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The Effect of using different Nano fluids on Heat Transfers through Flat Plate Solar Collector

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Abstract - In this paper investigation experimentally the effect of CuO-water and Al_2O_3/water nanofluids on heat transfer in flat plate solar collector. The volume fraction was used (0.125,0.25 and 0.5) % for flow flow rate of working fluid equal to (1 L/min) and the particles size was 20 nm. The experiments are conducted in Kerbala, Iraq with the latitude of 32.6^0 N. The result shows that the maximum outlet-inlet temperatures difference obtained at (0.5 vol. %) nanofluid are (16.2 ^{0}C) for (Al_2O_3/water), (15.5 ^{0}C) for (CuO/water) nanofluid, and (10.2 ^{0}C) for pure water. Also, Al_2O_3 shows high heat transfer compared to CuO, this lead to improve the performance of the solar fat-plate collector.

Keywords: Flat plate solar collector, nano fluid, flow rate, outlet-inlet temperatures difference

تأثير إستخدام موائع نانوية مختلفة على انتقال الحرارة خلال مجمع شمسي مسطح

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المستخلص - وتضمن البحث التحقق عمليا تأثير (الجزيئات النانوية من أوكسيد النحاس و أوكسيد الالمنيوم مع الماء) علي عملية انتقال الحرارة في المجمع الشمسي لوح مسطح. التراكيز الحجمية المستخدمة هي (0.125,0.25 and 0.5)% لمعدل جريان (1 lpm) وعند قطر جزيئة (20 nm). التجارب أُجريت في كربلاء، العراق مع خط عرض (32.6^0 شمالا). أظهرت النتائج أن الحد الأقصى لفروق درجات الحرارة بين الدخول والخروج تم الحصول عليه عند تركيز (0.5 vol. %) هو (16.2 ^{0}C) لمائع النانوي (اوكسيد الالمنيوم مع الماء) ,(15.5^0 C) لمائع النانوي (اوكسيد النحاس مع الماء) و ($10.2\ ^0$C) للماء. أيضا، جزيئات النانوية لاوكسيد الالمنيوم تبين انها تملك نقل حراري عالي بالمقارنة مع جزيئات النانوية لاوكسيد النحاس هذا يؤدي إلى تحسين أداء المجمع الشمسي لوح مسطح.

I. INTRODUCTION

Solar thermal energy is one of the most common renewable sources of sustainable energy with less environmental impact, free availability for every human being, all over the world and no requirement of transportation [1]. Solar thermal collector is used for collecting solar energy and convert it into thermal energy. The collection and storage of solar energy during radiation time can be required for the consuming period [2]. Water heating by solar energy was the most important application of direct solar energy that used frequently in the world today [3]. Choi was introduced the nanofluids are suspensions of metallic or nonmetallic nanoparticles in a base fluid that can be used to increase the energy density through enhanced heat transfer from solar collectors to the storage tanks [4]. Nanoparticles are A substantial that increase in liquid thermal conductivity, liquid viscosity, and heat transfer coefficient characteristics of nanofluids [5]. The thermal conductivity of nonmetallic liquids is lesser than metallic liquids. Therefore, fluids that containing suspended metal particles are enhanced thermal conductivities rather than base fluids [6].

In Ref. [7] the authors experimentally studied the conventional solar collector (area 2 m^2) using (Al_2O_3/water) nanofluid with concentrations of (0.2 wt.% and 0.4 wt.%) for three different flow rates (1 to 3 L/min) and found with 0.2 wt.% improvement in efficiency is 28.3% comparison to water. Jamal-Abad [8] investigated experimentally adding Cu nanoparticles at (0.05 wt.%) to water and observed that enhancement in the efficiency by 24%. In Ref. [9] the researchers experimentally investigated the effect of TiO2/water nanofluids on the performance of FPSC and with adding 0.3 wt.% of nanoparticles the efficiency was increased 30.2%. The authors in [10] experimentally investigated the effect of CuO/water on the performance and the efficiency of FPSC. The volume fraction of nanoparticles is set to 0.4% and the mean particle dimension is kept constant at 40 nm. It obtained that with mass flow rate of 1 kg/min for CuO/water nanofluid flow in a FPSC the increases the collector efficiency about 21.8%. The researchers in [11] dispersed metal oxide nanoparticles such as (TiO_2 and Al_2O_3) with weight fraction of 4.3 wt.%) in liquid and showed that the thermal conductivity is increased by (11% and 32%) respectively. In Ref. [12] the authors experimentally investigated thermal performance of the the FPSC under thermosyphon and two forced circulations with using (CuO/H_2O) at 0.05% volume concentration and water with flow rate (0.01, 0.1) kg/s. The results showed that the thermal efficiency was increased by 6.3% in thermosiphon of 0.4% at 0.1 kg/s and 2.7% at 0.01 kg/s flow rates. The authors in Ref. [13] investigated the thermal enhancement for FPSC with (Ag/water) nanofluid and concluded that thermal performance of flat plate collector improved where using nanofluid compared with water especially at high inlet temperature. In Ref. [14] the researchers experimentally investigated had been carried out on 25-L/day solar flat-plate water heater with a collector area of 0.5 m^2 has been designed and fabricated. The collector is operated with volume fractions of 0.2% and 0.4% were Al2O3 and CuO nanoparticles mixed with distilled water. The nanoparticle size (40 nm) for CuO and Al_2O_3. The result showed that the collector efficiency with 0.4% volume fraction which increased by 12% for Al_2O_3 and 7% for CuO. Similarly, 0.2% volume fraction resulted in an improvement of 7% for Al_2O_3 and 5.5% for CuO compared to that of the water base and the best collector efficiency that obtained at Al_2O_3.

