Experimental Investigation for Flow Rate Effect on a Flat Plate Solar Collector with the Using of Al_2O_3 Nanofluids as a Heat Transfer Fluid

Dr. Abbas Sahi Shareef, Dr. Mohammed Hassan Abbod, and Sura Qahtan Kadhim

***Abstract*— This work introduces experimental results of an Al_2O_3 -water based nanofluids as the working fluids for flat tube in plate type solar collector with the effect of three different flow rates. Experimental test setup comprises a solar collector, closed working fluid system and measurement devices (flowmeter, thermocouples, temperature meter and digital solar power meter). The Base case was experimented with di-ionized water. In second and third cases, Al_2O_3 nanoparticles are mixed in di-ionized water to get nanofluids of 0.1% and 0.5%) of volume fraction concentration. the maximum outlet-inlet temperature difference was achieved at (2 lpm) at the peak value of the curve which is (23.5℃) and at 0.5% , 0.1% Nanofluid volume fraction concentration respectively, while in case of water the maximum temperatures difference was 10.7˚C.**

***Index Term*-- Renewable energy, Flat plate solar collector, Mass flow rate, Nanofluids concentration, Al_2O_3 nanofluid.**

I. INTRODUCTION

A solar collector is a special kind of heat exchanger that transforms solar radiant energy into heat. Flat-plate collectors can be designed for applications requiring energy delivery at moderate temperatures, up to perhaps 100℃ above ambient temperature. They use both beam and diffuse solar radiation, do not require tracking of the sun, and require little maintenance. The major applications of these units are in solar water heating, building heating, air conditioning, and industrial process heat. **[1]** Traditional heat transfer fluid that HTFs used in flat plate solar collectors is water, however, have inherently poor heat transfer performance due to its low thermal conductivity. Research and development activities are being carried out to enhance the thermal conductivity by adding solid particles into HTFs since Maxwell initiated it in 1881 (Maxwell 1873). **[2]** The term Nanofluid is invented to describe a solid liquid mixture that consists of solid nanoparticles and a base liquid.The concept of nanofluids was first materialized by Choi **[3]** after performing a series of research at Argonne National Laboratory in USA. The first experiments were done by Masuda et al. **[4]** to show the extraordinary values of thermal conductivity of nanofluids.

Abbas Sahi Shareef
Ass.prof.Dr, Department of Mechanical Engineering, Karbalaa University, abbasmarem@yahoo.com.

Mohammed Hassan Abbod
Ass.prof.Dr, Department of Mechanical Engineering, Karbalaa University, Malmussawie@yahoo.com.

Sura Qahtan Kadhim
B.Sc. in Mechanical Engineering, Researcher in Thermal Engineering, Department of Mechanical Engineering, Karbala University, sura.q.kadhim@gmail.com

S. Lee et al [5] prepared Oxide nanofluids and measured their thermal conductivities by a transient hot-wire method. Their experimental results showed that these nanofluids, containing a small amount of nanoparticles, have significantly higher thermal conductivities than the same liquids without nanoparticles. The authors compared between experiments and the Hamilton and Crosser model and showed that the model can predict the thermal conductivity of nanofluids containing large agglomerated Al_2O_3 particles. However, the model appears to be inadequate for nanofluids containing CuO particles. This suggests that not only particle shape but size is considered to be dominant in enhancing the thermal conductivity of nanofluids.

Tooraj Yousefi et al [6] studied experimentally the effect of Al_2O_3–water nanofluid, as working fluid, on the efficiency of a flat-plate solar collector. The weight fraction of nanoparticles was 0.2% and 0.4% and the particles dimension was 15 nm. Experiments were performed with and without Triton X-100 as surfactant. The mass flow rate of nanofluid varied from 1 to 3 Lit/min. The ASHRAE standard was used to calculate the efficiency. The results show that, in comparison with water as absorption medium using the nanofluids as working fluid increase the efficiency. For 0.2 wt% the increased efficiency was 28.3%.

A.E. Kabeel et al [7] performed laboratory experiments with a thermal solar water heater consisting of a flat-plate solar collector and helical coil heat exchanger using Al_2O_3 nano-particles dispersed in water as a working. The experiments were carried out for various nano-particle concentrations, from 0% to 3% (by volume), through forced convection cooling under the climatic conditions of Tanta University, Egypt in August 2013. The experiments have an emphasis on the main parameters with impact on the water production temperature, as the solar radiation, the feed water mass flow rate and the nano-particle volume fraction. The outlet water temperature is increased with increasing of nano-particle concentration by 5.46% for concentration 2%.

