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EXPERIMENTAL AND NUMERICAL INVESTIGATION THE EFFECT OF MASS FLOW RATE ON THE HEAT TRANSFER FLAT PLATE SOLAR COLLECTOR WITH USING NANO FLUID

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ABSTRACT

A solar collector is the major componentof a solar water heating system. The heat energy from the solar radiation was utilized in the flat-plate solar collector can be enhanced by using nanofluid. This work investigates the experimentally and numericallythe effect (ZnO-water) nanofluid on heat transfer flat plate solar collector. The volume fraction was used (0.5) % for three flow rates (1,2 and 3) lpmand the particle size was 20 nm. The experiments are conducted in Karbala, Iraq with the latitude of 32.6 ^{0} N. The numerical is applied by ANSYS 15software.The result shows that the maximum the outlet-inlet temperature difference was obtained at (0.5 vol. %) nanofluid for (ZnO-water) at the peak value curve (15^{0}C) at a flow rate (1 lpm while in case of water the maximum the outlet-inlet temperature difference was (10.2 ^{0}C). Also, there was a good convention between the experimental and CFD results for outlet temperatures where the maximum error was (8.4%).

Keyword: flat plate solar collector, ZnO/water nanofluids, flow rate, the outlet-inlet temperatures difference, ANSYS 15.

1. INTRODUCTION

In recent years' solar energy has become a viable energy source. One of the easier applications of this energy was transformation the solar radiation into heat. Hence way that domestic strip can be reduced its influence on the ambience is through the installation of flat plate solar collectors for heating water [1]. The solar radiation is utilized as a heat source for different applications such as desalination, water heating with assistance of solar collectors. The major trouble that faced solar collectors was the inferior absorption properties of traditional fluids utilized in these collectors. With amalgamation of new category of fluids known as nanofluids observed enhancement for properties over the traditional fluids, these kind of collectors can be gain importance [2]. The nanofluid is suspending nanoparticles size have high thermal conductivity solid particles of metals, metal oxides etc. in the base fluid such as water [3]. The researches for enhancement and heat transfer in solar devices attracts importance these days.

Mahian [4]an analytical study was performed on the heat transfer in a flat plate solar collector. The working fluid was used Al_2O_3/water nanofluid with four different particle sizes including 25, 50, 75, and 100nm with volume fraction upto 4%. The results show that the outlet temperature increases with an increase in the volume fraction of nanofluid. Moghadam [5] obtained that with mass flow rate of 1 kg/min for CuO/water nanofluid flow in a flat plate solar collector to achieve the maximum thermal efficiency. Yousefi [6]experimentally studied on a tube in plate type conventional solar collector (area 2m^2)using (Al_2O_3/water) nanofluid with concentrations of (0.2 wt.% and 0.4 wt.%) f or three different mass flow rates from (from 1 to 3 Lit/min) and found with 0.2 wt.% improvement in efficiency is 28.3% comparison to water. Ekramian [7] numerical simulation was utilized for foretelling of thermal efficiency and heat transfer coefficients of water and different nanofluids in a flat plate solar collector. The working fluids was used Al_2O_3/water, CuO/water and Multi Wall Carbon Nano-Tube MWCNT/water nanofluids with mass Wight of 1, 2, and 3 wt%. It was observed that Good agreement between experimental data and numerical for foretelling. The results showed that the thermal efficiency and heat transfer coefficient of CuO/water nanofluid are greater than other working fluids. Yarshi [8] theoretical study to analyses the effects of different in the shape of tubes for flat plate solar collector. Also, the effect of mass flow rate, absorber material has been investigated. The numerical analysis is applied with ANSYS CFD FLUENT software. The result shows good agreement in the effect of various parameters.

The aim of this study experimental and numerical heat transfer in flat solar collector by using ANSYS FLUENT with using (ZnO/H_2O) as an absorbing medium (the working fluid) at volume fraction 0.5% and flow rate (1,2,3) L/min and compared with water.