The aim of the experimental work is to enhance heat transfer in FPSC with using (CuO/H_2O and Al_2O_3/water) as an absorbing medium (the working fluid) at volume fraction of (0.125, 0.25, 0.5) % and flow rate of (1, 2 ,3) L/min and compare the results with water.

II. EXPERIMENTAL DEVICE AND PROCEDURE

A schematic diagram of the experimental setup and the photographic of FPSC are shown in Figs (1) and (2), respectively. The collector specifications are given in Table (1).

When solar radiation passes through a glass cover and hitting the blackened absorber surface of high absorptivity, a large part solar energy is absorbed by the plate heat up, changing solar energy into heat energy. The heat is transferred to the transport medium in the fluid tubes, to be carried away for storage or use. The fluid circulates in a closed system with using the water pump.

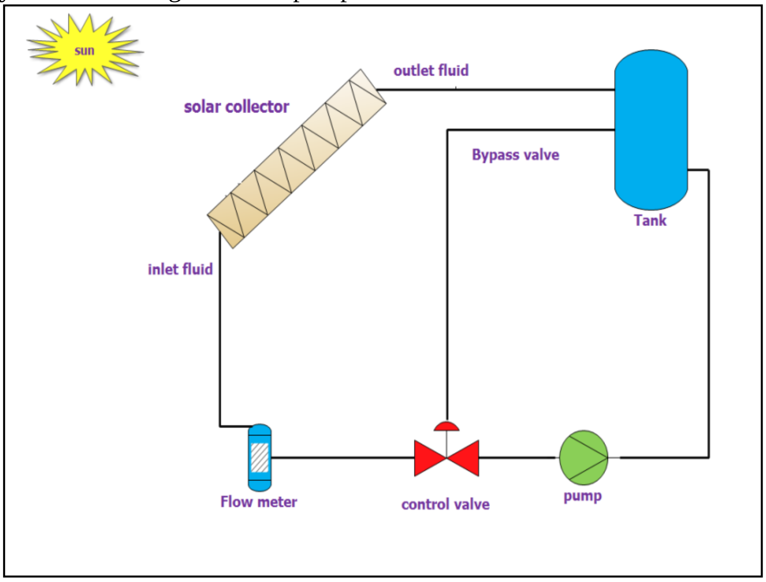


Fig. 1. The schematic of flat plate solar collector

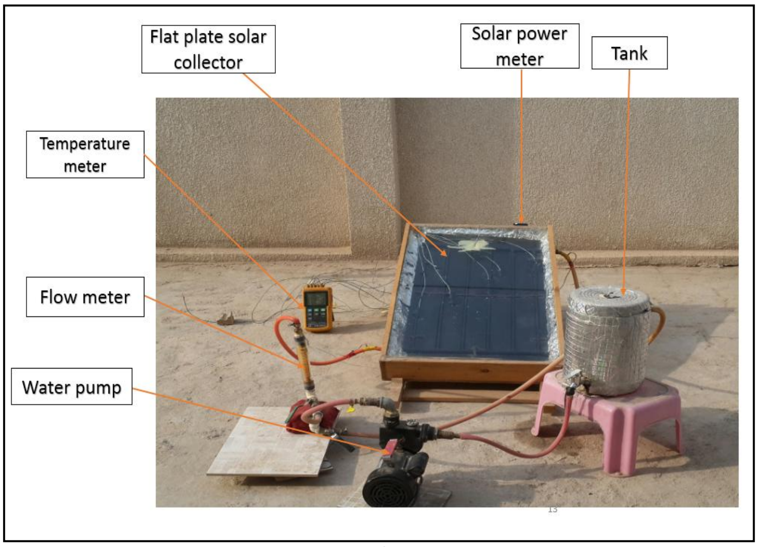


Fig 2. A photographic of the experimental setup

TABLE 1[1]. THE SPECIFICATIONS OF FLAT PLATE SOLAR COLLECTOR COMPONENTS

Component	Dimensions	Remarks
Absorber plate	(0.95x0.526x0.003)m	Material: stainless steel
Glass cover	Thick (4 mm)	window glass
Collector area	(1.04x0.64x0.12)m	
header pipes	Inner diameter (16) mm, outer diameter (20) mm Length (60) cm	Copper
Riser pipe	Inner diameter (8) mm, outer diameter (10) mm, Length (80) cm, center to center distance (7.5 cm)	copper Number of tubes: six
edges insulation	Thick (3) mm	glass wool
Bottom insulation	Thick (45) mm	glass wool
tilt angle	22^{o}	Due to Summer months

A. Experimental procedure

The solar collector performance has experimentally investigated in Karbala, Iraq (latitude 32.6 ^{o} N and longitude 44.02 ^{o} E). data is recorded under transient conditions. the solar collector is tilted to south facing with 22^{0} due to in Summer months (in Summer, the beam component is more than the diffuse component and thus the main contribution comes from the beam component) that leading to the optimum tilt is less (usually latitude -10^{0}) [15].

