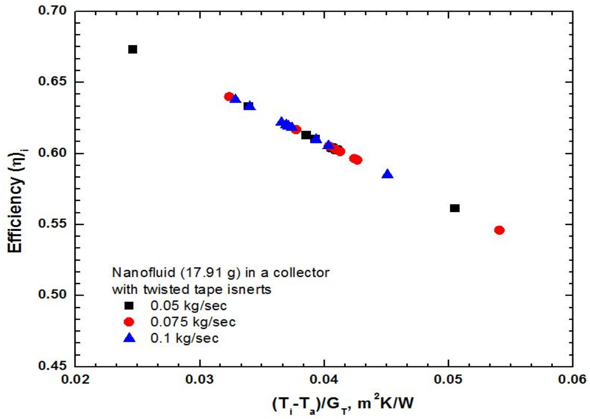


Figure 11. Efficiency of nanofluid (17.91 g) flow in a flat plate collector with longitudinal strip inserts of AR=1.

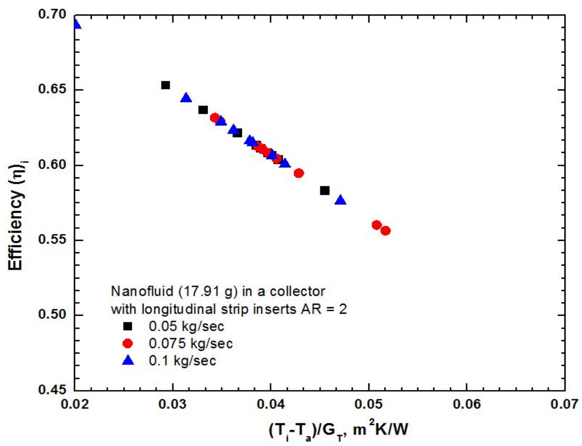


Figure 12. Efficiency of nanofluid (17.91 g) flow in a flat plate collector with twisted tape inserts.

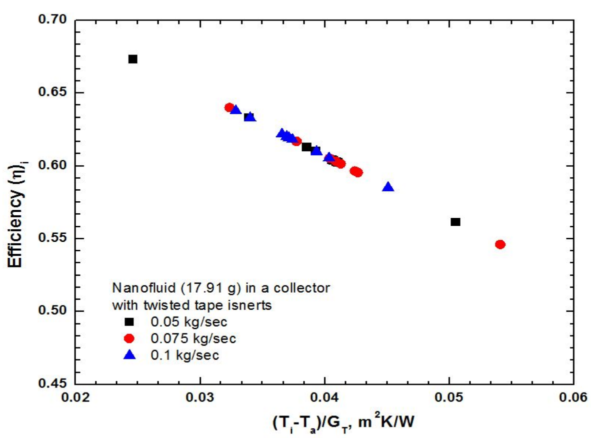


Figure 13. Efficiency of nanofluid (17.91 g) flow in a flat plate collector with longitudinal strip inserts of AR=2.

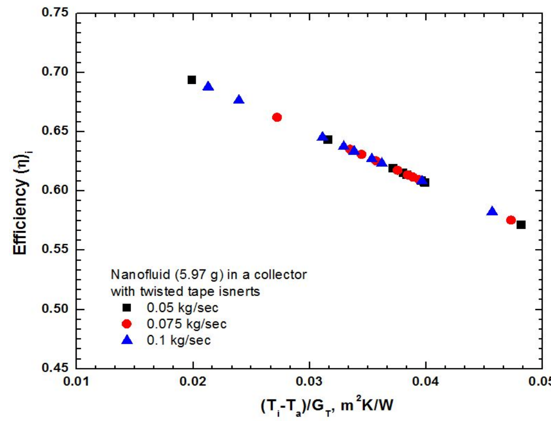


Figure. 14. Efficiency of nanofluid (5.97 g) flow in a flat plate collector with twisted tape inserts.

VI. TESTING METHOD AND PERFORMANCE EVALUATION

Water flows from cold water storage tank to the solar collectors. Due to the absorption of solar radiation, water temperature increase. The insulation provided at the bottom and all the sides of the solar collectors and glass cover serves the purpose of reducing direct convective losses to the ambient which further beneficial for rise in temperature of water in collector.