2. EXPERIMENTAL STUDY

An experimental set up of flat plate solar collector of size (1 x 0.64) m has been developed as shown in Figure-1. Experiments were applied at Karbala, Iraq (latitude 32.6 ^{o} N and longitude 44.02 ^{o} E). The solar collector is tilted to south facing with 22^0 due to in summer months; the optimum tilt is less (usually latitude - 10^0). The volume fraction was chosen 0.5% of ZnO/water nanofluids will be prepared and experimented in this research.

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Figure-1. Experimental setup of flat plate solar collector.

3. EXPERIMENTAL SETUP OF FLAT PLATE SOLAR COLLECTOR

A picture of the experimental setup Figure-1 show flat solar plate collector and the collector specifications are given in Table-1.

Table-1. The specifications of solar collector.

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, centre to centre 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	

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 pay pass 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 °C). The saving data will present into the EXCEL software. The temperature meter and thermocouple as are shown inFigure-2.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.

(a) Temperature meter (b) Thermocouples type K

Figure-2. Temperature meter and thermocouples.

Figure-3. 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.

4. PREPARATION OF NANOFLUID

The ultrasonic vibration method was utilized for preparation deionized water with dry powder of ZnO nanoparticles of 99+% purity and average particle size of 10-30 nm (procured from US Research Nanomaterial, Inc. USA based company) was used as the working fluid. Properties of the ZnO nanoparticles are tabulated in Table-2.

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Table-2. Physical properties of (ZnO) nanoparticles.

Properties	ZnO
Purity	99+ %
Average particles Size	10-30 nm
Morphology	nearly spherical
True density	5.606 g/cm^3
Surface area per unit weight (SSA)	20-60m^2/g
Colour	milky white

Sensitive balance (Make-Sartorius, model-224-1S, resolution-0.1mg) was used to weight ZnO nanoparticles and it is applied in an acrylic vacuum glove box (Make-MTI Corporation) as shown in Figure-4.

a) Sensitive balance b) acrylic vacuum glove box

Figure-4. Instruments for evaluating The Nano powder mass.

The mass in grams of ZnO nanoparticles required for preparation of nanofluid with different volume concentrations is calculated using Equation (2) [9]

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

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

Where, $\emptyset$: 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. A volume concentration of 0.5% was used in the study.

Initially, the powder was added to de-ionized water and stirred by magnetic stirrer for 30 min at slow speeds as shown in Figure-5a.ultrasonic vibration mixer (Make- MTI corporation, model-SJIA, power-1200W, frequency-20 ±3 kHz) is used to mixing dry ZnO nanoparticles with de-ionized water and Ultrasonic mixing for 2 hours to break the agglomerated particles and obtained on homogeneous mixture of the ZnO nanoparticles and water as shown in Figure-5(b).

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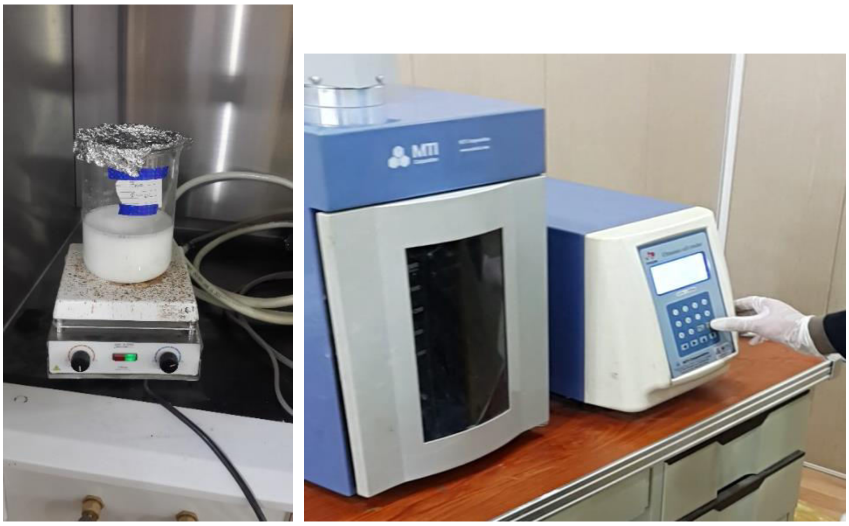

a) magnetic stirrerb) ultrasonic vibration mixer

Figure-5. Magnetic stirrer and ultrasonic vibration mixer processes of ZnO-water nanofluids.