Experimental set up consists from flat plate solar collector, closed working fluid system and measurement devices. The electric pump circulates the working fluid through the solar collector. The tank capacity is nearly 8L[*]. A flow meter is installed on the pipe after the electric pump. Simple manual valves and bypass pipes system was used to control on the flow rate of working fluid. The flow rate was measured by flow meter (range 1-8L/min, accuracy ±5%).

Ten thermocouples type K was used to measure inlet and outlet fluid temperatures, air gap, cover glass, ambient, three riser pipes, absorber plate temperatures and these thermocouples was connected through a temperature meter (12 channels Temperature recorder, Model: BTM-4208SD, SD Card real time data recorder, Accuracy ± (0.4 % + 1 ℃). The saving data will present into the EXCEL software. The temperature meter and thermocouple as are shown in Figure 3.

[1] * a) It was to control the high temperatures inside the tank and not lost and that because of the isolation of the reservoir from the air. b) The amount of fluid operating in the tank and interring into the solar collector is very sufficient to obtain high difference temperature because the size of the solar collector is suitable for experiments test, the amount of nanoparticles if increased too much also effect on the performance of the solar collector due to increased viscosity of nanofluid and thus will generate friction within the system solar collector resulting in a lack of temperature.

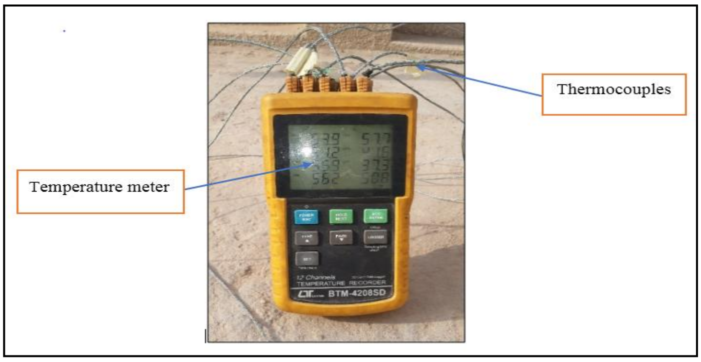


Fig.3.Temperature meter and Thermocouples

The total solar radiation was measured by digital solar power meter (TES, model- 1333R, accuracy ±5 %, Range-1 to 2000 W/m^2). The cosine loss of the beam component was removed because the collector is tilted from the horizontal. The digital solar meter is shown in Figure 4.

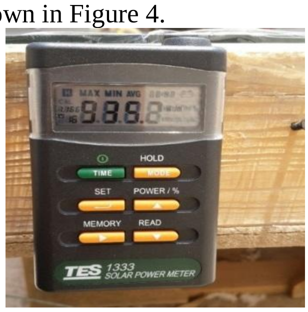


Fig.4. Digital Solar Power Meter

Thermocouples are connected to the solar collector by welding solder of end thermocouple with the surface to be estimating its temperature and covering with Adhesive thermal insulator for insulating from environment and outside effects. Figure 5 and Table II illustrates network thermocouples distribution of the solar collector.

