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"Design and Performance Analysis of Concentric Heat Exchanger Tank using MWCNT Nanofluid for Evacuated Tube Solar Collector"

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Abstract: **Solar energy is the most available, environmental friendly energy source and also renewable to sustain the growing energy demand. There are particular challenges in the effective collection and storage of solar energy though it is free for capturing. Solar energy is captured by solar collectors and an evacuated solar collector is the most efficient and convenient collector among various kinds of solar collectors. In the present study, the heat transfer characteristics of MWCNT – Demineralized water nanofluid as Heat transfer Fluid (HTF) is used in concentric type heat exchanger tank are presented. The heat exchanger is fabricated from copper concentric inner tank with a length of 1100 mm and Dia of 230 mm and with outer SS tank of length 1150 mm and dia 252 mm. The weight fraction of nanoparticles was 0.1% with the nanoparticles dimension ranging 20nm- 40 nm. Sodium Dodecyl Sulphate (SDS) as surfactant and Chitosan as dispersant was used in this experimental study. The performance of the concentric heat exchanger tank with Evacuated tube solar collector (ETSC) using MWCNT nanofluid as heat transfer fluid was compared with conventional solar water heater tank. The present study revealed that the maximum efficiency was found to be in between the range of 10% - 20% more than the conventional water heater in a day. The results of this study have technological importance for the efficient design of concentric heat exchanger tank to enhance heating performance of water even at low incident radiations. The collector efficiency shows greater enhancement with the use of MWCNT nanoparticles at a 0.1% weight fraction. In conclusions, results suggest that MWCNT Nanofluid can be used as the working fluid in an ETSC to absorb heat from solar radiation and to convert solar energy into thermal energy efficiently.**

Keywords**: Renewable energy, solar water heater, solar collectors, MWCNT Nanofluid. .**

I. INTRODUCTION

Solar energy is one of the cleanest, environmental friendly form of renewable energy which is inexhaustible and inexpensive [1], [2]. Solar energy is the most dependable form of renewable energy that can sustain the growing day to day energy demand. To collect/absorb the maximum heat radiations from the sun, solar collectors are the existing and the fast developing technologies which are used in many energy requirements such as air conditioning, water heating etc. are reported by R.Tang et.al., [3] which show that technologies have an experimental growth towards utilizing the solar energy to meet the demand. As it is known, water is a good conductor of heat and electricity, it can be used for receiving/collecting and storage of solar energy. Kumar et.al, [4] have reported that solar water heaters are one of the best applications that can collect and store the incident radiations through water and utilize the same for domestic purpose. Hence, SWH is one of the fastest growing application of direct solar energy conversions in the world toady [5]. Flat plate solar collectors (FPSC) are simple in construction that can collect the incident radiations as well as diffuse them. These FPC are generally popular and are ease of use for low temperature applications. As reported by C.Xiao et.al, [6], FPC'S have comparatively low efficiencies and outlet temperatures. As an upgradation in technology Evacuated Tube Solar collectors (ETSC) are emerging as outstanding solar collectors in thermal performance due to their lower heat losses, ease of transportation and their suitability for unfavorable climates [7]. ETSC work on a principle of heat absorption in a black body. A black body is one which absorbs all the incident radiations with a negligible heat loss. The ETSC'S used in solar water heaters use vacuum tubes made up of borosilicate glass with special coating to absorb solar energy. These vacuum tubes are an assembly of two concentric borosilicate tubes to absorb solar energy. This vacuum reduces the conduction and convection losses like as in FPC and thus, allow the collector to operate at high temperatures. Hence, ETSC'S as reported by [8], [9] prove to be more efficient over FPC from the literature [10] it can be observed that conventional fluids such as water which are used as the heat transfer medium in the collectors, suffer from poor thermal and heat absorptive behaviors and also these fluids have a limited capacity to carry the heat there by limiting the collector performance.

