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Experimental Investigation of the Heat Transfer for the Solar Collector with Different Nanoparticles Base Fluid and Tilt Angle

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Abstract: This research investigates the heat transfer performance for a flat plate collector using CuO/Water and CuO/Ethylene Glycol (EG). The scheme work concentrates on the process of energy transformation from the collector to the working fluid. This was achieved by using water and EG as base working fluid then using nanofluids as working fluids with different tilt angle and different flow rate. The experiment was constructed and conducted for several days from the September in Karbala Region. The base test has experimented with flow rates at (1.5 and 2.5 L/min) with 0.6% volume fraction nanoparticles. The result shows that the maximum temperature difference between the outlet and inlet was at the tilt angle 25° is (26.8) for CuO/EG and (33.6) for CuO/Water at the flow rate 1.5 L/min. In addition, it found that the best tilt angle which gives maximum solar radiation was at tilt angle 25° for Karbala Region in Summer days by test this experimentally with different tilt angles (15, 25, 35, 45 and 55°).

Key words: Tilt angle, nanoparticle, base fluid, CuO, ethylene glycol, constructed

INTRODUCTION

Environmental and atmospheric pollution due to lassitude fossil fuel in the life lead to serious happenings like acid rain, the greenhouse effect and ozone layer depletion. To avert supplemental effects of these phenomena, there is the essential alternative, either to amend the fossil fuel quality and decrease inimical emissions or the paramount choice is to supersede fossil fuel utilization as feasible with environmentally cordial, unsullied and renewable of the power sources (Sen, 2008). Choi first introduced the notion of nano-fluids after doing a list of researches at Argonne National Laboratory in USA (Choi and Eastman, 1995). Sundar *et al*., (2013) estimated experimentally thermal conductivity of EG/Water mix based Al_2O_3 and CuO nano-fluids at various volume fraction. The base fluid is a mix of 50% (by weight) of (EG/W). The researchers considered a particle consistency up to 0.8% and a range temperature from 15-50°C. The nanofluids exhibited larger thermal conductivity related to the base fluid. Under similar volume fraction, CuO nano-fluid thermal conductivity has high corresponded to Al_2O_3 nano-fluid. A new relationship was generated based on the empirical data for the estimate of thermal conductivity of both nanofluids. Kabeel *et al.* (2017) performed laboratory experiments with a heater solar water consist from of a flat-plate collector and heat exchanger using nano-particles (AL_2O_3) disbanded in water as a working fluid. The experiments were taken for different nano-particle concentrations, from 0-3% (by volume), under the climatic conditions of Tanta University, Egypt in August 2013. The main result is that the efficiency solar collector increased 11% with the increase of the nano-particle concentration 3%. The temperature outlet increases with a rise concentration of the nanoparticles 5.46% for concentration 2%. The heat exchanger effectiveness was enhanced by 4.25% for a concentration of 1%. Duffie and Beckman (2003) discuss the effect of angle of title solar collector between Summer and Winter must be latitude +15 at Winter and latitude-15 in Summer to take maximum the heat flux from the Sun and the effect of working fluid (Arslanoglu, 2016). The optimum angle for sloped surfaces varying from (0-90°) in step 1° was measured. In the research, a theoretical model was used to predict the global solar radiation on a sloped surface and to get the best tilt angle. It is determined that the best tilt angle ranges between 0 and 59° in (June and December), respectively. During the year in Winter, Spring (March, April and May) 19.6 in the Summer and (November) is 44.3° the yearly mean of this condition reached to be 31.1° and this would be the best-fixed incline during the year. Michael and Iniyan (2015) experimentally investigated the thermal performance of the flat-plate solar collector under thermosiphon and two forced rotations using (CuO/EG) at 0.05% volume concentration