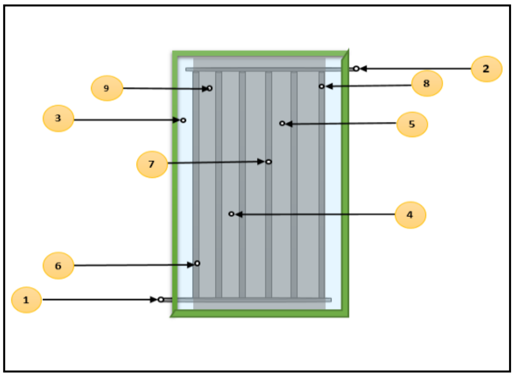


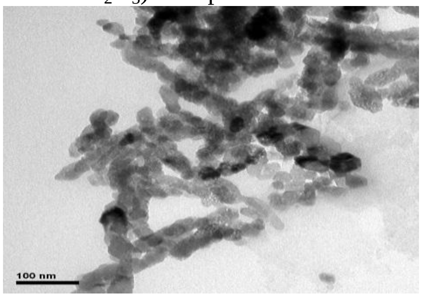
Fig.5.: network thermocouples distribution of the solar collector.

TABLE II: NETWORK THERMOCOUPLES DISTRIBUTION OF THE SOLAR COLLECTOR.

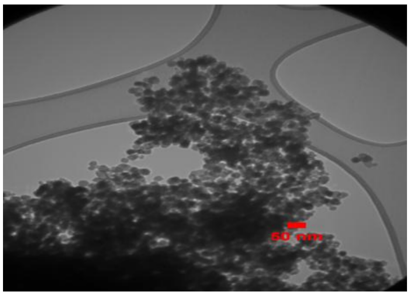
No.	Location
1	Inlet tube
2	Outlet tube
3	Glass cover
4,5	absorber plate
6,7,8	Tube top surface
9	air gap between the plate and glass
10	Ambient

B. Nanofluid preparation

In this research, deionized water with dry powder of (CuO and Al_2O_3) nanoparticles of 99.95% purity and average particle size of 20 nm (procured from US Research Nanomaterial, Inc. USA based company) were used as the working fluid. Properties of the CuO and Al_2O_3 nanoparticles are tabulated in Table III. Figure (6a, b) shows scanning electron microscopy (SEM) and the Transmission Electron Microscope (TEM) analyzed images of the used (CuO and Al_2O_3) nanoparticles.

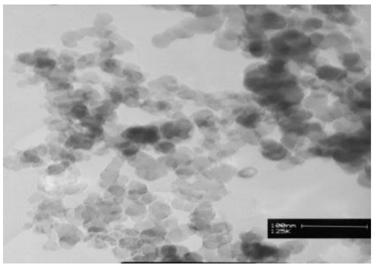


a) SEM image of nano-CuO

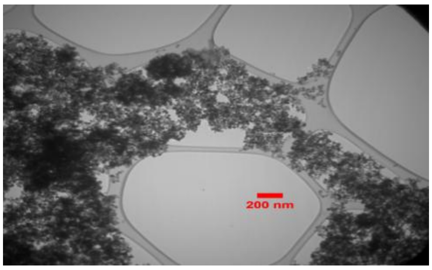


b) TEM image of nano-Cuo, size 20nm

Fig. 6a. Analyzed images of (SEM) and (TEM) of the used (CuO) nanoparticles.



a) SEM image of nano-Al_2O_3



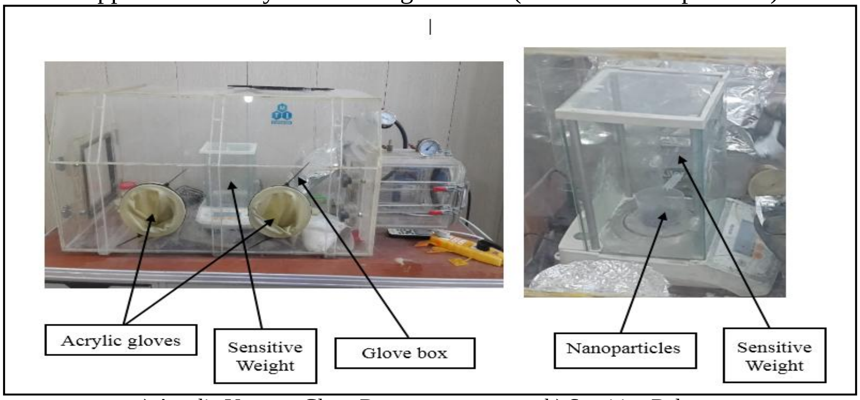
b) TEM image of nano-Al_2O_3, size 20 nm