The present reserch is attempt to experimentally study the effect of Al_2O_3-H_2O nanofluids as a heat transfer mediums with three differennt flow rates on the outlet inlet temperature difference of a tilted flat plate solar collector under outdoor condition. Two different concentrations (0.1% and 0.5%) of Al_2O_3 nanofluids with di-ionized water were compared their effects on the solar collector performance.

II. EXPERIMENTAL STUDY

An experimental set up of flat plate solar collector of size 1.04 m x 0.64 m has been developed as shown in Fig. 1.

Experiments carried out at the roof top of Mechanical Engineering Department, Kofa University, alnnajaf alashraf (32.05° latitude and 44.25° longitudes). The collector was oriented due south with a tilt angle of 45°. Two different concentrations (0.1% and 0.5%) of Al_2O_3 nanofluids will be prepared and experimented in this research.

Fig. 1. Flat Plate Solar Collector Experimental Setup

II.1. Solar Collector Experimental Set Up

Photograph of experimental set up (Fig. 1) show flat plate collector, which simply consists of an absorber plate (0.95 m long, 0.64 m wide, 0.003 m thick), mounted on a wooden box and insulated from bottom and edges of the box with a glass wool insulation to minimize conduction losses. Finley, the box closed from top with a sheet of glass for the purpose of transmitting about 90% of the incoming shortwave solar irradiation and transmitting none of the longwave radiation emitted outward by the absorber plate and to prevent convection losses with the environment.

The experimental test set up involves as well, closed working fluid system and measurement devices. The working fluid system has a tank, paypass pipes system and simple manual valves used to control flow rate of working fluid. The flow rate is measured with the help of flow meter (range 40–400 LpH, accuracy ±5%). A submersible pump circulates the collected fluid in the system. Eight T-type thermocouples were installed to measure collector inlet and outlet fluid temperatures, ambient, glass, tubes, absorber plate, and air gap between the plate and glass temperatures. the readings were collected and stored in a computer through a temperature meter (Make- Applent instruments, model- AT45xx, 8 channels, USB disk storage, Basic Accuracy 0.2% ±1℃). The software program of the temperature meter is AT45X_EN Software.exe. The temperature meter and thermocouples are shown in Fig. 2. the total solar irradiance measured in the plane which the collector stands using a digital solar power meter (Make-TES Electronical electronics, model- 1333, Range-1 to 2000 W/m^2, accuracy ±5 % of measurement). This manner removes cosine loss of the beam component since the collector is tilted from the horizontal. The digital solar meter is shown in Fig. 3.

a) Thermocouples type T

b) Temperature meter

Fig. 2. Thermocouples and Temperature meter

Fig. 3. Digital solar power meter

II.2. Nanofluids Preparation

In this study ultrasonic vibration method is used for preparation of nanofluid. Dry powder from Al_2O_3

nanoparticles of 99.99% purity and average size of 20-40 nm (procured from US Research Nanomaterial, Inc. USA based company) are used with de-ionized water as base fluid in nanofluid preparation. Properties of the Al_2O_3 nanoparticles are tabulated in Table I.

Table I
Physical properties of Alumina (Al_2O_3) nanoparticles.

Al_2O_3 Content	99.99%
Crystal Form	Gamma
Size of particles	20-40 nm
Surface area per unit weight	10-30 m^2/g
Density	3890 kg/m^3
Morphology	nearly spherical

To weigh the Al_2O_3 nanoparticles very accurately a sensitive balance (make-Sartorius, model-224-1S, resolution-0.1mg) is used. Weighting of nanopowder is carried out in an acrylic vacuum glove box (Make-MTI Corporation). As shown in Fig. 4. The mass in grams of Al_2O_3 nanoparticles required for preparation of nanofluid with different volume concentrations is calculated using Eq. 1. **[8]**

$$vol\% = \frac{m/\rho}{100mlwater + m/\rho} \quad (1)$$

Where: m and ρ is mass (g) and density (g/cm^3) of the nanoparticles respectively. This equation calculates the mass of Al_2O_3 nanoparticles dispersed into 100 ml of water. A volume concentration of 0.5 % was used in the study.