5. NUMERICAL INVESTIGATIONS

The 3D model of the solar flat plate collector was carried out by ANSYS Workbench software version 15 where the Design Modeller geometry was used to drawing the geometry as shown in Figure-6.

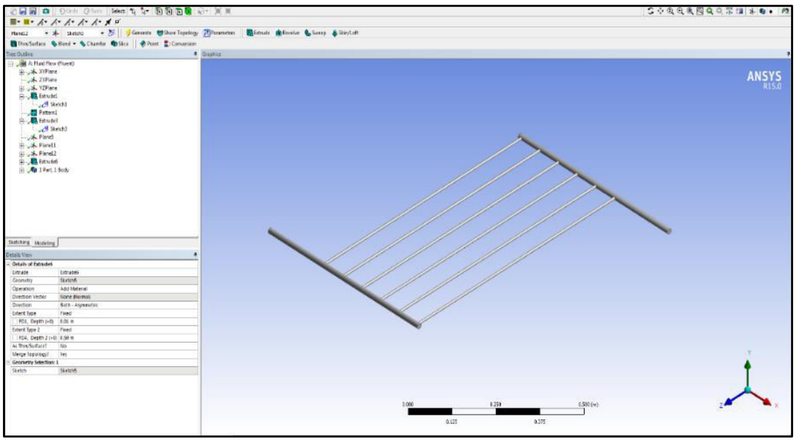

Figure-6. 3D model of solar collector

Then, the unstructured grid triangle shape mesh was carried out by ANSYS FLUENT Meshing as show in Figure-7where the numbers of elements are 3298831 and nodes 664622 and the numbers of iterations to converge results were 500 iterations.

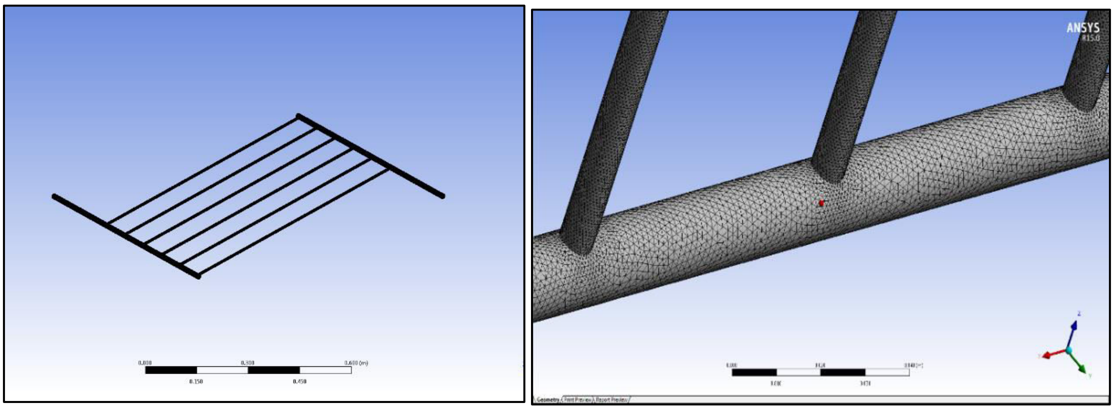

Figure-7. Meshing by using ANSYS fluent.

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5.1 Boundary conditions and assumptions

In this analysis flow rate (1,2 and 3) lpm with various inlet temperatures was introduced and the pressure outlet condition is carried at the exit. The thermo- physical properties of the working fluid (water and ZnO/water) assumed constant at mean bulk temperature. Impermeable boundary and no-slip wall conditions was performed on the channel walls.