Fig.6b. Analyzed images of (SEM) and (TEM) of the used (Al_2O_3) nanoparticles

TABLE III. PHYSICAL PROPERTIES OF (CUO AND AL2O3) NANOPARTICLES (FROM US RESEARCH NANOMATERIAL, INC. USA BASED COMPANY)

Properties	**Al_2O_3**	**CuO**
Purity	99.95 %	99.95 %
Average particles Size	20 nm	20 nm
Morphology	nearly spherical	nearly spherical
True density	3.89 g/cm^3	6.4 g/cm^3
Bulk density	0.18 g/cm^3	0.79 g/cm^3

Sensitive balance (Make-Sartorius, model-224-1S, resolution-0.1mg) was used to weight CuO, Al_2O_3 nanoparticles and it is applied in an acrylic vacuum glove box (Make-MTI corporation) as shown in Figure 7



a) Acrylic Vacuum Glove Bo b) Sensitive Balance

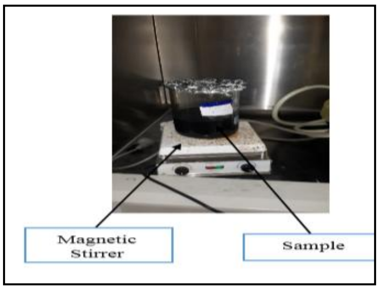
Fig.7: Instruments for evaluating the Nano powder mass

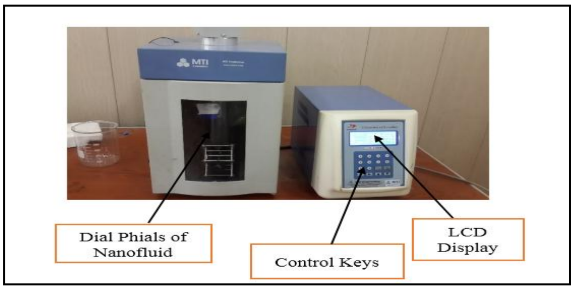
The mass in grams of CuO, Al_2O_3 nanoparticles required for preparation of nanofluid with different volume concentrations is calculated using Equation (2) [16]

$$\emptyset\ \% = \frac{V_{np}}{V_{np} + V_{bf}} \quad (1)$$

$$m = \rho_{np} V_{np} \quad (2)$$

Initially, the powder was added to de-ionized water and stirred by magnetic stirrer for 30 min at slow speeds as shown in Figure 8a. ultrasonic vibration mixer (Make- MTI corporation, model-SJIA, power-1200W, frequency-20 ±3 kHz) is used to mix dry CuO, Al_2O_3 nanoparticles with de-ionized water and Ultrasonic mixing for 2 hours to break the agglomerated particles and obtained on homogeneous mixture of the CuO, Al_2O_3 nanoparticles and water as shown in Figure 8b.





a) Magnetic Stirrer b) Ultrasonic Vibration Mixer

Fig.8: Magnetic Stirrer and Ultrasonic Vibration Mixer Processes of Nanofluids

III. RESULTS AND DISCUSSION

The experiments were conducted from 10 AM to 2 PM in Karbala, Iraq for flow rate of the working fluid (1) L/min at volume fraction (0,0.125,0.25 and 0.5) vol.% with using (CuO/water and Al_2O_3/water) nanofluid. The inlet, outlet and all temperatures and solar radiation intensity were recorded every 10 minutes.

Fig (9) shows the outlet-inlet temperatures difference of water-based nanofluids (Al_2O_3/water), the concentration of nanoparticles in water-based nanofluids have been used as (0,0.125,0.25 and 0.5) vol.% with flow rate (1 lpm). It is observed when the nano-fluid concentration was increased, the temperature difference increased and it was clearly appearing at (0.5 vol. %) nanofluid; since higher the concentration of nano-particles, higher thermal conductivity of the working fluid was obtained and leads to the fluid gets more heat rate from the solar collector. The maximum temperatures difference was (16.2 ^{o} C) at (0.5 vol. %) nanofluid.