Ultrasonic mixing was applied for one and half hour to disperse calculated amount of Al_2O_3 nanoparticles in de-ionized water using ultrasonic vibration mixer (Make- MTI corporation, model-SJIA, power-1200W, frequency-20 ±3 kHz,) as shown in Fig. 5.

Fig. 4. The Nanopowder Mass Evaluating Instruments

Fig. 5. Ultrasonic Apparatus for Sonication Process of Al_2O_3-Water Nanofluids

II. RESULTS AND DISCUSSIONS

Several experiments were conducted in the months of May and June 2015 to compare the effect of using water and nanofluids as working fluid with three different flow rates on the outlet inlet temperature difference of a flat plate solar collector. The selected cases represent the water as base case and two different concentrations of Al_2O_3 nanofluids.

All the experiments were conducted from 10 AM to 12 PM on the roof of Mechanical Engineering Department building of the University of Kufa for three flow rates of the working fluid (1, 1.667, 2 Lpm). The inlet, outlet and all temperatures were measured every five seconds. Whereas the value of the solar radiation intensity was recorded as an average over 5 minutes intervals.

III.1. Incident Solar Radiation Results

The data of the incident solar radiation was measured directly for two hours (10 AM-12 PM) from the weather at the selected experiments days as Figs. 6 to 14 showed. It can be noticed that the solar radiation during two hours are fluctuate since some days witnessed a few clouds although that the tests days were selected based on the weather conditions as the clear sky.

III.2. Temperature Difference Results

The outlet-inlet temperature difference of the solar collector working fluid is affected by the mass flow rate of the fluid flow and the characteristics of that fluid as seen from experimental temperature difference results and will discussed in the following suctions:

III.2.1 Flow Rate Effect

The mass flow rate of fluid flow influence on the temperature difference for the three cases (base case water, nanofluid with 0.1 vol% Al_2O_3 nanoparticle concentration, and nanofluid with 0.1 vol% Al_2O_3 nanoparticle concentration) are studied:

Case No. 1: (Base Case Water)

The outlet-inlet temperature difference of the water experiments with the three flow rates as shown in Fig. 15 was decreased with the mass flow rate increase because of the increase in fluid velocity so reducing the solar energy consumed during same interval of time. While, at low flow rates, the fluid residence time in the collector was high so greater absorption of solar energy allowing more temperature rise as clearly observed in the figure for (1 Lpm) with (10.7℃) difference after (70 min) from the experiment start.

Case No. 2: (0.1 Vol% Al_2O_3 Nanofluid)

Fig. 16 shows 0.1 Vol% nanofluid experiments and same results could be concluded as water temperature differences, which is that the temperature difference of the nanofluid was decreased with the flow rate increase because of reducing in consumed solar energy during same interval of time. From the figure could be observed that for (1 Lpm) temperature difference of (8.6℃) after (70 min) from the experiment start.

Generally, for two working fluids (water and 0.1 Vol% Al_2O_3 nanofluid) used it can be concluded that at low flow rate (1 Lpm) the maximum outlet-inlet temperature difference was achieved and this occur at the peak values of their curves which indicate that they reached to maximum temperature at (70 min) and start decreasing after that were the fluid temperature would not rise more, while the minimum temperature difference was achieved at highest flow rate (2 Lpm).

Case No. 3: (0.5 Vol. % Al_2O_3 Nanofluid)

Fig. 17 shows (0.5 vol. %) nanofluid experiments results, it can be seen that is on the contrary of water and (0.1 vol. %) Al_2O_3 nanofluid results. Where the temperature differences increase with the flow rate rise and maximum outlet-inlet temperature difference was achieved at (2 lpm) at the peak value of the curve which is (23.5℃) at (80 min), however for (1 Lpm) mass flow minimum temperature difference with (14.4℃) was achieved at (70 min).