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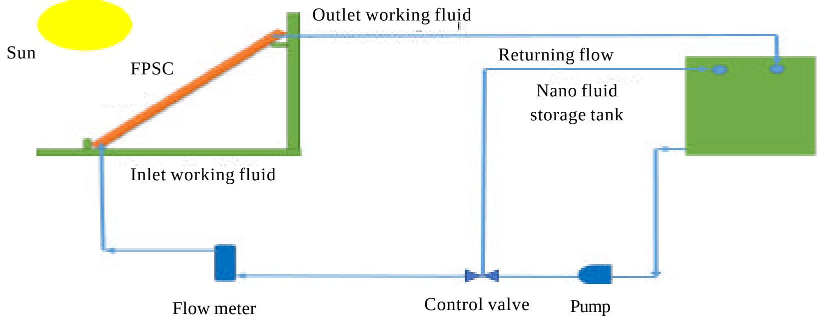

Fig. 1: The schematic diagram of the experimental rig

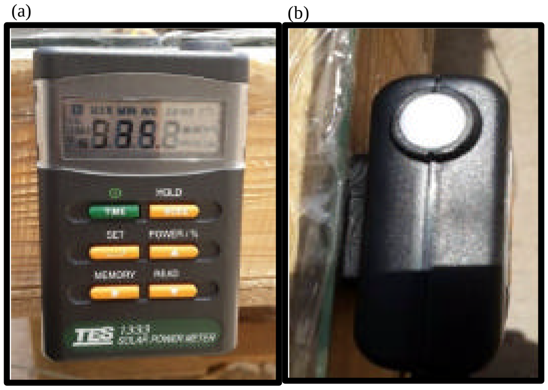

Fig. 2: a, b) Digital solar power meter

and water. The results show that the thermal efficiency increased to 6.3% in thermosyphon, 0.4% at 0.1 kg/sec and 2.7% at 0.01 kg/sec.

This study investigates the heat transfer performance for a flat plate collector using CuO/Water and CuO/Ethylene Glycol (EG). The scheme work concentrates on the process of energy transformation from the collector to the working fluid. This was achieved by using water and EG as base working fluid then using nanofluids as working fluids with different title angle and different flow rate.

Experimental setup: The schematic diagram of the experimental rig is shown in Fig. 1. Solar radiation transmitted through a glass to the absorber plate. The solar radiation was converted to thermal energy and the heat transferred to working fluid in the tube. The fluid rotation is in a closed operation by the pump and storage tank.

The experimental setup of the flat plate solar collector is shown in the Fig. 2. The incident solar radiation was moving through the glass cover to the absorber plate then converted to thermal energy.

The experimental study was made in Karbala, Iraq "Latitude 32.6°N, the Longitude 44.02°E". The data were carried out under a transient state. The flat plate solar collector is at inclination to the South facing with different tilt angle (15, 25, 35, 45 and 55°). The incident radiation was measured by using a solar meter. Table 1 is the specification of flat plate solar collector, it gives the details about collector dimensions.

Table 1: The specification of the solar collector

Parts	Notes
Dimensional	Width 0.7 m, length 1 m and thickness 0.15 m
Absorber plate	Aluminum (0.8 m long, 0.5 m width and 0.002 m thickness)
Header	Inner diameter is 0.023 m and thickness is 0.002 m and length 0.62 m
Riser	Inner diameter is 1cm and thickness is 0.002 m and length 0.64 m
Cover	Two glass window type had thickness 0.004 m
Painted	Black type (Matt 890) with 50% by weight river sand
Insulation	All side is 0.1 m and the bottom is 0.9 m
Tilted angle	(15, 25, 35, 45 and 55°) angles

Experimental test used many measurement devices like temperature meter, thermocouples, solar power meter, flow meter and pump. Solar power meter "Model-1333 (accuracy±5%, Range-1 to 2000 W/m^2)" was used to measure the total incident solar radiation on the solar collector. The digital solar meter is shown in Fig. 2. The calibration was performed in the Ministry of Science and Technology, Iraq.

Temperature meter, temperature recorder "Model, BTM-4208SD, 12 channels, SD storage and accuracy 0.1% ±0.1°C" were used to read thermocouples where it's stored in SD storage. Thermocouples type K was joined by a temperature meter "12 channels temperature recorder" are shown in Fig. 3. The calibration was performed in the Central Organization for Standardization and Quality Control, Iraq.