Assumptions:

a) water and ZnO/water nanofluid was utilized as working fluid, it is incompressible fluid

b) The flow regime was considered to be laminar

c) The thermal-physical properties of water and absorber tube are independent of temperature.

d) The face of the absorber plate and the bottom part of the absorber tube was supposed to be adiabatic.

Analysis

The Analysis was applied at Steady state with various inlet temperatures and solar radiation for flat plate solar collector, the dimensions of geometry was shown in Table-1. The model was imported ANSYSFLUNET 15 after doing meshing for it and applied the boundary condition to doing to do analysis for heat transfer.

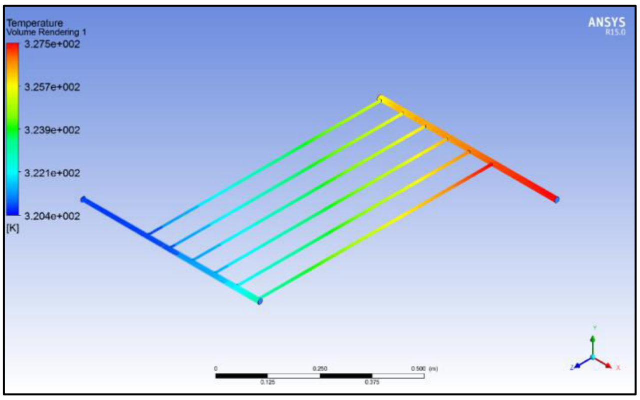

Figure-8. The distributions of temperature of the collector.

6. RESULTS AND DISCUSSIONS

The experiments were conducted from10 AM to 2 PM in Karbala, Iraq for three flow rates of the working fluid (1,2 and 3) L/min at volume fraction 0.5% with using (ZnO/water) nanofluid. The inlet-outlet temperatures and solar radiation intensity were recorded every 10 minutes.

Figure-9shows the outlet-inlet temperatures difference with three mass flow rates when ZnO/water nanofluid is used as the working fluid. Since, the temperature difference of the nanofluid was decreased with increase the flow rate of the working fluid due to reduction in consumed solar energy at same period of time, the maximum temperatures difference was (15 ^{0}C) at (1 L/min). Therefore, it can be concluded that the optimum mass flow rate depends upon the working fluid thermal characteristics.

Figure-10 shows the outlet-inlet temperatures difference of the water with the three flow rates. It is observed that decreasing the mass flow rate leads to increase the outlet-inlet temperature difference of the water; since at the low mass flow rate the velocity of the fluid is small and hence causes absorbing more solar energy, the maximum temperatures difference was (10.2^0 C) at (1 L/min). It can be concluded that the optimum mass flow rate depends upon the working fluid thermal characteristics.

Figure-11, Figure-12 and Figure-13: show the outlet-inlet temperatures difference with (ZnO/water) nanofluid and water. In this study, the concentration of nanoparticles used in water-based nanofluid (0.5%). It is observed from the figure 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 that lead to the fluid get more heat energy rate from the solar collector. The maximum difference temperatures of nanofluid at 1 L/min is 15^{0}C, at 2 L/min is 14.1 ^{0}C and 3 L/min is 13.1 ^{0}C. This can be attributed the heat capacitance of water was decreased with the adding of nanoparticles.

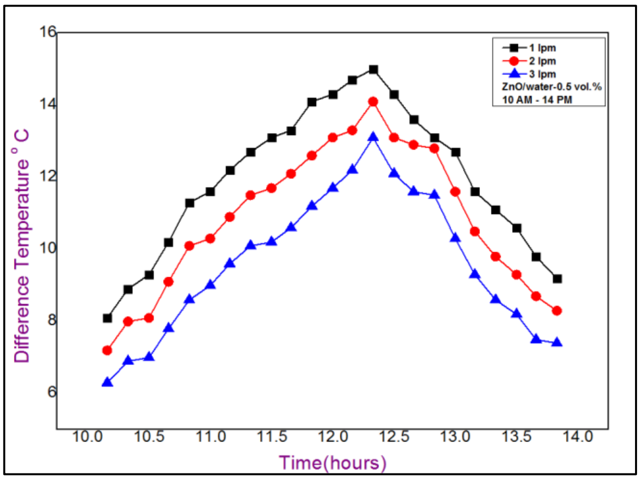

Figure-9. The inlet outlet temperatures difference of ZnO/Water nanofluid for three flow rates with time.

