VOL. 12, NO. 13, JULY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EXPERIMENTAL AND NUMERICAL STUDY THE HEAT TRANSFER OF FLAT PLATE SOLAR COLLECTOR BY USING NANOFLUID UNDER SOLAR SIMULATION

Abbas Sahi Shareef and Ali Abd Alrazzaq Abd Dibs
Department of Mechanical Engineering, Kerbala University, Kerbala, Iraq
E-Mail: ali.dibs88@gmail.com

ABSTRACT

A new automatic solar simulator was designed and constructed to provide a test platform for the simulation of solar radiation and controlling by Arduino board. The light source and fabrication of the simulator is described. And tested on the flat plate solar collector, and using nanoparticles Al2O3 for enhancement heat transfer of working fluid, using the Al2O3 with three different volume fraction (0.2%, 0.4%, and 0.6%), by using ultra-sonic for preparing Nano fluid and used distilled water for base of nanoparticles. This test under 1lpm (laminar flow). The numerical CFD-Model by using interfaces between laminar flow and heat transfer by COMSOL version 5.2a, the validation between the experimental and numerical is agreement variable error, the maximum error had 6.211 %, the experimental tested had the greatest difference temperature between the inlet and outlet is 15.343°C at nanofluid had volume fraction 0.6%.

Keyword: flat plate solar collector, solar simulator, Al2O3/water nanofluids, volume fraction, COMSOL V5.2a.

1. INTRODUCTION

The fossil fuel is not enough for human's daily using that lead to increase the air population and very expensive, the solar energy has one of most important heat energy source, that great utility for power generation and is one of the oldest sources in the universe and is one of the sources of clean energy environmentally friendly, the flat plate solar collector is one of renewable energy application using for heating by gain the heat energy directly from the sun, but the weather is not control parameter this problem led to building the solar simulation for compression between different cases. [1], [2]. Wen and Ding [3] probed experimentally the convective heat transfer of Al_2O_3/water nanofluids in the laminar flow regime and showed that the use of Al_2O_3/water nanofluids can significantly enhance the convective heat transfer in the laminar flow regime, and the enhancement increased with Reynolds number and particle volume concentration. They also showed that (i) the enhancement is significant in the entrance region and decreases with axial distance, and (ii) the thermal developing length of nanofluids is greater than that of pure base liquid. They attributed the enhancement of the convective heat transfer to particle migration, which may result in a non-uniform distribution of thermal conductivity, and viscosity field, which will reduce the thermal boundary layer thickness. Using the same experimental setup. Shokouhi [4] carried out an experimental investigation of hydrodynamic and thermal behavior of nanofluids in the entrance region of a circular tube under constant surface temperature boundary condition in laminar flow regime. The authors studied effects of nanoparticles volume concentrations and Reynolds number on the convective heat transfer coefficient and pressure drop along the tube. The experiments were conducted for 0.5% and 1% nanoparticles volume fractions while Reynolds number varies between 650 and 2300. The results showed that the presence of nanoparticles in the base fluid caused a significant increase in heat transfer with respect to that of the base fluid. The results indicated that heat transfer coefficient of nanofluids increases with increasing particle volume fraction as well as Reynolds number and showed that the pressure drop of nanofluids was slightly higher than the base fluid and increases with nanoparticles volume concentrations. Tooraj [5] studied experimentally the effect of Al2O3-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%. Yousefi T [6] in direction to upsurge the effectiveness or performance of solar collectors, one of the most appropriate methods is to change the working fluid like water, ethylene glycol by higher thermal conductivity fluids like aluminum oxide, copper oxide. The blend of base fluids like water or ethylene glycol with suitable nanoparticles like silicon oxide or aluminium oxide are called nanofluids. In comparison with conventional heat transfer fluids Nano fluids exhibits exceptional heat transfer properties. Dawood [7] presented numerical simulation for three dimensional laminar mixed convective heat transfers at different nanofluids flow in an elliptic annulus with constant heat flux. A numerical model is carried out by solving the governing equations of continuity, momentum and energy using the finite volume method with the assistance of SIMPLE algorithm. The authors used four different types of nanofluids Al_2O_3, CuO, SiO_2 and ZnO, with different nanoparticles size 20, 40, 60 and 80 nm, and different volume fractions ranged from 0 % to 4% using water as a base fluid. The investigation covers a Reynolds

number in the range of 200 to 1000. The results revealed that SiO_2–Water nanofluid has the highest Nusselt number, followed by Al_2O_3–, ZnO–, CuO–water, and lastly pure water. The Nusselt number increased as the nanoparticle volume fraction and Reynolds number increased; however, it decreased as the nanoparticle diameter increased.

2. EXPERIMENTAL WORK

In this work flat plate solar collectors will be studied tested by Nano fluid design and build automatic solar simulator after applied the solar irradiance from 11:00 to 13:00 at (30/09/2016) for location latitude 32.546°, and longitude 44.237° and testing the rig under controlling environment, collectors are made from the absorber aluminum plate was painted black car paint with 50% by weight river sand for enhancement the absorbing, and double glazing cover type window glass had thickness 0.04cm, the flat plate solar collector are insulation from all side and bottom the is study of effect of the volume fraction concentration on base fluid. Table-1 the specifications of solar collector using the solar power meter device for measuring solar irradiance anemometer for wind speed, thermo-meter (data logger by computer), using thermocouple type k for measuring the temperature from different location all measuring device are calibrate.

Table-1. The specifications of solar collector.