Nanofluid preparation: The weighting of the CuO nano-powder was carried out by a sensitive balance "Make-Sartorius, Model-224-1S, resolution of (-0.1 mg) as shown in Fig. 4.

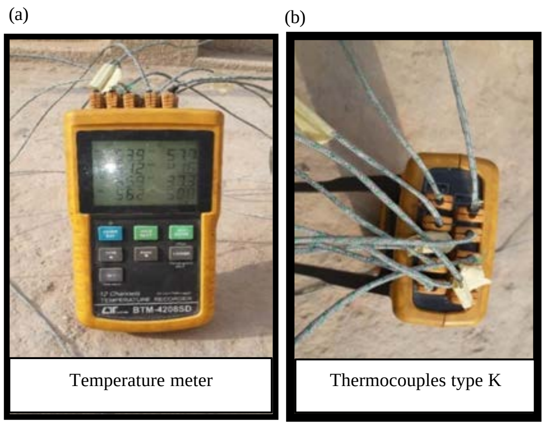

Fig. 3: a, b) Temperature meter and thermocouples

Fig. 4: Magnetic stirrer

The preparation of the mass required for the CuO nanoparticles was calculated using Eq. 1 (Pak and Cho, 1998):

$$\varphi\% = \frac{\text{Volume of nanoparticle}}{\text{Volume of nanoparticle} + \text{Volume of base fluid}} \times 100$$

$$\varphi\% = \frac{\left(m/\rho\right)_{\text{Nanoparticle}}}{\left(m/\rho\right)_{\text{Nanoparticle}} + \left(m/\rho\right)_{\text{base fluid}}} \times 100 \quad (1)$$

Where:

$(m/\rho)_{\text{Nanoparticle}}$ = Volume of nano-particle
$(m/\rho)_{\text{base fluid}}$ = The volume of base fluid
$m\rho$ = The mass of nano-particle in game

Initially, the powder was ethylene glycol and water mixed by a magnetic stirrer for 40 min as shown in Fig. 5. Then an ultrasonic vibration mixture “Make-MTI corporation, Model-SJIA, power-1200 W, frequency -20±3 kHz” were used for dispersing CuO nanopowder in the water for 1 h as shown in Fig. 6. “Make-Sartorius, Model-224-1S” was applied to weight nanoparticles as shown in Fig. 7. The base fluid specification using for preparation the nanofluid as shown in Table 2 and 3

Fig. 5: Sensitive balance

Fig. 6: Ultrasonic vibration mixture

Fig. 7: Acrylic vacuum glove box

Table 2: Physical properties of the base fluids

Properties	Ethylene glycol	Water
K (w/m.k)	0.252	0.60
ρ (kg/m^3)	1111.4	998.20
C_P (J/kg.K)	2415	4182
μ (kg/m.sec)	0.001	0.0157

Table 3: Physical properties of (CuO) nanoparticles

Purity	Average particles size	Morphology	True density	Surface area per unit weight (SSA)	Color
99+%	20 nm	Nearly spherical	6.4 g/cm^3	35 m^2/g	Milky white

Fig. 8: DV-III ultra viscometer measurement

shows physical properties of (CuO) nanoparticles. The density of nano-fluid was calculated using the Pak and Cho (1998) Eq. 2:

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

where, ρ_{np} is the density of nanoparticle.

The test of nanofluids: The thermal conductivity measuring digital device by using KD2-Pro (Decagon, Inc. Pullman, USA) that Consists of needles for sensor and handheld microcontroller. The dynamic viscosity measuring by using viscometer type (Cone-Plate test DV-3 ultra) as shown in Fig. 8 and a high accuracy density measuring experimentally by type (Gp-120S).

RESULTS AND DISCUSSION

The experimental data of the incident radiation were measured from the 6 h (9am-15pm). Figure 9-12 show the incident radiation with time for case CuO/water and CuO/EG at mass flow rate of (1.5 and 2.5) L/min.