From previous investigations [11], [12] Nano particle suspensions in these fluids have shown significant enhancement in their thermo-physical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients compared to those of only the conventional fluids. Nanofluids are dilute liquid suspensions of nanoparticles with dimensions ranging from 40 to 100nm. Several researchers have already used different types of nanofluids investigate the performance of ESTC. Mahindran et.al, [13] conducted an experiment to determine the efficiency of ESTC using TiO2/water nanofluid of 4wt% with average particle size ranging from 30-50nm. The temperature enhancement during this test was about 19% higher than that of water. The maximum efficiency of the system using TiO2/water was 0.73 as compared to conventional system which was 0.53. Tiwari et.al. [14] Investigated the effect of Al2O3/water nanofluid as heat transfer fluid in the collector and also studied the effect of mass flow rate and particle volume fraction on the efficiency of the collector. Their results showed that 1.5wt% of Al2O3 nanofluid increased the solar collector efficiency by 31.64% than the conventional system. Yousefi et.al, [15] studied the effect of Al2O3 and MWCNT/ water nanofluid on the efficiency of FPSC experimentally. The results conclude that using Al2O3 and MWCNT/ water nanofluids increased the efficiency up to 28.3% and 35% respectively. From these literatures, carbon Nanotubes based nanofluids are expected to exhibit superior heat transfer properties than the other nanofluids. Hence MWCNT'S have been a topic of tremendous scientific interest in recent years. Depending on the properties of the base liquid, CNT geometry and volumetric concentration, a wide range of enhancement can be noticed.

Since, ETSC'S are the energy technology that are proving capable to work in high temperature ranges, any attempt for improving the rate of energy harvest can be very effective. Considering the previous studies, use of concentric type heat exchanger tank with nanofluid as HFT in ETSC is a new effort put in to study its behavior under various experimental conditions.

The concentration in this present work is mainly focused on the performance of concentric type heat exchanger tank using MWCNT/distilled water based nanofluid under varying experimental conditions like, temperature, incident radiation etc. in comparison to the conventional solar water heater.

II. EXPERIMENTAL PROCEDURE

2.1 Nanofluid preparation

Preparation of nanofluids plays an important role in any experimental analysis. There are several methods followed to prepare nanofluids out of which the widely accepted and followed methods are single step and two step methods as observed by Adityakumar et.al, [17].

In this experiment, two step method was selected to prepare the nanofluids which involves dispersing the readily available Nanopowder as shown in **Fig.1** into the base fluid in a magnetic stirrer. This solution is stirred in it for about 2 hours. The solution (stirred) is then put for sonication to prepare the nanofluid. Magnetic stirrer and Sonicator are shown in **Fig. 2&3** respectively. Dispersants and surfactants are also added as additives in to the base fluid which enhance the suspension stability.

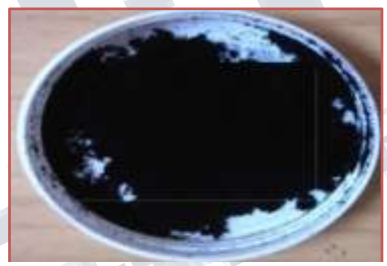

Fig.1: MWCNT Nanopowder

Fig.2: Magnetic stirrer

Fig.3: Ultra Sonicator bath

As a part of this procedure, an MWCNT nanoparticle of properties as shown in Table.1 was selected. Distilled water was taken as base fluid followed by Sodium Dodecyl Sulphate (SDS) and Chitosan as surfactant and dispersant respectively to prevent the quick settlement and agglomeration of nanoparticles. The additives in addition to these also have an advantage of enhancing the fluid stability. The MWCNT nanoparticles were tested for different Thermo-physical properties such as Heat absorption rate (Q), thermal conductivity for different weight concentrations. The obtained results depicted in **Fig4, 5**have shown that the performance of these particles increase with increased weight concentration and then decrease after 0.1 wt%. Hence 0.1 wt% of MWCNT nanoparticles was chosen for the study.