No.	Components	Remarks
1	Collector	The dimension of collector is (width 70cm ,length 100cm, and thickness14.8cm)
2	Absorber plate	Aluminum type dimension is (80cm long, 50 cm wide, and 0.02cm thickness)
3	Header	The number of header is two pipe had inner diamter is 2cm and thickness is 0.02 cm and long 62cm
4	Riser	The number of riser is six pipe had inner diamter is 1cm and thickness is 0.02 cm and long 64cm
5	Cover	The number of cover is two glass window type had thickness 0.04cm
6	Painted	plate was painted Black car paint type (matt 890) with 50% by weight river sand
7	Insulation	The insulaton from all side is 10cm, and bottom is 9cm
8	Tilted angle	Heat flux of the the tilted angle is (22°) by compression between (12°, 32°, 42°, 52°)

The schematic indoor system as shown in Figure-1, and the indoor system as shown in Figure-2, the experimental indoor as shown in test Table-2.

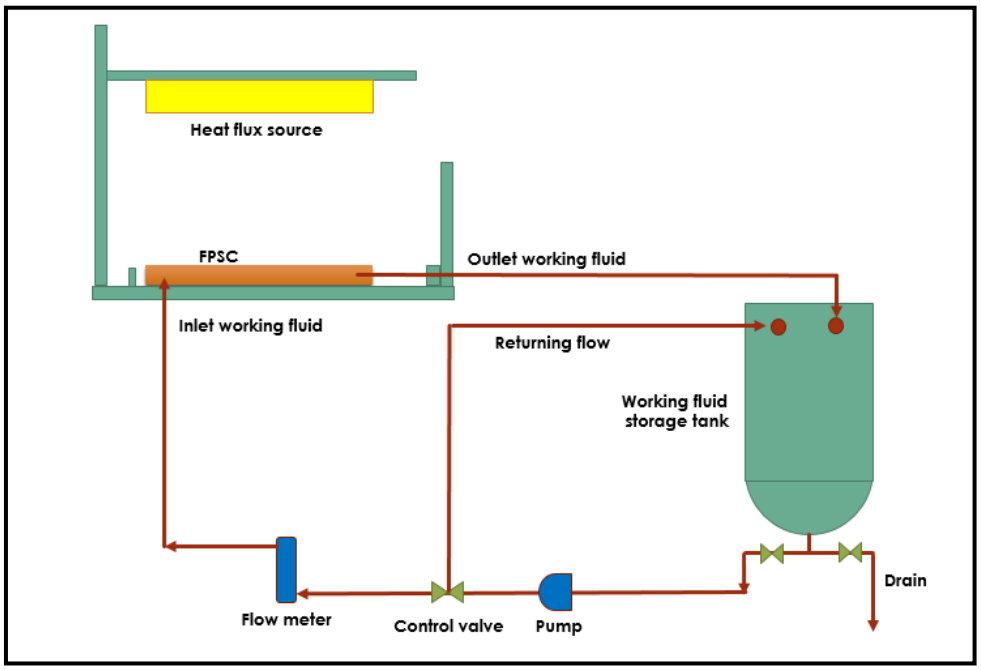

Figure-1. The schematic indoor system.

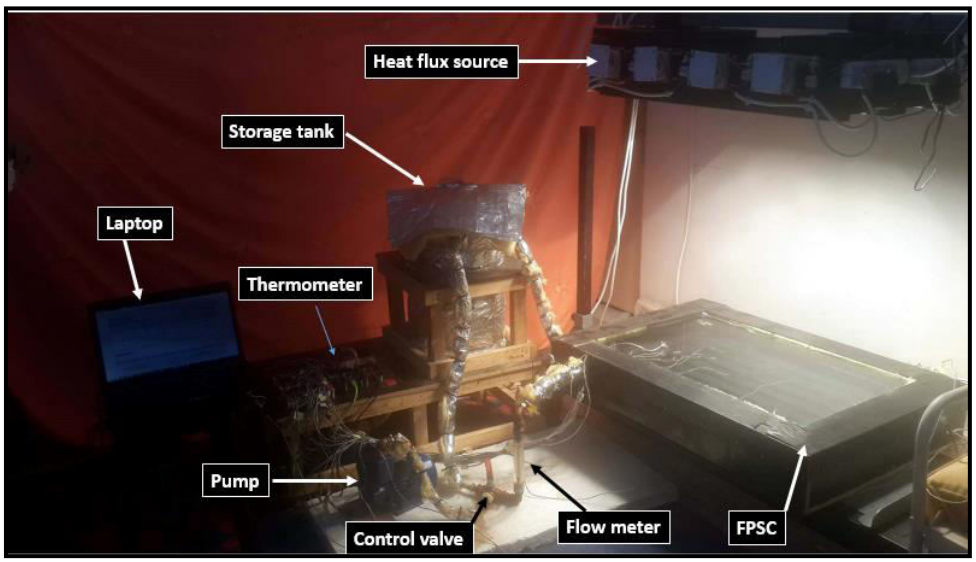

Figure-2. The indoor system.

3. PREPARATION OF NANOFLUID

Preparation the nanofluid by using Two-step method, produced dry nanopowders are trifling in distilled water base fluids, with three different of volume fraction concentrations, are (0.2%, 0.4%, and 0.6%). By using equation (1), and (2) for calculate the quantity of the nanoparticles added [8]. Table-2 Physical properties of (Al2O3) nanoparticles

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

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

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 (g).

Table-2. Physical properties of (Al2O3) nanoparticles.

Properties	Al_2O_3
Purity	99+ %
Average particles Size	20 nm
Morphology	nearly spherical
True density	3.95 g/cm^3
Specific heat capacity	860 J/kg.K
Color	white

The weighing of nanopowders by using electronic balance under the vacuum condition using a vacuum device to avoid pollution and oxidation of nanopowders as shown in Figure-3 and suspension by ultrasonic crasher cell type MTI Corporation had power 1200W as shown Figure-4.

Figure-3. The electronic balance inside the vacuum device.