III.2.1 Nanoparticles Concentration Effect

The Al_2O_3 nanoparticles concentration of fluid influence on the temperature difference for three experimental mass flow rates (1, 1.667, and 2 Lpm) is studied:

A. 1 Lpm flow rate

Fig. 18 shows the variation of the temperature difference as a function of nanoparticle concentration. In this experimental study, the concentration of nanoparticles in water-based nanofluids have been used as (0 vol. %, 0.1 vol. % and 0.5 vol. %). It is observed from the figure that at the first section of the curve there is a fluctuation in water and nanofluids temperature difference, then the temperature difference increased with the nanofluid concentrations increase and it was clearly appears at (0.5 vol. %) nanofluid where maximum outlet-inlet temperature difference was achieved of (14.4℃). This may be attributed to the decrease in heat capacitance of water with the adding of nanoparticles, this decrease implies that for the same temperature increment, heat energy needed is lesser for nanofluid compared to base fluid. So for the same heat energy the temperature difference will increase with the nanofluid than that of base fluid. The figure showed that the temperature difference curves of water (0 vol. %) and (0.1 vol. %) nanofluid are interfere with each other in many points but the nanofluid show the maximum difference (10.7℃).

B. 1.667 Lpm flow rate

Fig. 19 shows that the temperature difference increased with the nanofluid concentrations increase were (0.5 vol%) nanofluid curve obviously higher than that of (0.1 vol. %) nanofluid and water curves and (0.1 vol%) nanofluid higher than water temperature difference curve. The maximum difference (22.6℃) for (0.5 vol. %) nanofluid. This can be attributed to the same trend above of the decrease in heat capacitance of water with the adding of nanoparticles.

C. 2 Lpm flow rate

Fig. 20 shows that the temperature difference increased with the nanofluid concentrations increase especially at (0.5 vol. %) nanofluid with maximum difference of (23.5℃), then (0.1 vol. %) nanofluid comes after with maximum difference of (4.5℃). This can be attributed to the same trend of the decrease in heat capacitance of water with the adding of nanoparticles.

Adding solid Nano size particles to base fluid at such small volume concentration has many advantages (compared with pure water) other than the improved thermo physical properties of fluid such as thermal conductivity and heat transfer coefficient, which is responsible for high thermal efficiency. Nanoparticles mass migration phenomenon in the nanofluid working media increases the heat transfer enhancement. Mixing of a small amount of nanoparticles to the base fluid enlarge heat transfer surface area and the indicated experimental results are well justified.

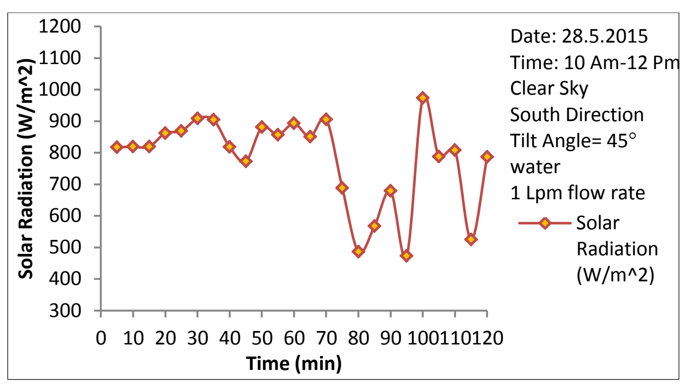

Fig. 6. Incident Solar Radiation for the Day (28.5.2015)

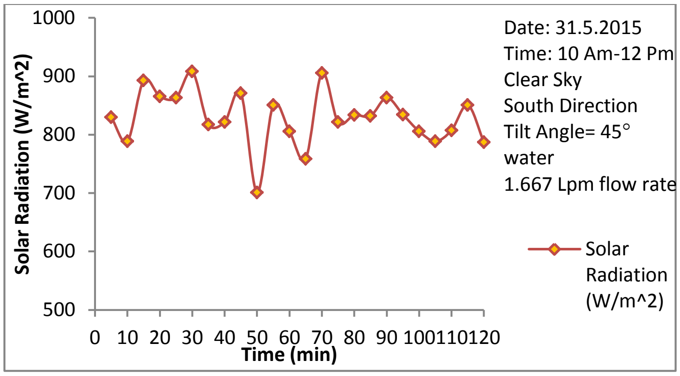

Fig. 7. Incident Solar Radiation for the Day (31.5.2015)