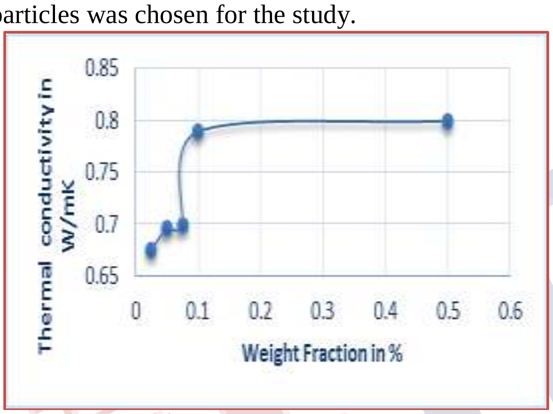

Fig 4: Heat absorption rate v/s weight fraction

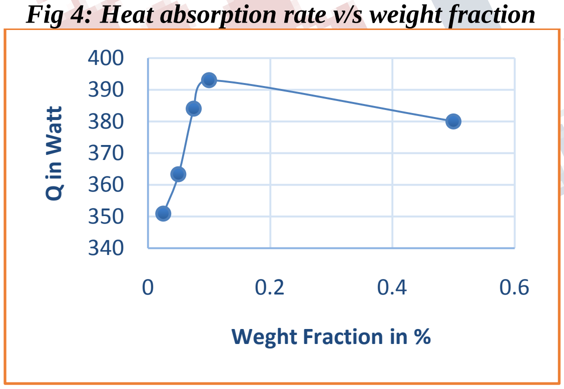

Fig 5: Thermal conductivity v/s weight fraction

The measured percentage weight concentration of 0.1% of MWCNT was suspended in distilled water along with 1:1 wt % of the additives i.e. SDS and chitosan. This suspension was stirred in a magnetic stirrer for about 2hours as a pre homogenization process and then sonicated in an ultra Sonicator (capacity -150 Hz, 260W) for 4hrs to obtain a homogenized nanoparticle suspended fluid solution. The so obtained solution was kept stationary under observation to check for the stability and then was visually analyzed in a XRD as shown in Fig.6.This shows that sonication time had a positive influence on de-agglomeration of MWCNT particles which influenced for a stable solution and a better zeta potential.

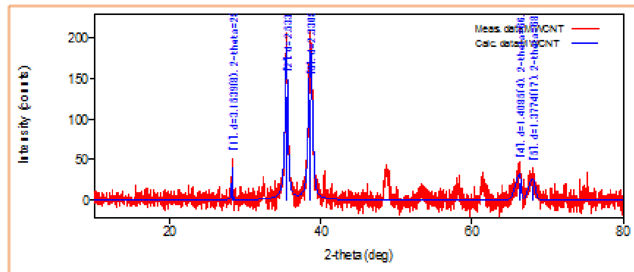

Table.1: MWCNT nanoparticles of properties

Properties	Value
Morphology	Tubular
Diameter (nm)	15-25
Length (μm)	~5
Purity (wt %)	90
Bulk density (kg/m^3)	200-350
Thermal conductivity (W/m-K)	2500-3000
Specific heat (kJ/kg-K)	4.6

Table 2: Properties of nanofluid of 0.1% weight fraction

Properties	Values
Density (kg/m^3)	999.75
Thermal conductivity W/m-K	0.7866
Viscosity (Pa-sec)	0.0008945
Specific heat (J/kg-K)	4175.15

Table 2 shows the analyzed values of the prepared Nanofluid from which it can be concluded that the properties are nearer to that of normal water and hence do not affect the experimental setup chemically but increase the heat absorption capability when used as Heat Transfer Fluid (HTF).

2.2 Experimental setup

A concentric type heat exchanger SWH tank was designed, modeled and fabricated as shown in Fig.7-9. The inner tank was made out of copper due to its high thermal conductivity and also other thermo-physical properties. The outer tank was made out of stainless steel of 304 grade. The fabrication dimensions are according to the desired specifications as shown in Table.2.