The effect of tilt angle: Figure 11 and 12 shows the incident radiation with time for the case with mass flow rate 1.5 L/min and all cases are measured with different tilt angles (15, 25, 35, 45 and 55°). It observed that the higher solar radiation at tilt angle 25° because of in the months of Summer the collector needs to regulate at low angles due to the elevation of the radiation of the sun is high and the diffuse component is less than the beam component and thus the major contribution coming from the beam component. This leads to ability the surface of the solar collector to absorb the most amount of solar radiation. Figure 13 and 14 show the outlet-inlet temperature difference with CuO/Water nanofluid at different mass flow rate (1.5 and 2.5 L/min). It was observed that the temperature difference decreases with increasing the tilt angle of the collector up to 25°, therefore, it was started decreasing because of the nano-particles suspension in the water which has a considerable effect the outlet-inlet temperature difference because of its greater thermal conductivity and larger specific heat capacity of working fluid. The maximum of the outlet and inlet temperature difference was at a tilt angle 25° is (33.6°C) at the mass flow rate equal 1.5 L/min. Figure 15 and 16 show the outlet-inlet temperature difference with CuO/EG nanofluid with different mass flow rate, the maximum of the temperature difference between inlet and outlet was at a tilt angle 25° is (16.7°C) with mass flow rate 1.5 L/min.