The heated working fluid moves upwards due to decrease in density whereas the colder water settled at the lower portion due to more in density.

The hot water is collected from the outlet which is connected to the solar water storage tank, cold water temperature (T_{inlet}, °C), solar collector temperature ((T_{outlet}, °C), surface temperature ($T_{surface}$, °C) and ambient temperature (T_{atm}, °C) were recorded intervals in between 11:00 to 15:00 and figure 2 shows the photographs with thermocouples.

VII. RESULTS AND DISCUSSIONS

A. WATER AS WORKING FLUID

The tests have performed around solar noon at time 11 A.M. to 3.00 P.M. The experimental results are presented in the form of graphs that describe the collector efficiency against a reduced temperature parameter. Fig. 4.3 presents an example of typical recorded data for water base fluid at 3 Litters/min (0.05 kg/s) in one of the test days. All the presented data were divided into several test runs (each test run was chosen 60 min). Each test run was divided into several test periods in a quasi-steady state condition. The maximum variations in ambient, inlet and outlet temperatures in each test period are 0.7°C, 0.4°C, and 0.6°C respectively, while in global radiation, it is 21 W/m^2. The above phrase reveals that the data presented here satisfy the necessities presented in ASHRAE Standard 93-86. The solar collector was tested for various mass flow rates of 0.05, 0.075, and 0.1 kg/sec. Because of the special climate of the test run place, some days became suddenly cloudy or windy. In these days getting the data violated the requirement of ASHRAE standard. Therefore, each test was performed in several days and the best experimental data has been chosen. Notice that the time constant of solar collector at every mass flow rate is accounted separately. Fig. 4.4 presents the variations of collector efficiency versus the reduced temperature parameters, for each mass flow rate. The experimental data are fitted with linear equations to provide the characteristic parameters of the flat-plate solar collector in order to compare the effect of various mass flow rates. The efficiency parameters, and, at each mass flow rate are expressed in Table 4.2. In this table, time constant values for each mass flow rate are expressed. Fig. 4.3 and Table 4.2 show that the value of the collector for 0.05 kg/s is highest, and the value in this mass flow rate is lowest. Therefore based on the Eq. (6), the efficiency of solar collector in this mass flow rate is highest. According to Fig. 4.3, the solar collector efficiency decreases with decreasing the mass flow rate.

B. AL_2O_3 NANOFLUID AS WORKING FLUID

The nanofluid has been prepared by adding 5.97 g, 11.94 g and 17.91 g of nanoparticles to the distilled water and the experiments were conducted at different mass flow rates with and without twisted tape and longitudinal strip inserts. Fig. 4.5 shows the effect of nanofluids at two different mass fractions on the efficiency of solar collector. The efficiency of collector for water and nanofluid is plotted versus reduced temperature, as shown in Fig. 4.5, the efficiency of flat-plate solar collector for 0.2 wt% Al_2O_3 nanofluid is lower than that for water as base fluid. This can be described by referring to the Table 4.3 and comparing the values. Although the for water and 0.2 wt% Al_2O_3 nanofluid are the same, however, the value for Al_2O_3 nanofluid is greater than that of water by 27.35%. It is concluded that the increasing of thermal conductivity of nanofluid compare to base fluid is smaller than the increasing of thermal boundary layer of nanofluid with respect to the base fluid. Therefore, there is a decrease in heat transfer. For Al_2O_3 nanofluid containing 0.4 wt% of nanotubes and values were increased 65.51% and 45.84% respectively in comparison with water. Therefore the increase in absorbed energy parameter can compensate the increase in removed energy parameter. Therefore, the efficiency of the flat plate solar collector, Eq. (7), at this concentration was increased with respect to water. These results show that the efficiency of collector for 0.4 wt. % nanofluid is greater that than for 0.2 wt. %.