The gap between the 2 tanks was maintained constant to 20mm. the filling capacity of the copper tank was 50litres and that of the SS tank was 25litre. The nanofluid (MWCNT/water) was made to flow in the SS tank and the normal water in the copper tank as a result of which the absorbed heat from the nanofluid with less volume was transferred to the normal water in the copper tank with a larger volume. The SS tank is connected to the ETSC through which a continuous circulation of nanofluid takes place. The specifications of the ETSC used for this experiment are tabulated in the Table 3. The fluid through this ETSC flows to the tank due to thermo siphon effect

Table 3: The specifications of the ETSC

Parameters	Value
Length of the tube (mm)	1500
Diameter of the outer tube (mm)	45
Diameter of the inner tube (mm)	38
Glass thickness (mm)	3.5
Capacity of tube (lit)	1.2
Absorber Coating (mm)	0.2

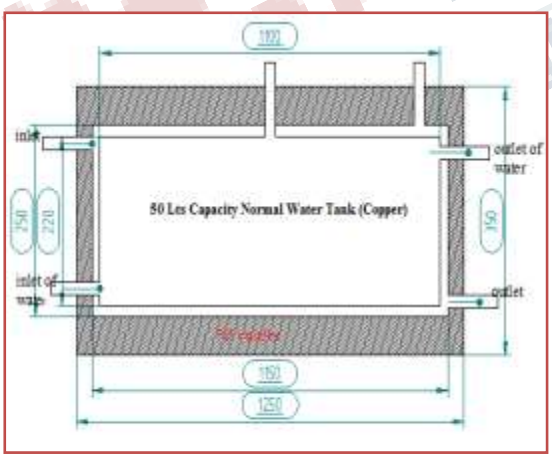

Fig 7: Design of the solar water heater tank

Fig.8: Setup of concentric type heat exchanger ETSC

Fig.9: Cross sectional view of ETSC

Thermocouples were placed inlet, outlet and also at different positions of both the tanks. The continuous variations in the temperature were recorded using a data logger (make-ENVADA)

The experiment was conducted by continuously circulating the nanofluid and replacing the copper tank with fresh water every day. The variations in the temperature for varying radiations in a time interval of 30min were recorded to study the rate of heat transferred during the day. The radiations were recorded continuously using a pyranometer. The performance of the experimental setup was evaluated by recording the values for 5 days and the average values of the readings were used for calculations.

The efficiency of ETSC can be calculated by **eq.1**

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$$\eta = \frac{mC_{p_{nf}}(T_o - T_i)}{A_c G} \qquad eq.1$$

The specific heat of the MWCNT can be estimated by **eq.2**

$$C_{p_{nf}} = \frac{(1-\emptyset)(\rho C_p)_{bf} + \emptyset(\rho C_p)_{np}}{(1-\emptyset)\rho_{bf} + \emptyset\rho_n} \qquad eq.2$$

The weight of the nanoparticle to be added to the solution for 0.1 wt% concentration of the nanofluid was calculated based on the **eq.3** and corresponding weight of the surfactant was added in the ratio 1:1 into the solution. **Table.4** shows properties of 0.1 wt% nanofluid.

$$\varphi = \frac{\frac{w_{np}}{\rho_{np}}}{\frac{w_{np}}{\rho_{np}} + \frac{w_w}{\rho_w}} \times 100 \qquad eq.3$$

III.RESULTS AND DISCUSSION

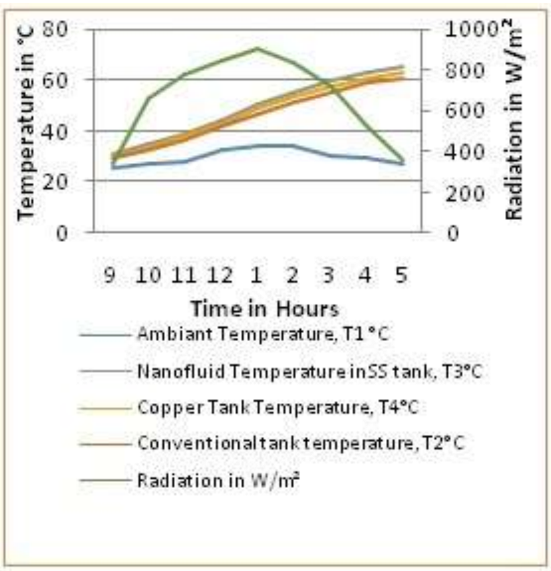

Fig 10: Variation of radiation and temperature with time

Fig 10 shows the hourly average variation of radiation and temperature of conventional ETSC and ETSC with concentric type heat exchanger tank on 5 days of observation. It is seen from the fig that the water temperatures in both the storage tanks increase gradually with the time. Radiation gradually increases from morning and reaches the peak value around 1pm due to high solar radiation and angle of incidence. The outlet temperature of ETSC with Concentric type tank and that of the conventional ETSC tank are compared which show that the temperature in all the tanks increases gradually. The temperature attained in concentric type ETSC tank was 8-10°C more when compared to that in the conventional type even at the end of the day.