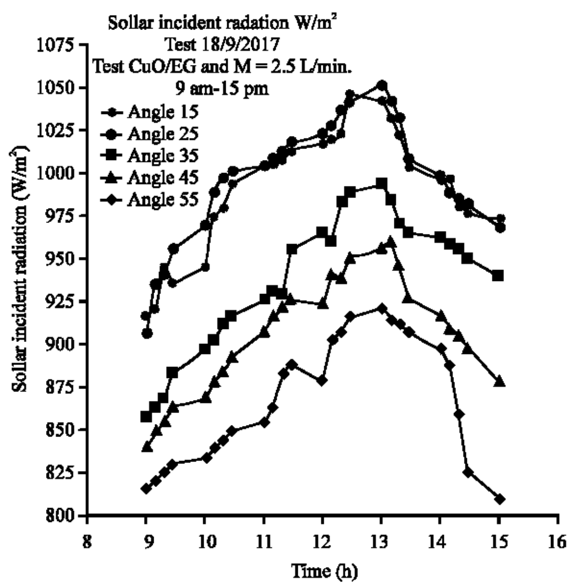

Fig. 9: Solar radiation for CuO /EG for different tilt angles. At 18-Sep-2017

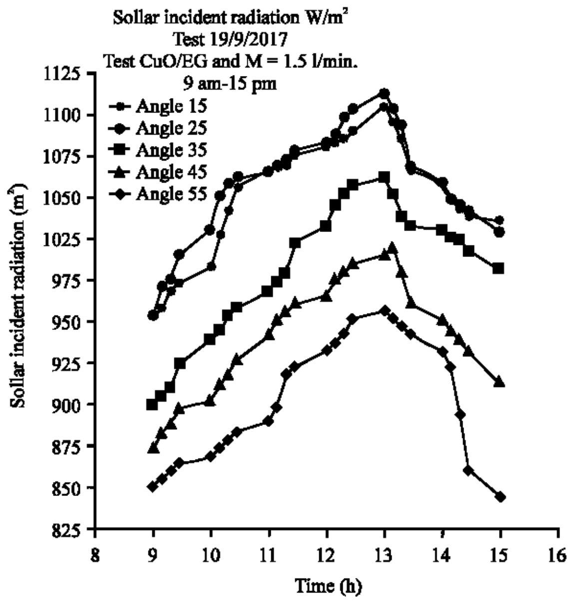

Fig. 10: Solar radiation for CuO/EG for different tilt angles. At 19-Sep-2017

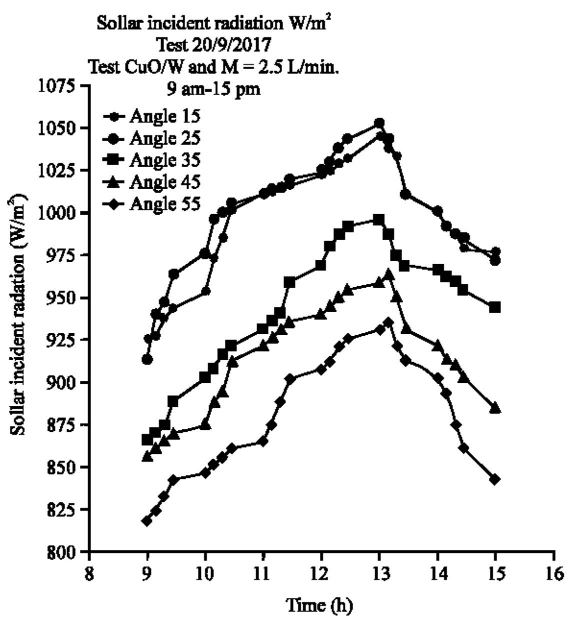

Fig. 11: Solar radiation for CuO/Water for different tilt angles. At 20-Sep-2017

Figure 17 and 18 show outlet-inlet temperature difference between CuO/Water and CuO/EG nanofluid at an angle 25° with different flow rate. It was shown that the CuO/Water is higher than CuO/EG at the same angles, since, the thermal capacity of the water was greater than EG", therefore, it increases the absorption of solar energy from the solar collector.

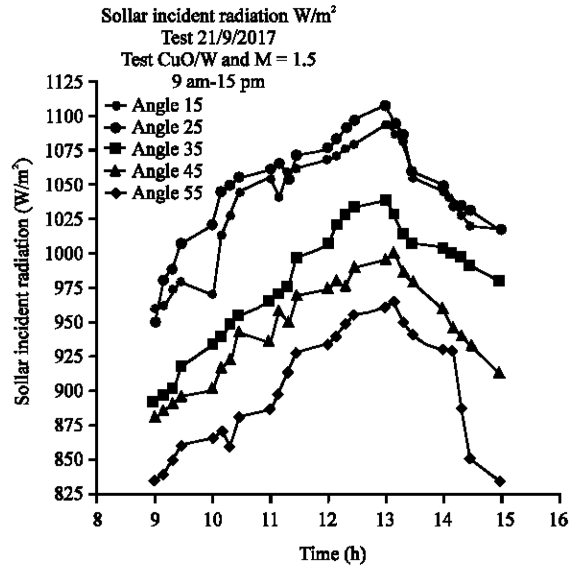

Fig. 12: Solar radiation for CuO /Water for different tilt angles. At 21-Sep-2017

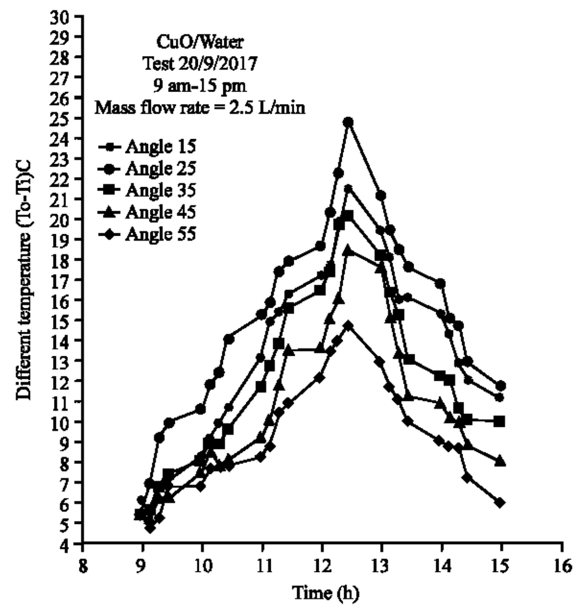

Fig. 13: Temperature difference CuO/Water with time at m = 1.5 Lpm

The effect of flow rate: The temperature difference between inlet and outlet of flat plate solar collector is affected by a flow rate of working fluid". Figure 13-16 present a temperature difference between outlet and inlet of the base fluid with tow flow rate 1.5 and 2.5 L/min with the different base fluid (CuO/EG) and (CuO/water). The maximum of the difference temperature was at a tilt angle 25° is 33.6°C at mass flow rate equal 1.5 L/min but at the tilt angle 15° is 29.1°C while at angles (35, 45 and 55° are