Figure-4. Magnetic stirrer and ultra-sonic crasher cell.

4. NUMERICAL INVESTIGATIONS

The 3D model of the solar flat plate collector was carried out by COMSOL software version 5.2a where the geometry was used to drawing of COMSOL geometry as shown in Figure-5 and meshing using the normal size has consist of 47834 domain elements, 65064 boundary elements, and 7659 edge elements. As shown in Figure-6.

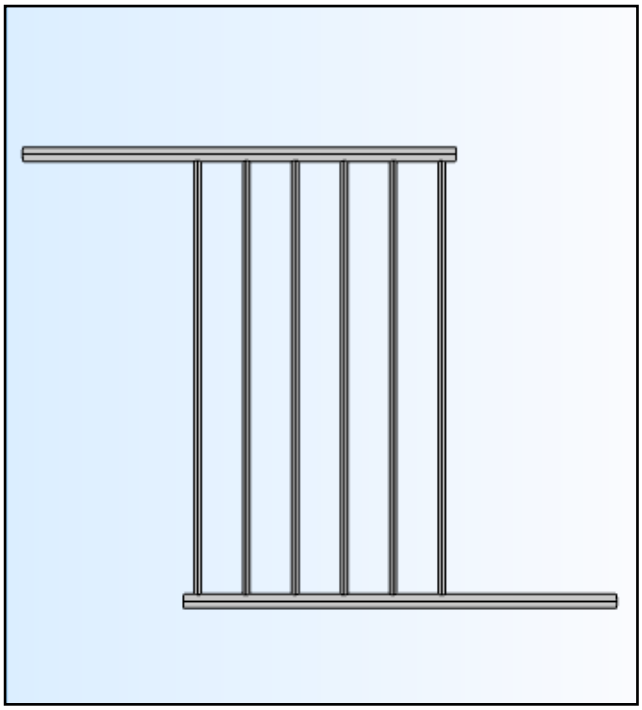

Figure-5. COMSOL geometry.

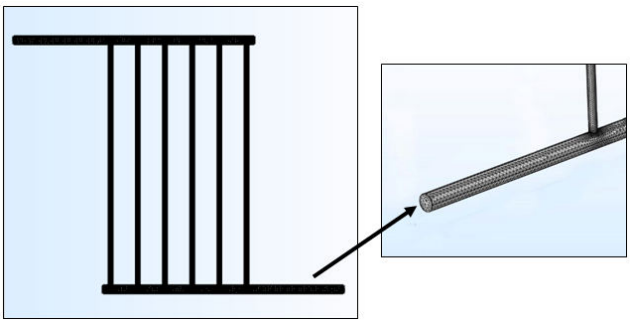

Figure-6. Meshing the geometry.

4.1 Boundary conditions and assumptions

In this analysis three volume fraction concentrations (0.2%, 0.4%, and 0.6%) that effected on physical properties, with volume flow rate 1 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 (distilled water and Al2O3) is variable with temperature input. Impermeable boundary and no-slip wall conditions was performed on the channel walls.

Assumptions:

a) Incompressible fluid

b) The flow considered to be laminar

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

Analysis

The Analysis was applied at unsteady 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 COMSOL 5.2a using the interfacing laminar flow and heat transfer in fluid after drawing the geometry, input the parameter and boundary condition, meshing, and solve the case unsteady state with timing 120 min for 5 min to one step.

5. RESULTS AND DISCUSSIONS

The experimental indoor take all parameter by tested the system outdoor at home roof location in hindyai city at the Holy of Karbala (latitude 32.546°, and longitude 44.237°), the test time from (11:00 to 13:00) for date (30/09/2016), the average solar irradiance distribution with time as shown in Figure-7, the working fluid is distilled water, and enhancement heat transfer of the working fluid by added Nano particles Al2O3 with three volume fraction (0.2%, 0.4%, and 0.6%), and the flow rate is 1 lpm under laminar flow and compression between, the maximum ΔT for distilled water, Nano fluid (0.2%, 0.4%, and 0.6%) is (6.051, 9.014, 12.654, and 15.343)°C as shown in Figure-8, the validation only for outlet by input Tin experimental measuring. The maximum experimental difference between the inlet and outlet temperature for distilled water is (6.051°C) as shown in Fgure-9, and the validation between the experimental and theoretical had the variable error between (-4.373%, +5.905%) as shown in Figure-10, the maximum experimental difference between the inlet and outlet temperature for Nano fluid has volume fraction 0.2% is (9.014°C) as shown in Figure-11, and the validation between the experimental and theoretical had the variable error between (-6.025 %, +1.688%) as shown in Figure-12, the maximum experimental difference between the inlet and outlet temperature for Nano fluid has volume fraction 0.4% is (12.654°C) as shown in figure (13), and the validation between the experimental and theoretical had the variable error between (-6.211%, +1.791%) as shown in Figure-14, and the maximum experimental difference between the inlet and outlet temperature for Nano fluid has volume fraction 0.6% is (15.343°C) as shown in Figure-15, and the validation between the experimental and theoretical had the variable error between (-2.573%, +5.360%) as shown in Figure-16. The maximum difference between inlet and outlet temperature, and the validation error by COMSOL program using CFD-model for all test as shown in Table-3.