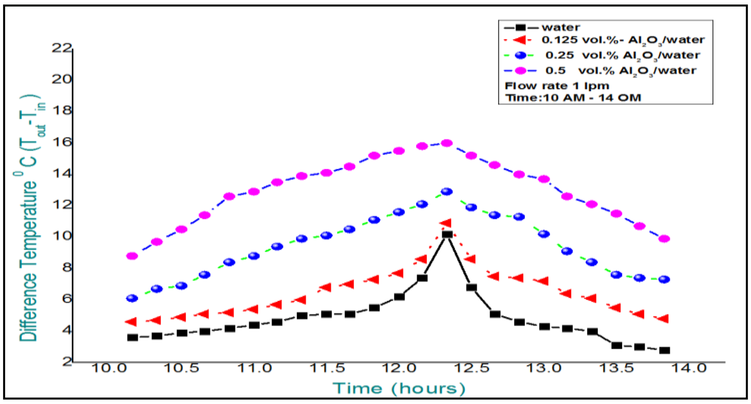


Fig.9: The Inlet Outlet Temperatures Difference of Pure Water and Al_2O_3/water for Flow Rate (1 lpm) with Time.

Figure(10):Shows the outlet-inlet temperatures difference of water-based nanofluids CuO/water, the concentration of nanoparticles in water-based nanofluids have been used as (0, 0.125, 0.25 and 0.5) vol.% with flow rate (1 lpm). It is observed when the nano-fluid concentration was increased, the temperature difference increased and it was clearly appearing at (0.5 vol. %) nanofluid; since heat energy needed for heating the nanofluid is less than that needed for heating the base fluid because of the heat capacitance of water is decrease with the adding of nanoparticles. The maximum temperatures difference was (15.5 ^{o} C) at (0.5 vol. %) nanofluid.

Figure (11 to 13): Shows the outlet-inlet temperatures difference with (CuO/water, Al_2O_3/water) nanofluid for volume fraction of (0, 0.125, 0.25 ,0.5) % with pure water respectively. It is observed from the figures that the temperature difference of nanofluid is high compare to the water and with adding nanoparticle to the water. The temperature difference increased because of high thermal conductivity of nanofluid. Also, it is observed from the figures that the Al_2O_3 nanofluid gives a higher temperature difference than CuO because of Al_2O_3 has higher thermal conductivity and for same volume fraction Al_2O_3 nanofluid has larger number of nanoparticle than CuO due to lower density of Al_2O_3.

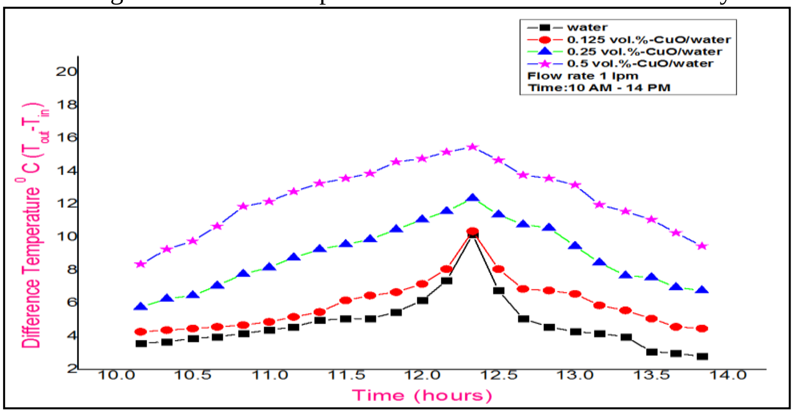


Fig.10: The Inlet Outlet Temperatures Difference of Pure Water and CuO/water for Flow Rate (1 lpm) with Time.

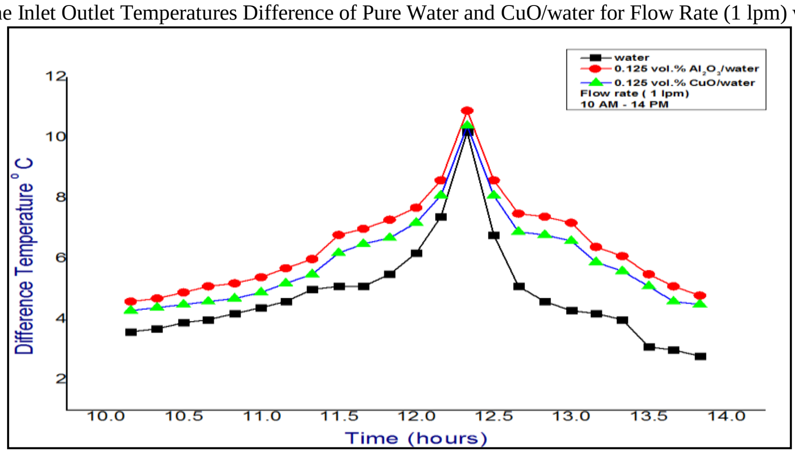


Fig.11: The Inlet Outlet Temperatures Difference of Nanofluid and Pure water at Flow Rate 1 L/min at 0.125 vol.%