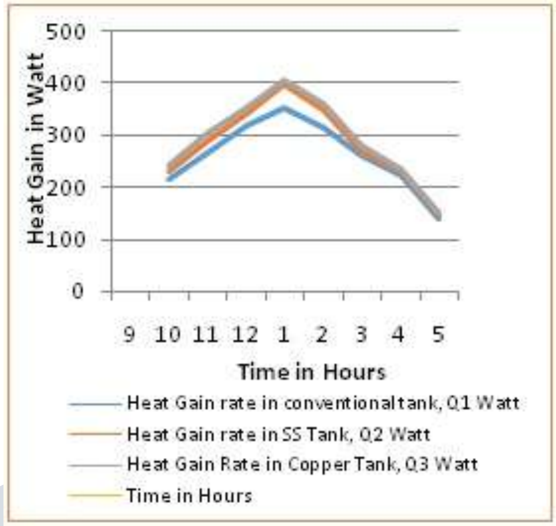

Fig 11: Graph of Heat Gain v/s Time

Fig .11 shows that the heat input in the storage tank increased gradually with respect to time. The heat gain rates of ETSC with concentric type tank and conventional ETSC are compared which shows there is a 70-80 Watt difference between the tanks. Thus, there is a better heat absorption capacity in the ETSC with concentric type tank and so is the efficiency difference of 12% as shown in **Fig.12**.

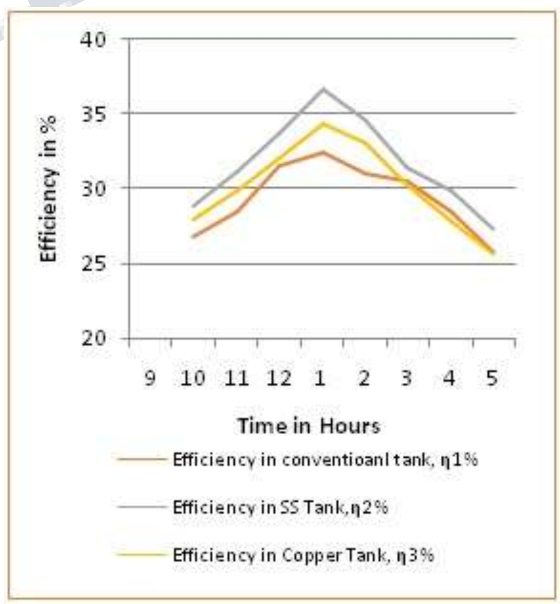

Fig 12: Graph of Efficiency v/s Time

Thus this performance analysis can be concluded that the nanofluid has the ability to absorb more radiations and has a higher heat transfer capability than the water alone.

IV. CONCLUSIONS

In this research Copper is used as inner tank material for the concentric type tank because it has very less fouling factor and higher thermal conductivity. Thus effective heat transfer takes place from nanofluid to normal water inside the copper tank. MWCNT nanofluid used as the Heat transfer fluid in Stainless steel tank which showed effective performance through better absorption and transferability characteristics which added up for the higher efficiency than the conventional tank.The performance of the ETSC with concentric type heat exchanger tank with heat absorption rate (239.44W to 489.69W) and the efficiency (45%) was better than compared to the conventional ETSC (242.06W to 403.6W) and 33%. Hence the performance of the concentric heat exchanger type solar water heater with Evacuated Tube Solar Collector is efficient than the conventional type. Thus in conclusion, ETSC'S are the energy technology that are proving capable to work in high temperature range along with nanoparticle working with high heat transfer rate. Any attempt for improving the rate of energy harvest can be very effective.

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