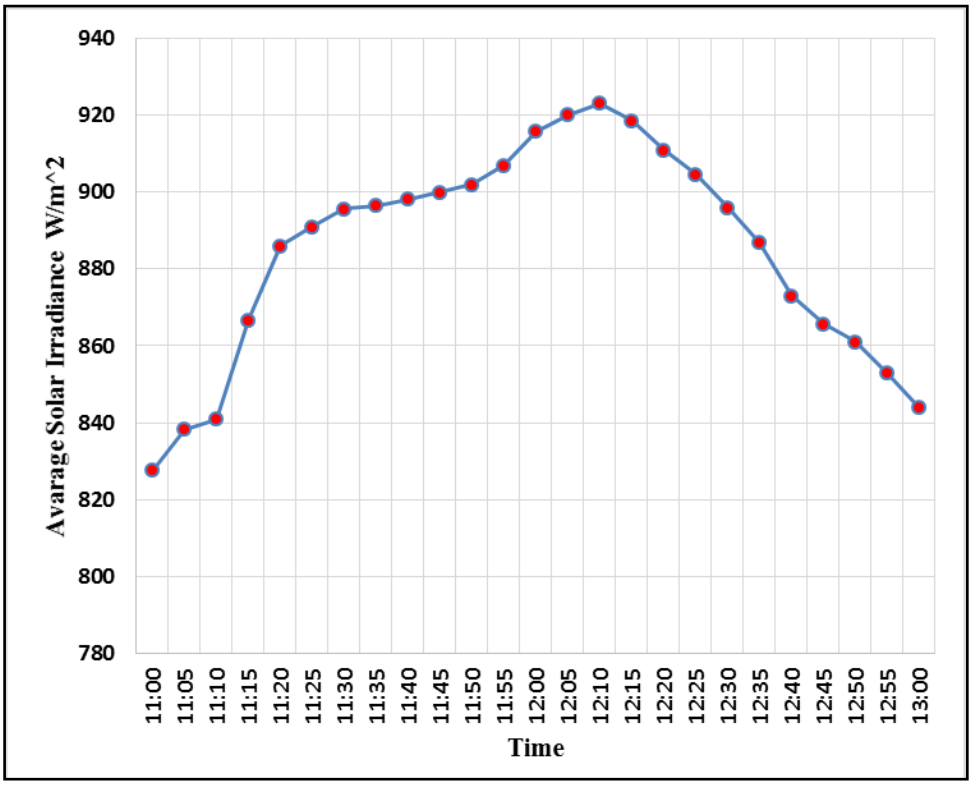

Figure-7. The solar irradiance distribution with time.

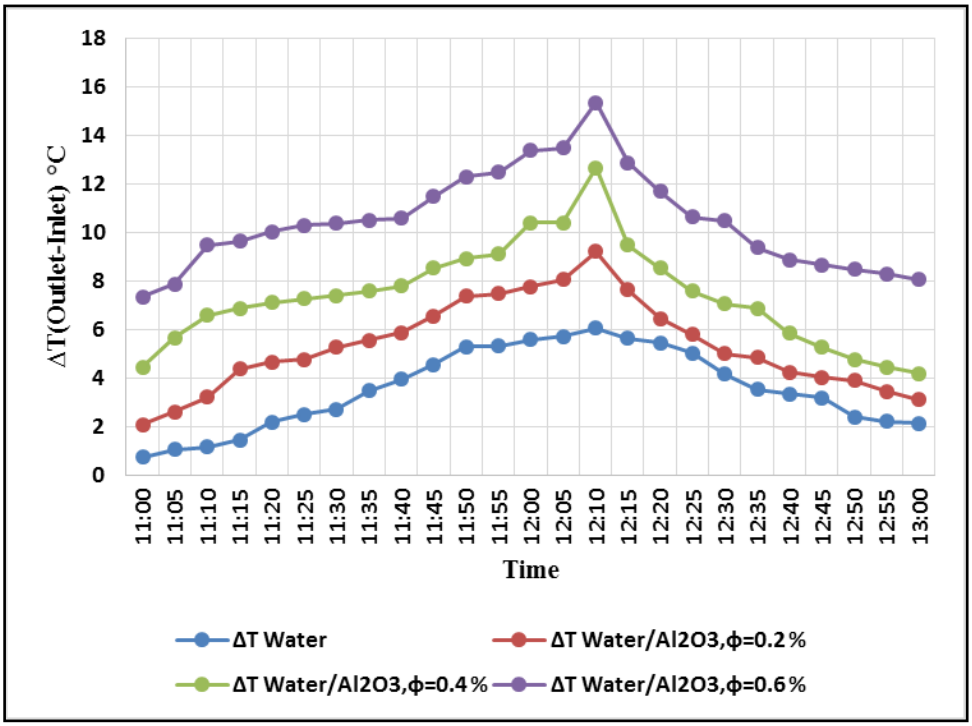

Figure-8. The compression between working fluid.

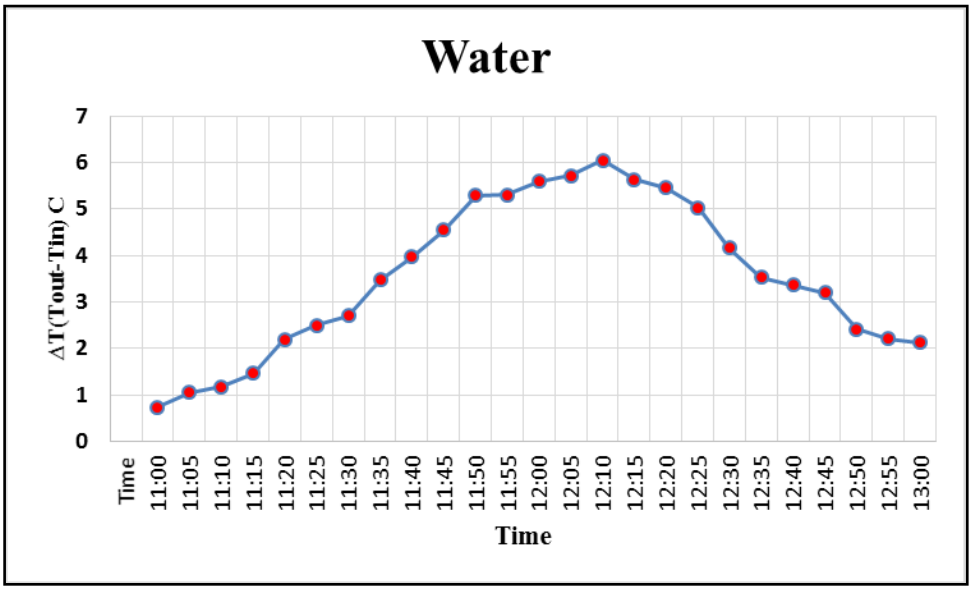

Figure-9. The difference between the inlet and outlet.