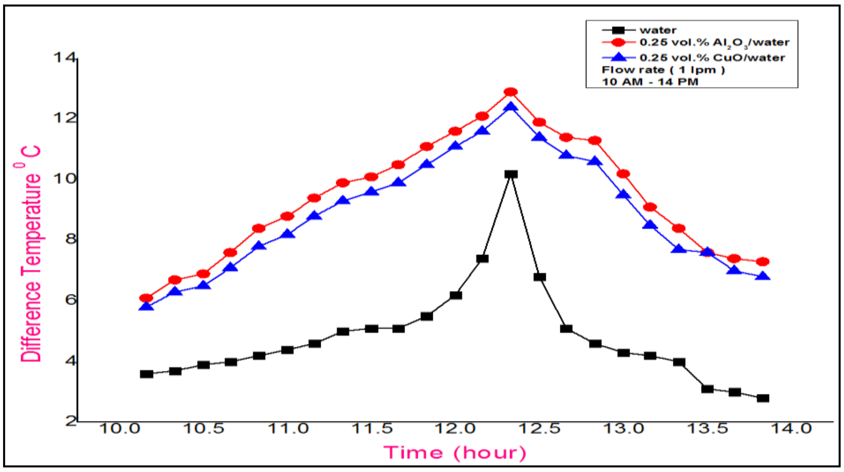


Fig.12: The Inlet Outlet Temperatures Difference of Nanofluid and Pure water at Flow Rate 1 L/min 0.25 vol.%

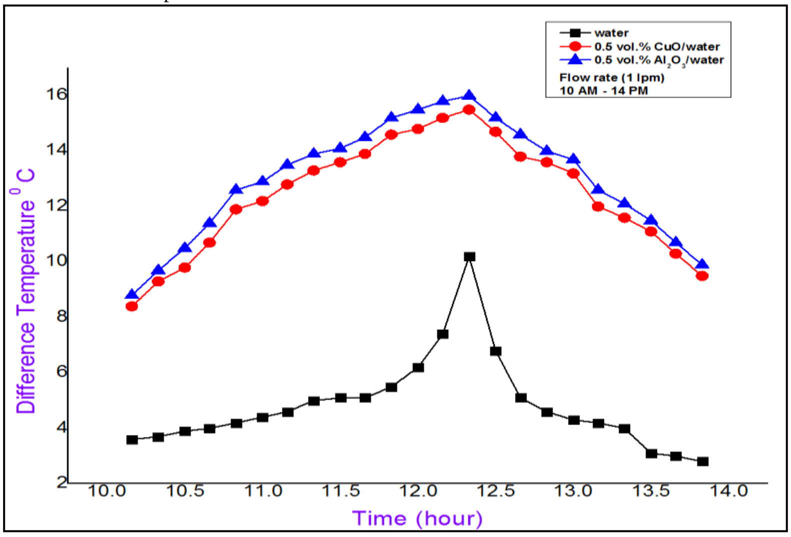


Fig.13: The Inlet Outlet Temperatures Difference of Nanofluid and Pure water at Flow Rate 1 L/min and 0.5 vol.%

The data of experimental case for the solar radiation was recorded from the weather for (August, September and October) / 2016 and four hours (10 AM-2 PM). Figures (14 to 16) shows the solar radiation with variation time for CuO/water, Al_2O_3/water and water with different concentration. It noticed that the solar radiation is fluctuate due to Some days contain very few clouds though the tests days were selected in conditions can be the clear sky.