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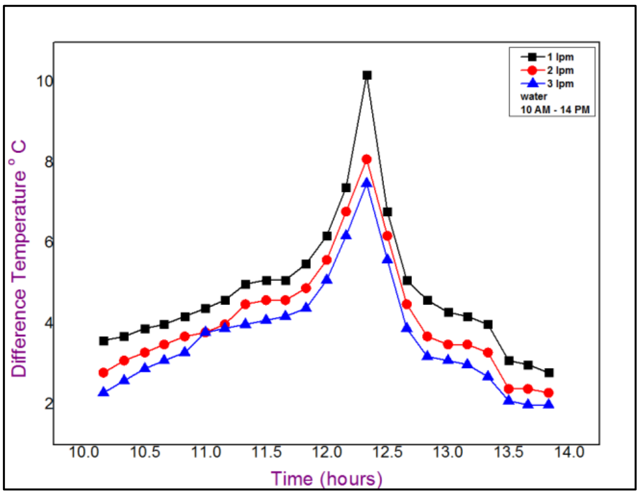

Figure-10. The inlet outlet temperatures difference of water for three flow rates with time.

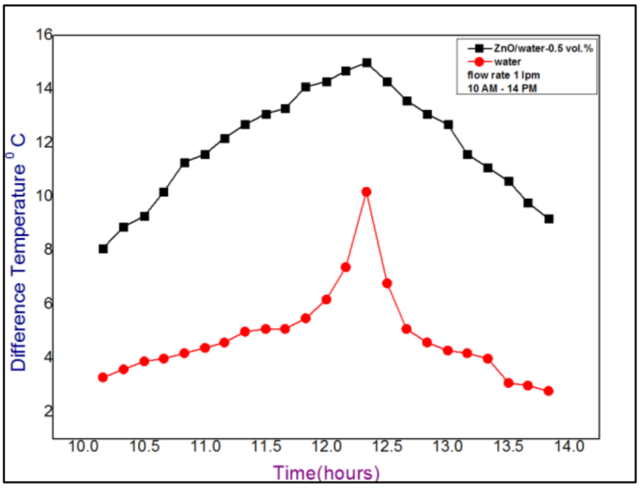

Figure-11. The inlet outlet temperatures difference of nanofluid and water at flow rate 1 L/min.

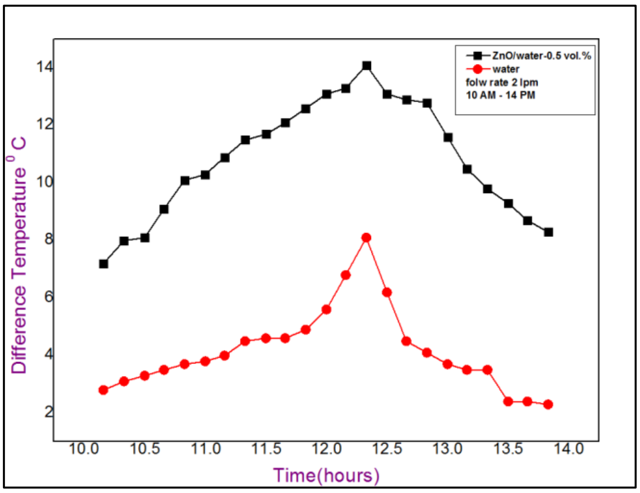

Figure-12. The inlet outlet temperatures difference of nanofluid and water at flow rate 2 L/min.