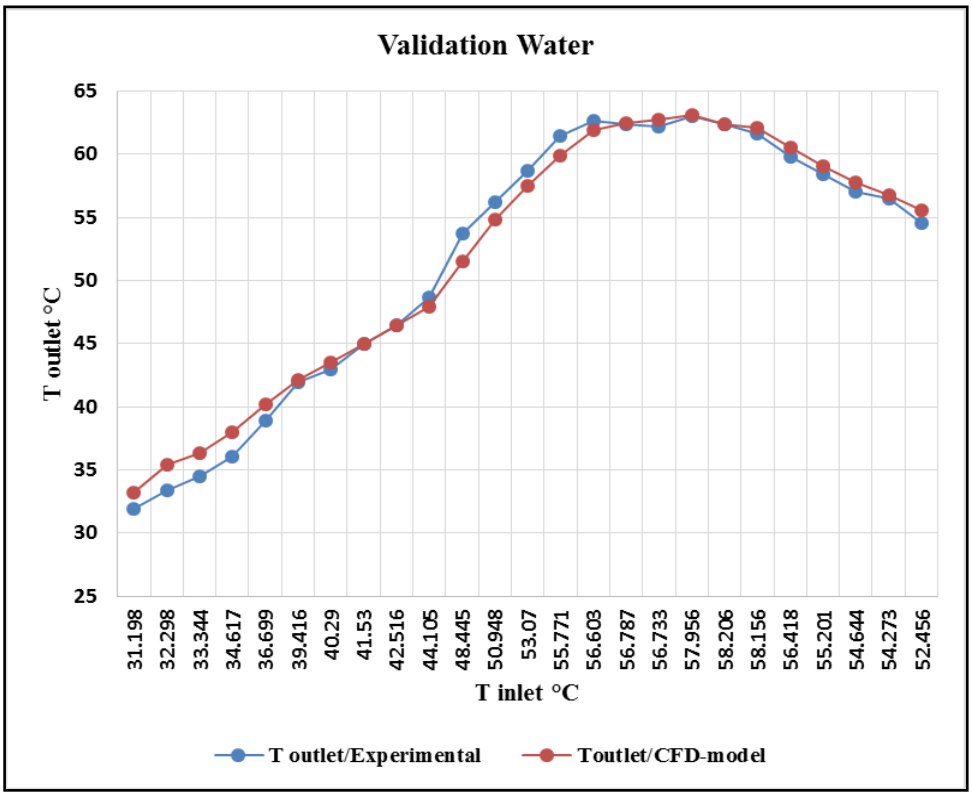

Figure-10. The validation between experimental and CFD-Model.

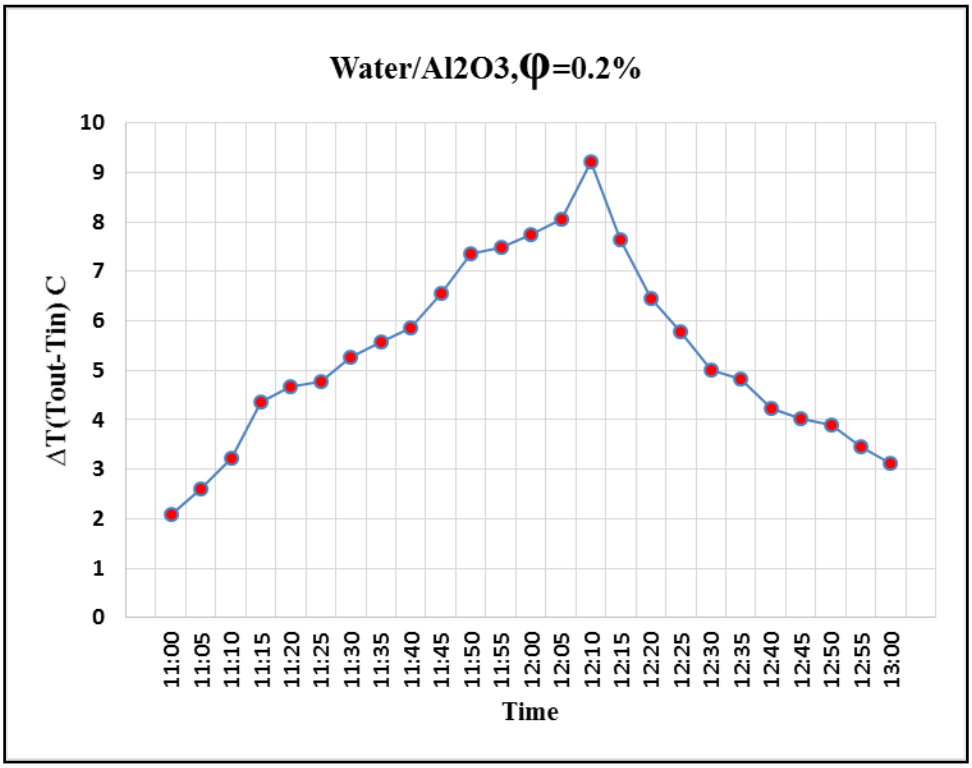

Figure-11. The difference between the inlet and outlet.