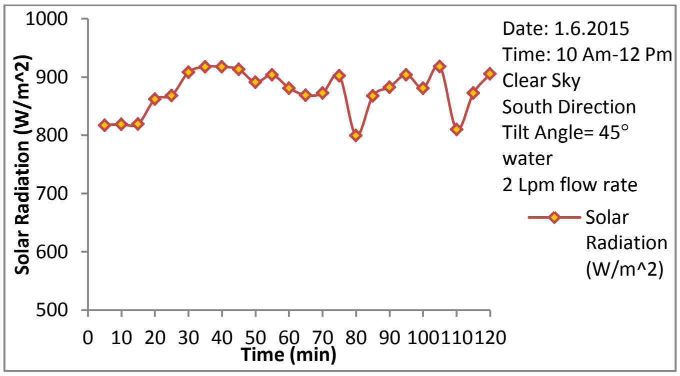

Fig. 8. Incident Solar Radiation for the Day (1.6.2015)

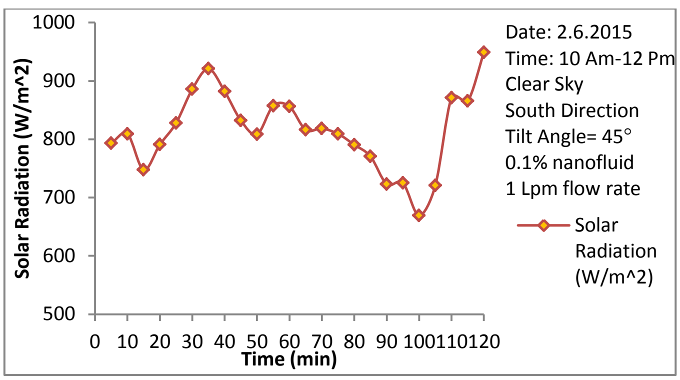

Fig. 9. Incident Solar Radiation for the Day (2.6.2015)

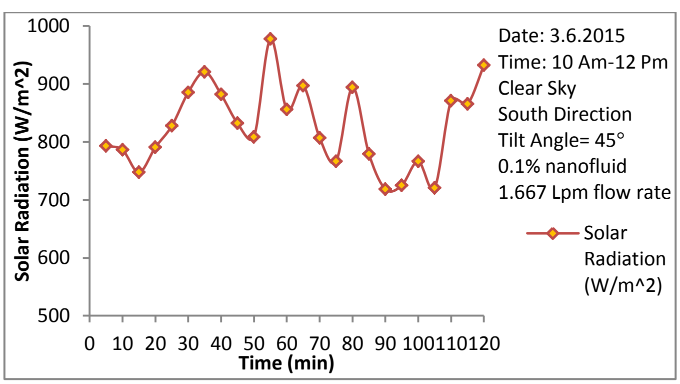

Fig. 10. Incident Solar Radiation for the Day (3.6.2015)

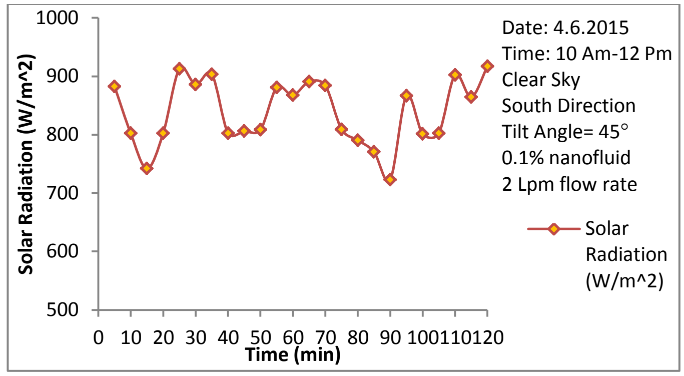

Fig. 11. Incident Solar Radiation for the Day (4.6.2015)

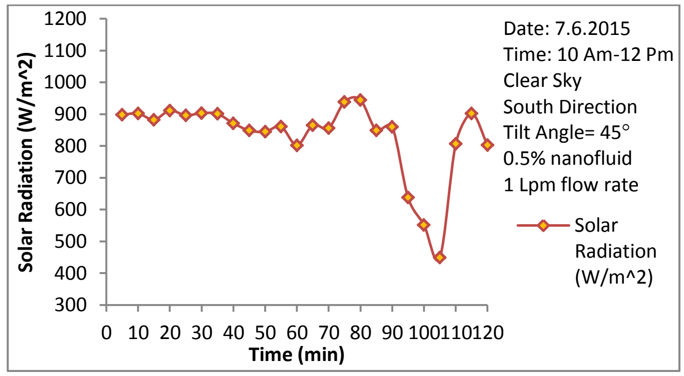

Fig. 12. Incident Solar Radiation for the Day (7.6.2015)