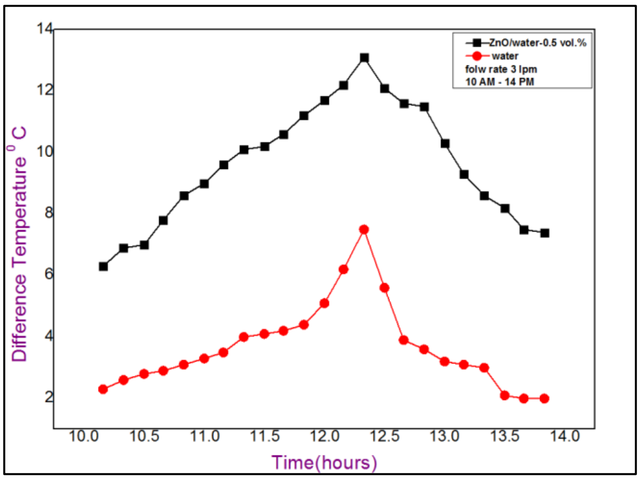

Figure-13. The inlet outlet temperatures difference of nanofluid and water at flow rate 3 L/min.

The data of the solar radiation was recorded from the weather for two months and four hours (10 AM-2 PM). Figures 14 and 15 shows the solar radiation with variation time for ZnO /water and water and three flow rate.

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.

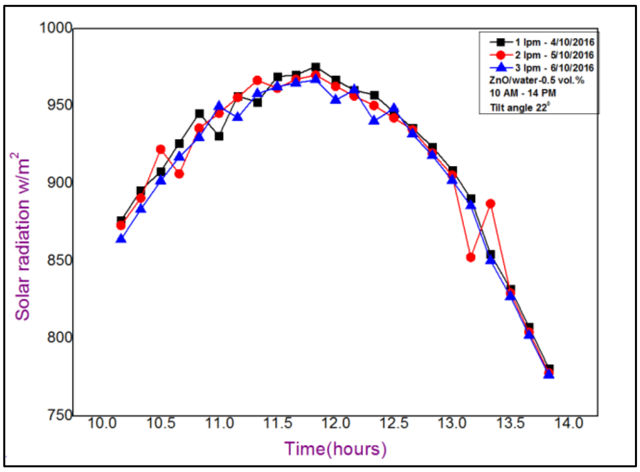

Figure-14. Solar radiation for Days of ZnO/water.

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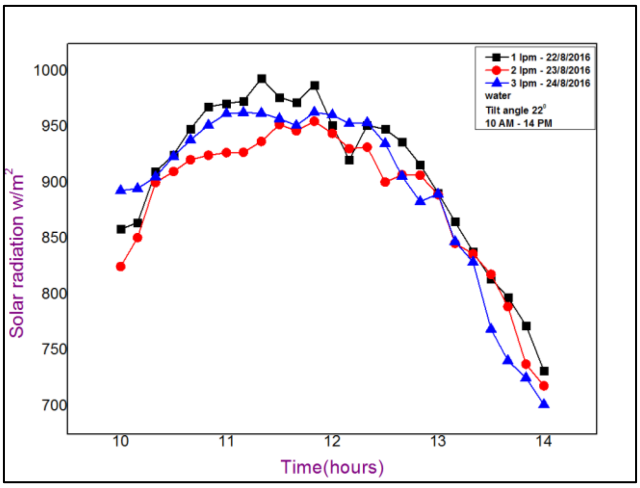

Figure-15. Solar radiation for days of water.

Figures (16, 17, 18, 19, 20and 21) show the outlet temperature between CFD and experimental with time for ZnO/water and water. It observed that the small difference in the outlet temperature due to the experimental outlet temperature was recorded in one specified position of the outlet header, whilst at CFD the temperature of the working fluid flow during the outlet header was indicated. The maximum difference between CFD and experimental outlet temperature was (8.4%).