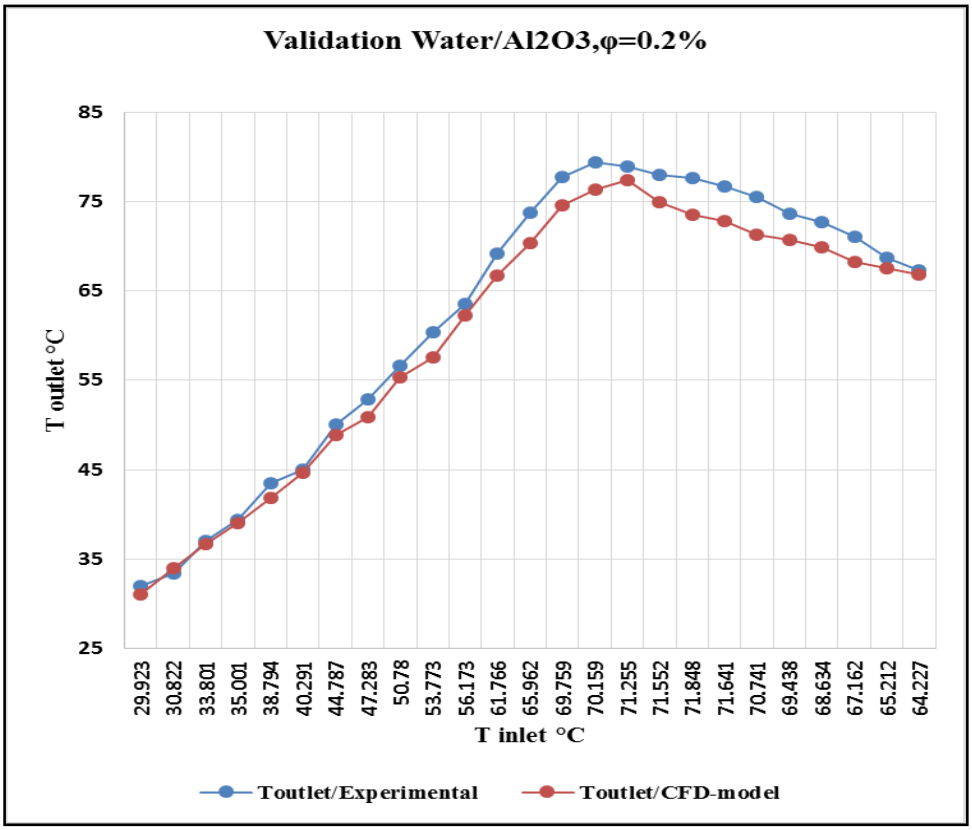

Figure-12. The validation between experimental and CFD-Model.

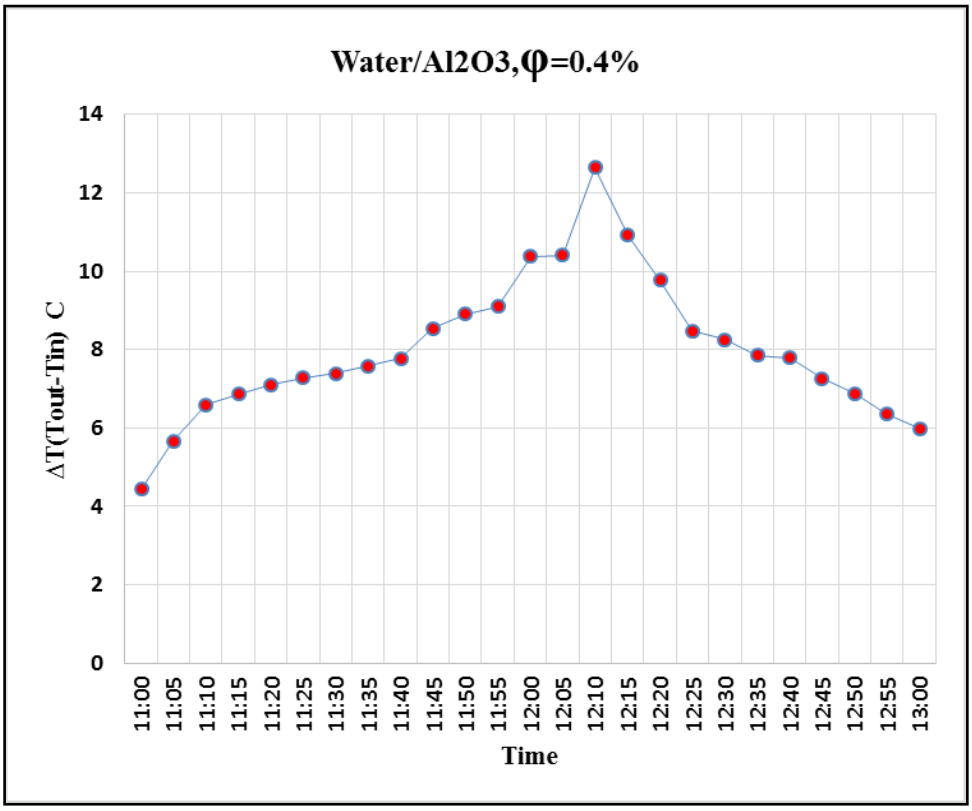

Figure-13. The difference between the inlet and outlet.