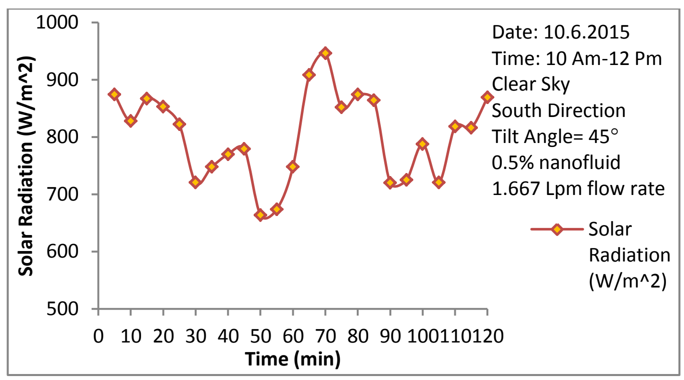

Fig. 13. Incident Solar Radiation for the Day (10.6.2015)

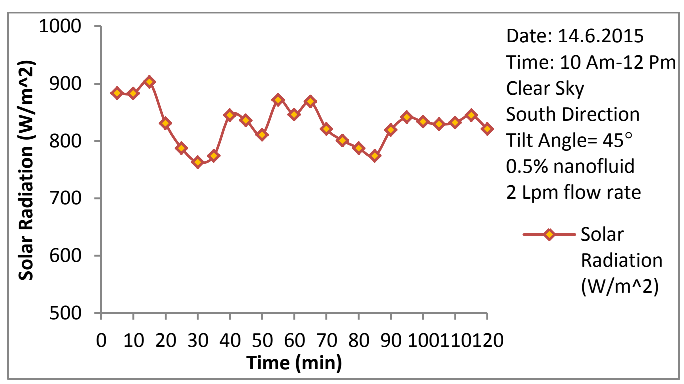

Fig. 14. Incident Solar Radiation for the Day (14.6.2015)

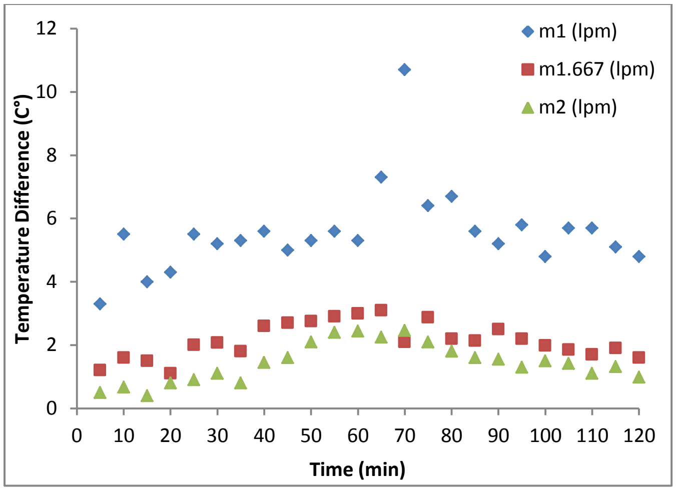

Fig. 15. The Inlet Outlet Temperature Difference of Water for Three Flow Rates Variation with Time

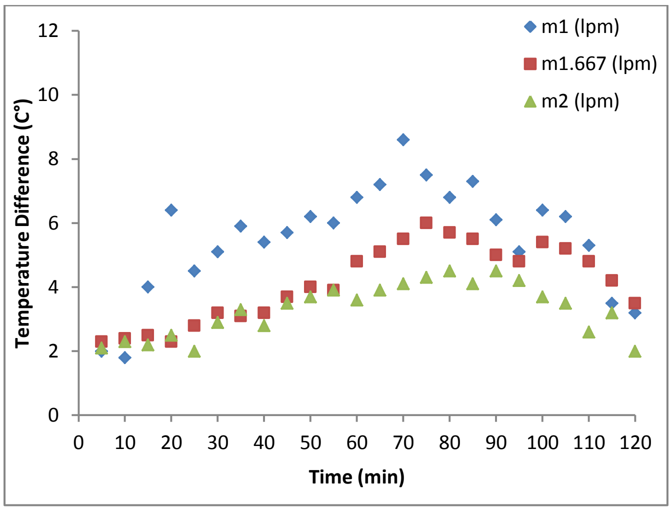

Fig. 16. The Inlet Outlet Temperature Difference of (0.1 Vol. %) Nanofluid for Three Flow Rates Variation with Time