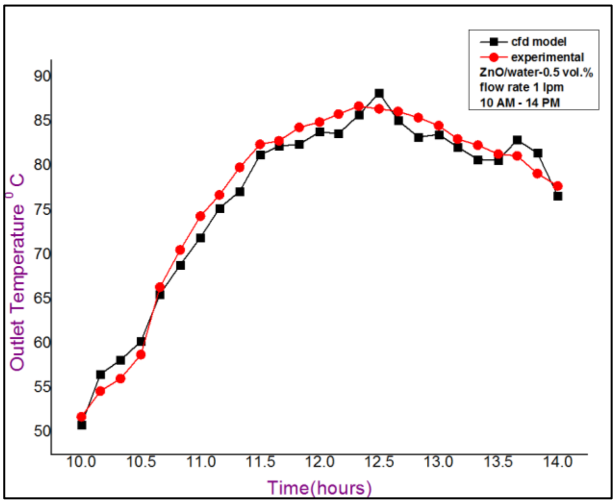

Figure-16. The outlet temperature between CFD and experimental for ZnO/water at 1 lpm.

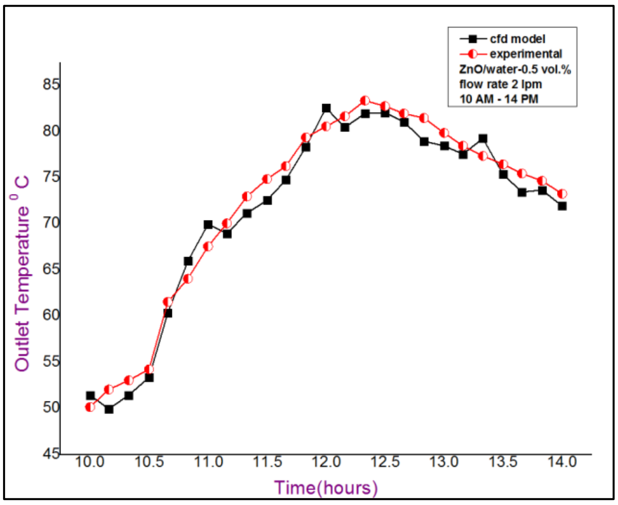

Figure-17. The outlet temperature between CFD and experimental for ZnO/water at 2 lpm.

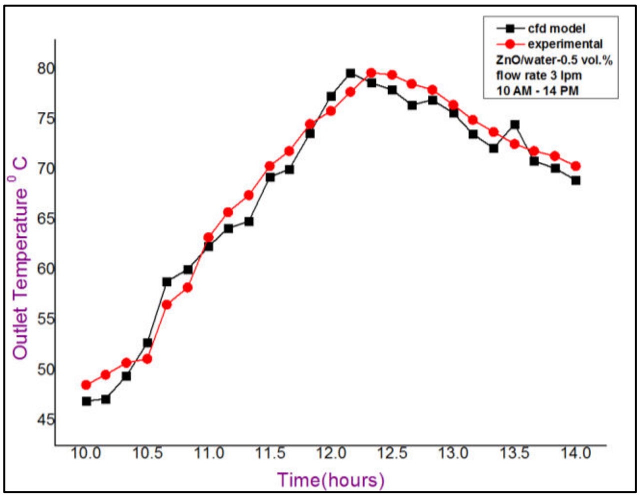

Figure-18. The outlet temperature between CFD and experimental for ZnO/water at 3 lpm.

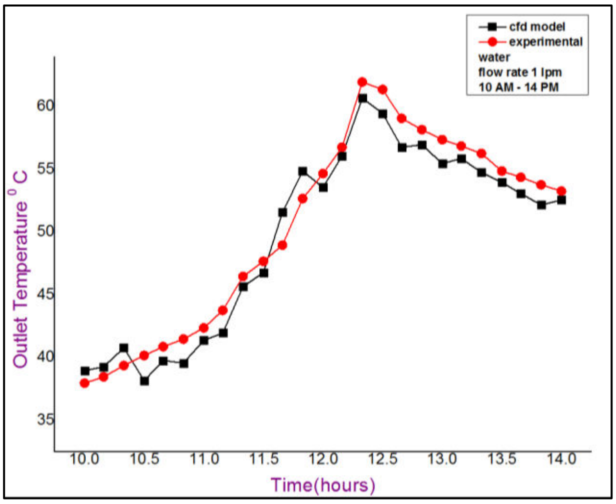

Figure-19. The outlet temperature between CFD and experimental for water at 1 lpm.