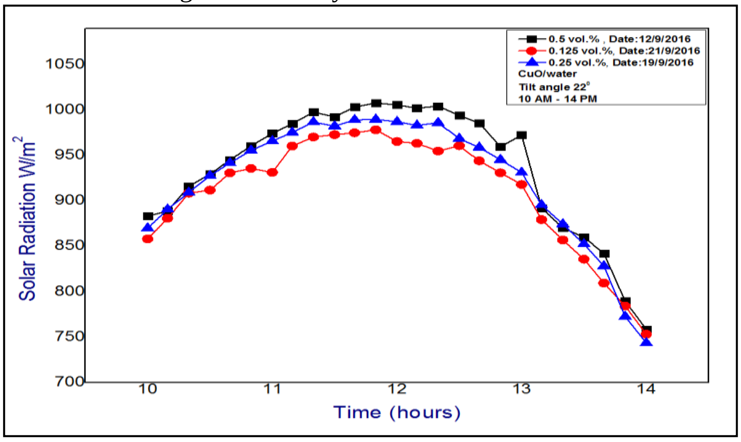


Fig.14: Solar Radiation for (12/ 9), (19/9), (21/9) / 2016 of CuO/water

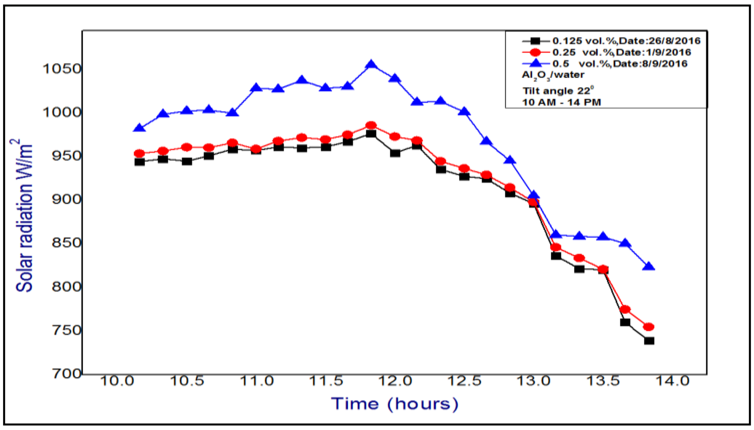


Fig.15: Solar Radiation for (26/ 8), (1/9), (8/9) / 2016 of Al_2O_3/water

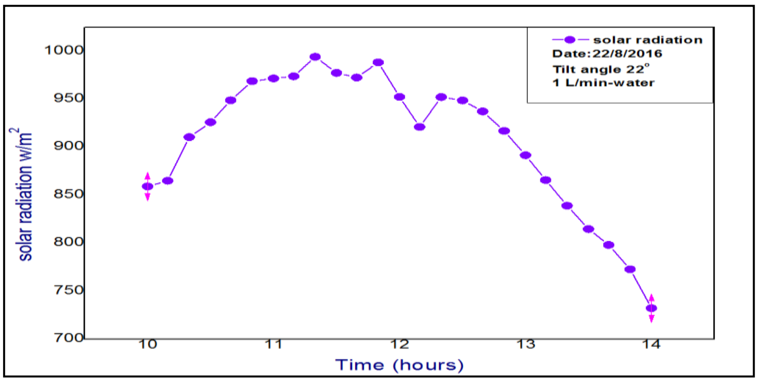


Fig.16: Solar Radiation for 22/ 8 / 2016 of the water

IV. CONCLUSION

- The effect of using (CuO/water and Al_2O_3/water) nanofluid as the absorbing medium with flow rates (1) L/min with different volume fraction (0.125,0.25 and 0.5) % on the flat plate solar collector has been studied experimentally.
- When the concentration of nano-fluid increased lead to more heat from solar collector or less heat loss was obtained and the difference temperatures between inlet and outlet of the working fluid increased.
- By using CuO/water and Al_2O_3/water nanofluid as absorbing medium the outlet-inlet temperature differences were increased comparison with that of pure water.
- The maximum temperatures difference was (16.2 ^{o} C) at (0.5 vol. %) nanofluid for Al_2O_3/water while The maximum temperatures difference was (15.5 ^{o} C) at (0.5 vol. %) nanofluid.for CuO/water.
- For the same volume fraction of nanoparticles, Al_2O_3 shows high heat transfer compared to CuO this lead to improves performance of the solar fat-plate collector.
- Significant enhancement in solar radiation absorption and collector temperatures difference makes nanofluids as an appropriate heat transfer fluid for solar collectors and can be make a Significant develop in the solar renewable energy applications.

Nomenclature

$\emptyset$: volume concentrations

V_{np}: volume of nanoparticle

V_{bf} : volume of base fluid

ρ_{np} : density of nanoparticle (g/cm^3)

m: mass of nanoparticle in game

Subscripts

bf : Base fluid

np : Nanoparticle

FPSC: Flat Plate Solar Collector

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