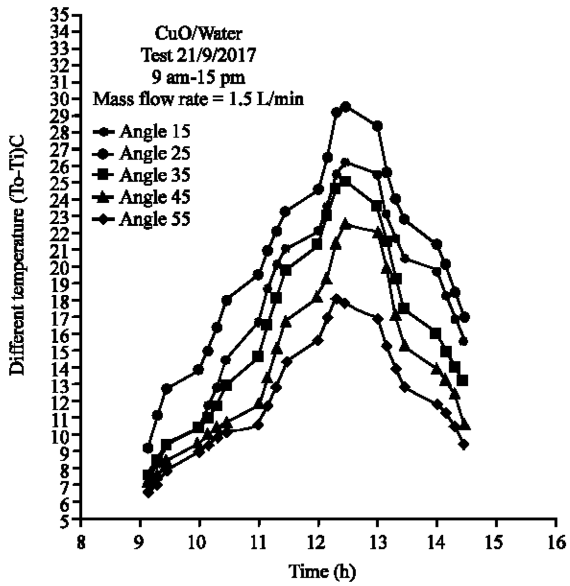

Fig. 14: Temperature difference CuO/Water with time at m = 2.5 Lpm

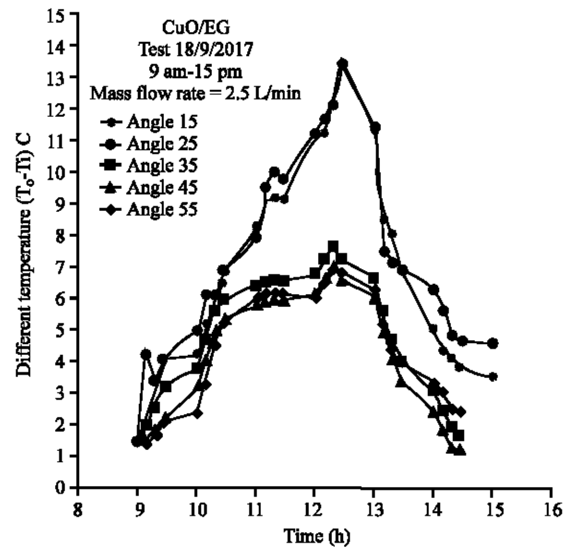

Fig. 16: Temperature difference CuO/Water with time at flow rare 2.5 Lpm

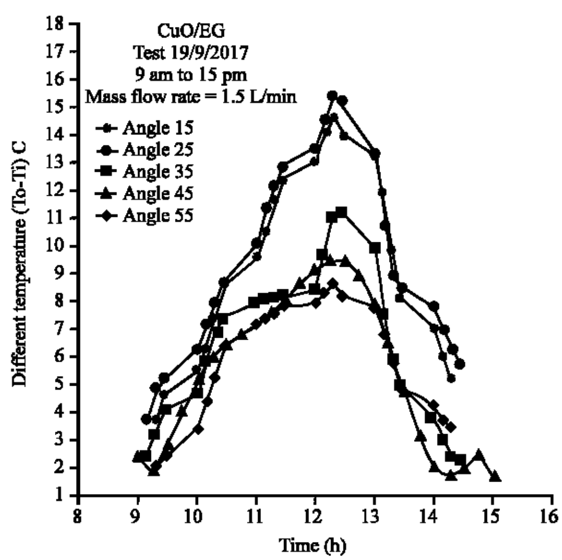

Fig. 15: Temperature difference CuO/EG with time at flow rare 1.5 Lpm

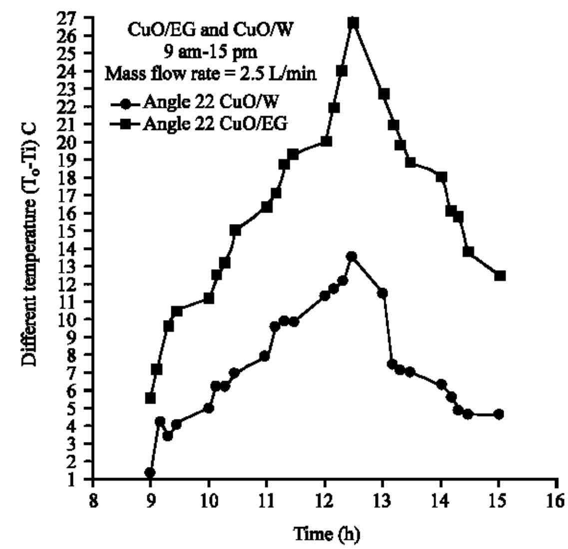

Fig. 17: Temperature difference for CuO/Water and CuO/EG with time at flow rare 2.5 Lpm and angle 25°