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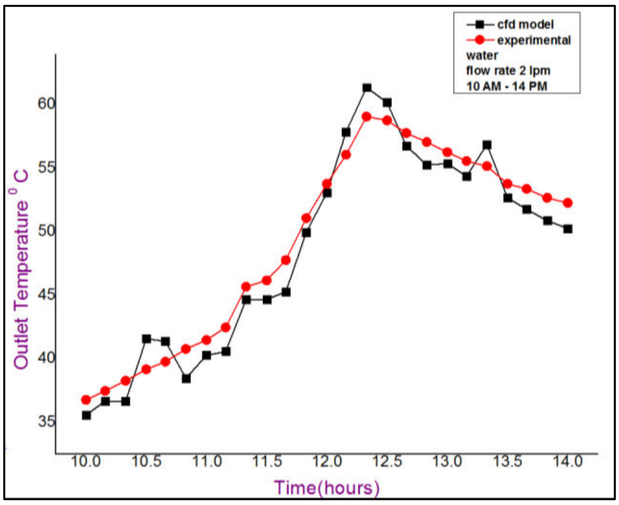

Figure-20. The outlet temperature between CFD and experimental for water at 2 lpm.

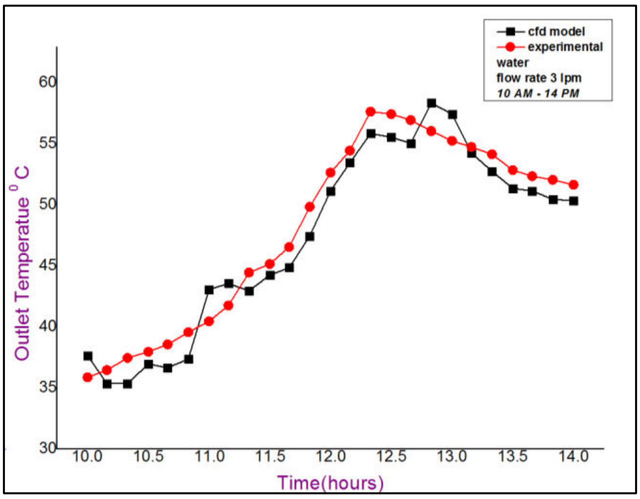

Figure-21. The outlet temperature between CFD and experimental for water at 3 lpm.

7. CONCLUSIONS

The effect of using (ZnO/water) nanofluid as the absorbing medium with three flow rates (1,2and 3) lpm with volume fraction 0.5 % on the flat plate solar collector has been studied experimentally and numerically.

It can be concluded that for (0.5 vol. %) (ZnO/water) nanofluid used as working fluids, the outlet-inlet temperature differences were increased with the decreasing mass flow rate and maximum outlet-inlet temperature difference are obtained at low flow rate (1 L/min) was 15 ^{0}C at while the minimum temperature difference are obtained at highest flow rate (3L/min) was 13.1 ^{0} C for nanofluid. The results demonstrate that by using ZnO/water nanofluid as absorbing medium the outlet-inlet temperature differences were increased compared with water. The outlet-inlet temperature differences increased with nanofluid than pure water for all flow rates. There was a good convention between the experimental and CFD results for outlet temperatures where the maximum error was (8.4%).

Significant enhancement in solar radiation absorption and collector temperatures difference makes nanofluids as proper fluid solar thermal applications and heat transfer fluid for solar thermal applications and can used in solar collectors for transmitting thermal energy.

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