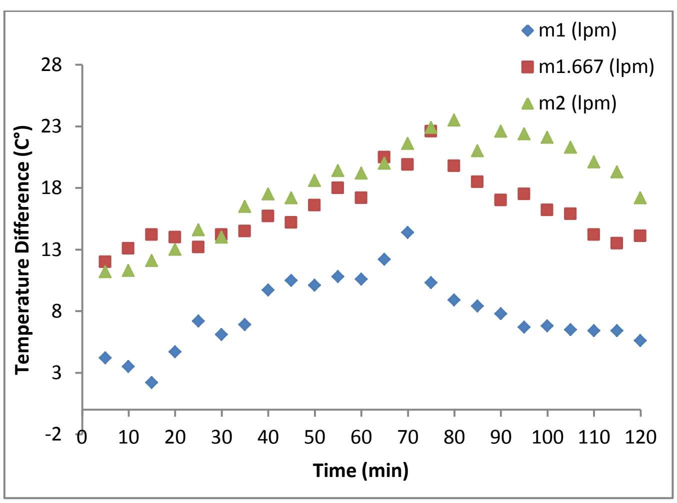

Fig. 17. The Inlet Outlet Temperature difference of (0.5 Vol. %) Nanofluid for Three Flow Rates Variation with Time

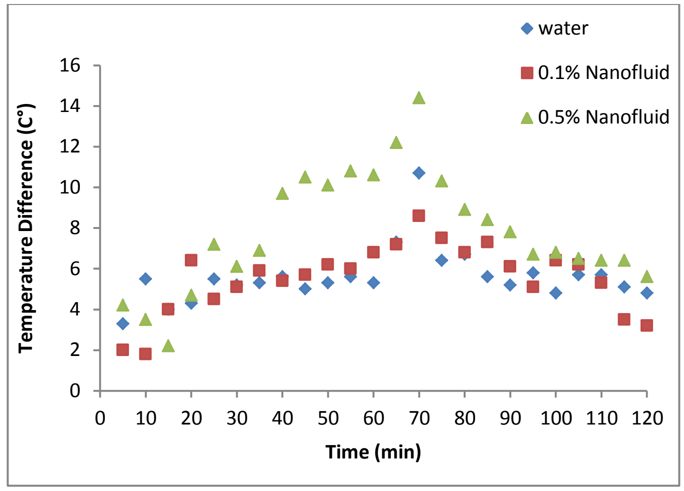

Fig. 18. The Inlet Outlet Temperature Difference at 1 Lpm Flow Rate for Water and Nanofluids Variation with Time

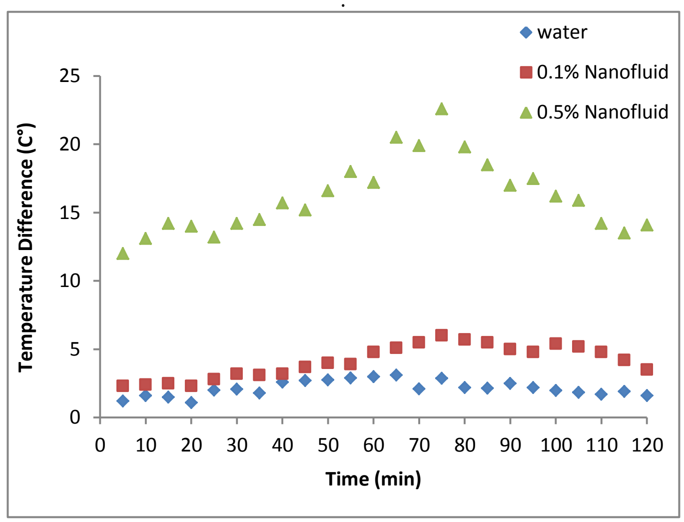

Fig. 19. The Inlet Outlet Temperature Difference at 1.667 Lpm Flow Rate for Water and Nanofluids Variation with Time