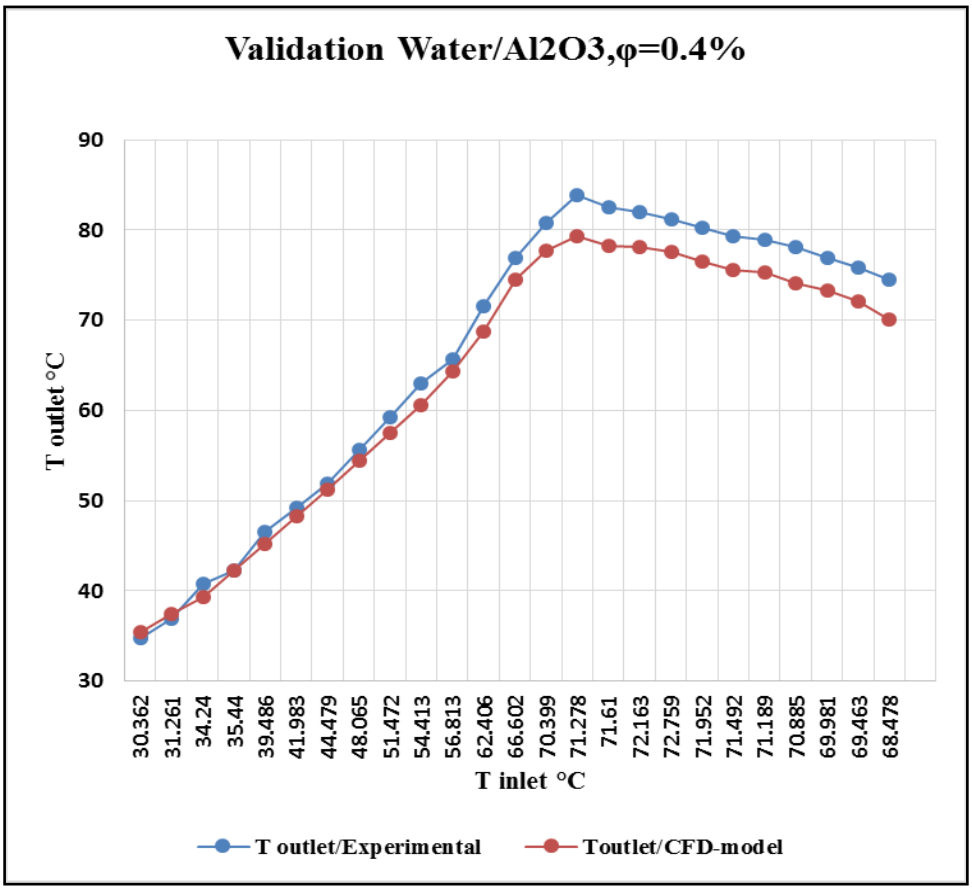

Figure-14. The validation between experimental and CFD-Model.

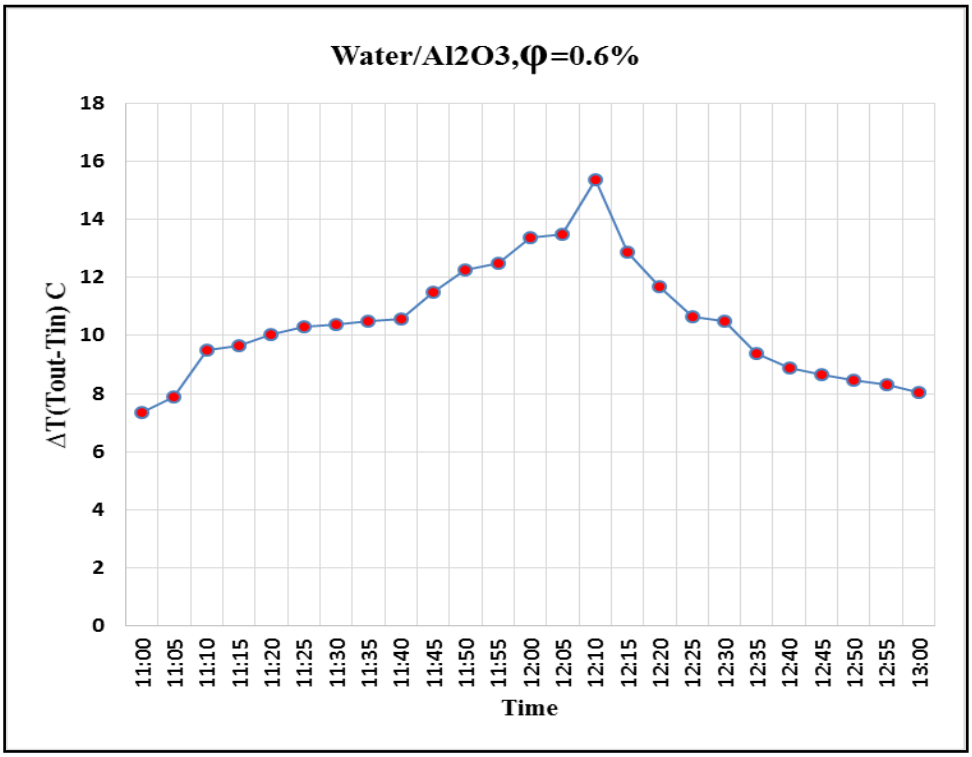

Figure-15. The difference between the inlet and outlet.