The effect of mass flow rate: Fig. 4.6 shows the variation of the efficiency versus the reduced temperature parameter, for different mass flow rates of 0.05, 0.075 and 0.1 kg/s for nanofluid. and values of the solar collector for various mass flow rates of Al_2O_3nanofluid are represented in Table 4.4. From Fig. 4.6, it can be concluded that for small values of reduced temperature differences parameter, the efficiency is increased by increasing the mass flow rate. Beyond these small values, the efficiency gets a reversed trend. This can be described as follow. The thermal conductivity enhancement has considerable dependence on the bulk temperature of the nanofluid. Therefore, due to increase of mass flow rate, the bulk temperature of the Al_2O_3 nanofluid is decreased; thus its thermal conductivity enhancement is decreased.

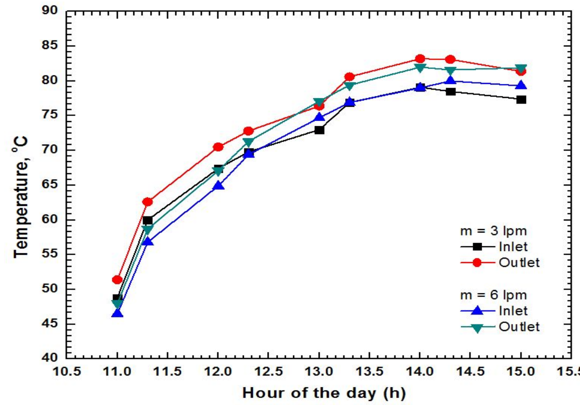


Figure 15. Inlet and outlet temperatures of the state measurements on a clear day.

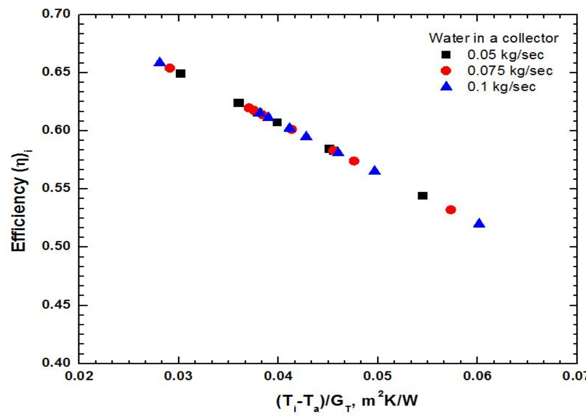


Fig. 16. Efficiency of water flow in a flat plate collector.

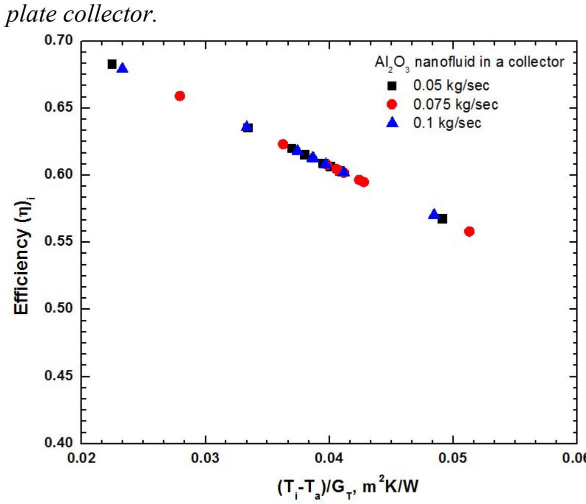


Figure 17. Efficiency of nanofluid flow in a flat plate collector.

VIII. CONCLUSIONS

The effect of using the Al_2O_3 nanofluid as absorbing medium in a flat-plate solar water heater is investigated. The effect of mass flow rate, nanoparticles at two mass fraction, and the presence of surfactant on the efficiency of the collector is studied. The results show that using the 0.2 wt% Al_2O_3 nanofluid without surfactant decrease the efficiency and with surfactant increase it. The increase in the efficiency depends on the temperature differences parameter. However, for 0.4 wt% Al_2O_3 nanofluid without surfactant an increase for the efficiency was observed. For small values of reduced temperature differences parameter, the efficiency is increased by increasing the mass flow rate. Beyond these small values, the efficiency gets a reversed trend.

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