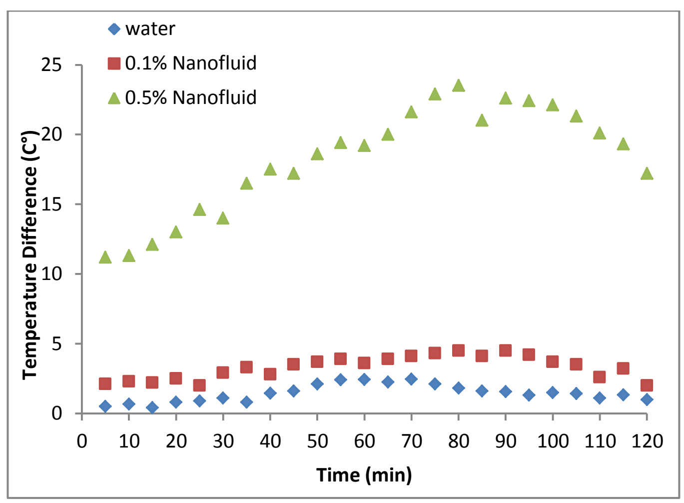

Fig. 20. The Inlet Outlet Temperature Difference at 2 Lpm Flow Rate for Water and Nanofluids Variation with Time

III. CONCLUSION

The effect of using Al_2O_3-water nanofluid with differennt flow rates on the flat plate solar collector has been studied experimentally.

It can be concluded that for water and (0.1 vol. %) Al_2O_3 nanofluid used as working fluids, the outlet-inlet temperature differences were decreased with the mass flow rate increase and maximum outlet-inlet temperature difference were achieved at low flow rate the while the minimum temperature difference was achieved at highest flow rate.

While (0.5 vol. %) nanofluid on the contrary of that where the temperature differences increase with the flow rate rise and maximum outlet-inlet temperature difference was achieved at highest flow rate.

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.

ACKNOWLEDGEMENTS

The authors would like to thank the Department of Mechanical Engineering, Kofa for supporting in experiments facilities. The researcher would like to show the appreciation to Dr. Maher Al-Baghdadi for providing remarkable support in this study.

REFERENCES

[1] Zekai Sen. Solar Energy Fundamentals and Modeling Techniques: Atmosphere, Environment, Climate Change and Renewable Energy. Springer, 2008.

[2] Han Zenghu. Nanofluids with Enhanced Thermal Transport Properties, Ph.D. thesis, University of Maryland, 2008.

[3] Choi S.U.S., Singer D.A., Wang H.P. Enhancing Thermal Conductivity of Fluids with Nanoparticles, Developments and Applications of Non-Newtonian Flows. J. American Soi. New York, 1995.

[4] Masuda H., Ebata A., Teramae K., Hishinuma N. Alteration of thermal conductivity and viscosity of liquid by dispersing Ultra fine Particles(Dispersion of Al2O3, SiO2 and TiO2 ultra fine particle). Netsu Bussei , Japan, 1993, 7, 33, 227.

[5] Lee, S., Choi, S. U. S., Li, S. and Eastman, J. A., "Measuring Thermal Conductivity of Fluids Containing Oxide Nanoparticles", J. Heat Transfer, Vol. 121, No. 2, pp. 280-289, Online December 05, (2007).

[6] Yousefia Tooraj, Veysia Farzad, Shojaeizadeha Ehsan, Zinadinib Sirus, "An experimental investigation on the effect of Al2O3–H2O nanofluid on the efficiency of flat-plate solar collectors", Renewable Energy, Vol. 39, Issue 1, Pages 293–298, March (2012).

[7] Kabeel, A.E., El-Said, Emad M.S., Abdulaziz, Mohamed, "Thermal solar water heater with H2O-Al2O3 nano-fluid in forced convection: experimental investigation", International Journal of Ambient Energy, (2015).

[8] Duan fei. Thermal property measurement of Al_2O_3-water nanofluids. chapter 15 in Smart Nanoparticles Technology (book edited by Abbass Hashim), pp. 336-352, intechopen, 2012.