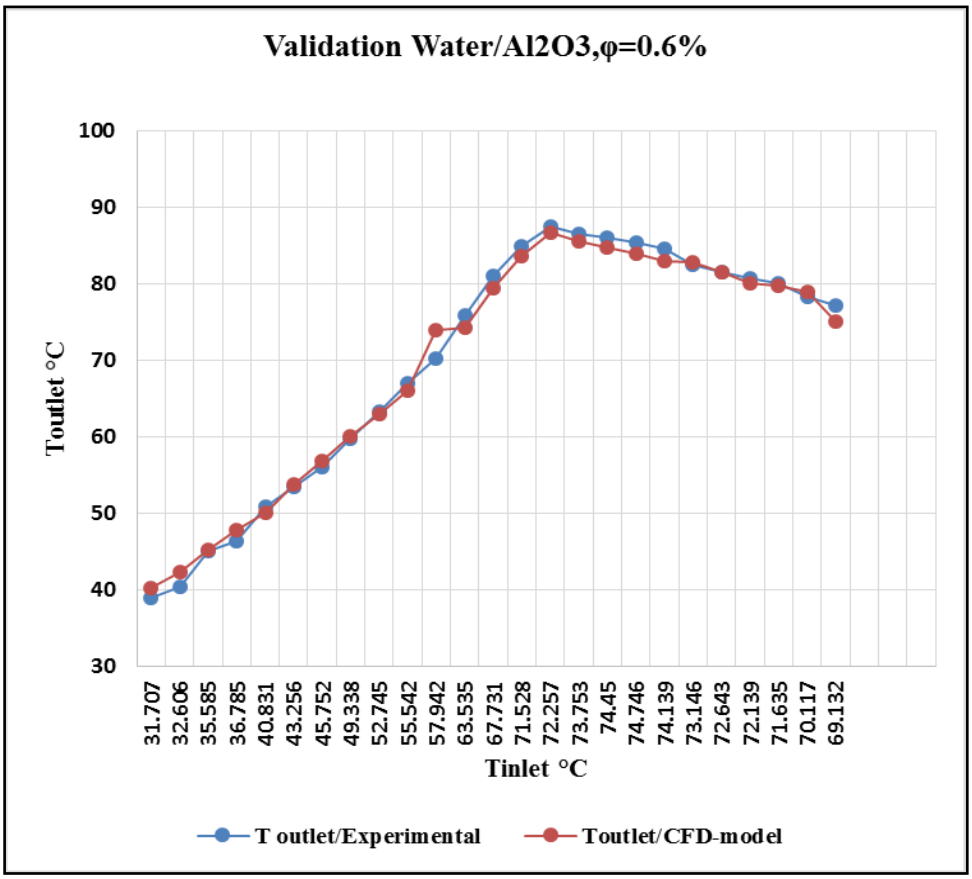

Figure-16. The validation between experimental and CFD-Model.

Table-3. ΔT (inlet-outlet) and the validation.

Case	Maximum ΔT °C by experimental	Error range %
Water	6.051	-4.373 to +5.905
Water/Al2O3:φ=0.2%	9.014	-6.025 to +1.688
Water /Al2O3:φ=0.4%	12.654	-6.211 to +1.791
Water /Al2O3:φ=0.6%	15.343	-2.573 to +5.360

6. CONCLUSIONS

The solar simulator given the perfect compression between cases due to the all parameter and boundary condition are controlled. The effect of Al2O3 on the distilled water volume fraction (0.2, 0.4 and 0.6) % on the flat plate solar collector has been studied experimentally and validation by design the model in COMSOL program with two interface laminar fluid and heat transfer we had a good agreement compared with the experimental result. It can be concluded that when the concentration of nanoparticles increased lead to enhancement the physical properties the nanoparticles is effect to increasing the thermal conductivity, density, viscosity, and decrease the specific heat. The thermal conductivity is limited to reach the fluid temperature, but the specific heat when be small at unsteady state for increase the heat absorbing heat from solar collector to working fluid. The maximum difference temperature between inlet and outlet is 15.3°C, at Nano fluid for volume fraction 0.6%. 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.

REFERENCES

[1] K. Sopian, M.A. Alghoul, Ebrahim M. Alfegi, M.Y. Sulaiman, E.A. Musa. 2009. Evaluation of thermal efficiency of double-pass solar collector with porous-nonporous media. Renewable Energy. 34: 640-645.

[2] M. Y. H. Othman, B. Yatim, H. Ruslan, K. Sopian, Z. Anuar, S. Khairuddin. Fabrication and Irradiance Mapping of a Low Cost Solar Simulator for Indoor Testing of Solar Collector, Journal of Solar Energy Engineering, Transactions of the ASME. 133(4), [044502]. DOI: 10.1115/1.4004548.

[3] Wen D., Ding Y. 2004. Experimental Investigation into Convective Heat Transfer of Nanofluid at the Entrance Region under Laminar Flow Conditions. International Journal of Heat Mass Transfer. 47: 51818.

[4] Shokouhi A., Keshavarz Ali, Ziabasharhagh M., Mojarrad Mohammad S. and Raveshi Mohammad Reza. 2012. Experimental Investigation of Nanofluid Convective Heat Transfer in the Entrance Region of a Circular Tube. Proceedings of the ASME 2012 3rd Micro/Nanoscale Heat & Mass Transfer International Conference MNHMT. 75253, Atlanta, Georgia, USA, March 3-6.

[5] Yousefia Tooraj, Veysia Farzad, Shojaeizadeha Ehsan, Zinadinib S. 2012. An Experimental investigation on the effect of Al_2O_3 -H_2O nanofluid on the efficiency of flat-plate solar collectors. Renewable Energy. 39(1): 293-298.

[6] Yousefi T., Veisy F., Shojaeizadeh E., Zinadini S. 2012b. An experimental investigation on the effect of MWCNT-H2O nanofluid on the efficiency of flat plate solar collectors. Experimental Thermal and Fluid Science. 39: 207-212.

[7] Dawood H.K., Mohammed H.A. and Munisamy K.M. 2014. Heat transfer augmentation using nanofluids in an elliptic annulus with constant heat flux boundary condition. Case Studies in Thermal Engineering. 4: 32-41.

[8] Khanafer K, Vafai K. 2011. A Critical syntesis of thermo physical Characteristics of Nanofluids. International Journal of Heat and Mass transfer (Under Press).