27.2, 24.8 and 19.7°C), respectively. Figure 15 and 16 show the maximum of the difference in temperature with CuO/EG nanofluid was at a tilt angle 25° is 16.7°C with mass flow rate 1.5 L/min and a tilt angle 15° is 16.2°C while at angles (35, 45 and 55° are 10.4, 10.0 and 9.9°C), respectively. On the otherwise the maximum of the difference temperature was at a tilt angle 25° is 26.8°C at the mass flow rate equal 2.5 L/min but at the tilt angle 15° is 23.1°C while at angles (35, 45 and 55° are 21.7, 19.8 and 15.7°C), respectively. Figure 13 shows the maximum of the difference in temperature with CuO/EG nanofluid was at a tilt angle 25° is (13.4) with mass flow rate 2.5 L/min and a tilt angle 15° is 13.2°C while at angles (35, 45 and 55° are 8.3, 7.9 and 7.7°C), respectively. It was noticed that lessening the flow rate which leads to increasing the temperature difference between outlet and inlet of the base fluid, at the low flow rate (1.5 L/min) the velocity of the flowing fluid is small, therefore, causes

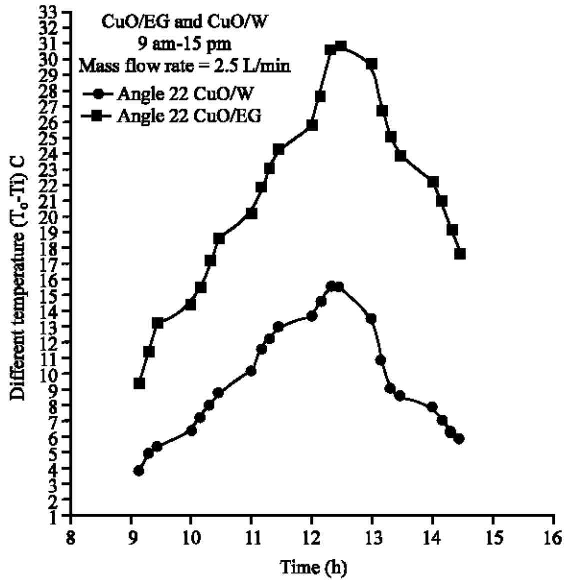

Fig. 18: Temperature difference for CuO/Water and CuO/EG with time at flow rare 1.5 Lpm and angle 250

gain more solar energy during the time, that mean is allowing the rise of outlet temperature. The maximum temperature difference is (33.6°C) at (12:30 PM), then that the all cases by observed (Fig. 13-16), indicate the temperature difference between outlet and inlet of working fluids (CuO/water and CuO/EG) with volume fraction (0.6)% for flow rate (1.5 and 2.5) L/min, the working fluids temperature difference are lessening with increasing the flow rate of working fluid", vice versa. While the low flow rate the working fluid is taken a long time inside the solar collector that means more absorber solar energy through the time.

CONCLUSION

Heat "transfer of a solar collector is enhanced by adding nanopowder to the base fluid that means enhancing the physical properties to get high performance of heat transfer.

CuO/water and CuO/EG used as working fluid. The temperature differences between the outlet and inlet decrease with increasing the tilt angle of the collector up to 25°.

The optimum tilt angles at 25° due to the average mean of solar radiation during the time is greater at 25° than (15, 35, 45 and 55°). The temperature differences between the outlet and inlet increase with decrease the flow rate.

The maximum temperature was occurs at the CuO/water and less flow rate. The heat transfer enhancement is more in water than EG due to the specific heat of the EG less than that means the water absorbing heat is greater than EG.

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