Performance Improvement of the Parabolic Trough Solar Collector Using Different Types of Fluids with Numerical Simulation

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Abstract

Solar concentrators are an important facility to utilize the solar energy. There are many kinds of solar concentrators. In this work an experimental has been implemented to improve the thermal performance of Parabolic Trough Solar Collector (PTSC) using three different fluids as a working fluid (water, nanoparticles of CuO mixed with distilled water nanoparticles of Al_2O_3 mixed with distilled water) with concentration ratio 0.01% and mass flow rate 20Lt/hr without tracking system. The experimental tests have been carried out in electro-mechanical engineering department at university of technology in Baghdad city during October 2017 and daytime between (9am -15pm) hours. The obtained results for three different fluids are as follows:

- Using (CuO + distilled water) as a working fluid increases the average of the output temperatures by 10.4%, the average of useful heat gains increases by 11% and the average of the collector efficiencies increases by15%.

- Using (Al_2O_3+distilled water) as a working fluid increased the average of output temperatures by 4%, the average of useful heat gains is increased by 6.5% and the average of collector efficiencies is increased by 8.2%.

Key Words: Parabolic Solar collector, Nanofluid effect, Solar energy, Efficiency improvement of PTC.

Symbols	Definition	Unit
A_a	Collector aperture area	m²
C_p	Heat capacity	J/kg.K
C_{p_f}	Heat capacity of fluid	J/kg.K
$C_{p_{nf}}$	Heat capacity of nanofluid	J/kg.K
C_{p_p}	Heat capacity of nanoparticle	J/kg.K
I_b	Beam solar radiation	W/m²
K_f	Thermal conductivity of fluid	W/m.K
K_{nf}	Thermal conductivity of nanofluid	W/m.K

K_p	Thermal conductivity of nanoparticle	W/m.K
M	Mass flow rate	Kg/hr
m_f	Mass of fluid	Kg
m_p	Mass of nanoparticle	Kg
$Q_{u,exp}$	Experimental useful energy	W
$Q_{u,th}$	Theoretical useful energy	W
$T_{f,i}$	inlet fluid temperature	^oC
$T_{f,o}$	Outlet fluid temperature	^oC
V_f	Volume of fluid	m^3
V_p	Volume nanoparticle	m^3

Greek Symbols

Symbols	Definition	Unit
η_{th}	Theoretical efficiency	----------
η_{ex}	Experimental efficiency	----------
φ	Concentration ratio	----------
ρ_{nf}	Density of nanofluid	Kg/m^3
ρ_f	Density of fluid	Kg/m^3
ρ_p	Density of nanoparticle	Kg/m^3
μ_{nf}	Viscosity of nanofluid	m^2/s
μ_f	Viscosity of fluid	m^2/s

1. Introduction

The sun is the best energy source in this contextually and is almost a wellspring. Energy efficiency and solar technology are very important parameters to the building or community design. The radiation of the sun can be converted into other forms of energy by direct or indirect way, for example heat and electricity, which can be utilized by human. The researches and developments which started before 1970 are carried out in few countries to utilize the thermal energy in best manner, but most of these researches remained academic **[1]**.

There are many regions and countries suitable to use the solar energy that is depending on their climate, Iraq is one of these countries because the solar rays that received with approximate time of 4000 hours per year in convenient places of solar energy **[2]**. The Concentrated Solar Power (CSP) is the best technology in consuming solar radiation, which bestirs the way to produce energy. Different types of CSP are used in crafting for generation of power. The Parabolic Solar Collectors (PSC) are the best technology proliferate in power plants. Efficiency of the (PSC) and heat losses during storage times are two main drags while utilizing the PSC in solar energy. Recent finds suggested that adding nano-particles to the heating fluid improve the thermal conductivity, thermo-physical and heat transfer properties of the fluid **[3]**. Nano-fluid will have a favorable effect on the performance of (PSC). **[4]** Described the heat transport enhancement by means of nano-powder. Altered nanofluids including Al_2O_3 (20 nm), CuO (50 nm), and Cu (25 nm) nanoparticles in water were considered in their work and has been conducted in the course of laminar flow with heat transfer development through the circular tube. They specified their results to identify the improvement of heat transfer with the increase in concentration of nanoparticle. They had taken the optimum concentration value of Cu nanoparticles to be 2% of volume fraction and the other nanoparticles Al_2O_3 and CuO as 2.5% of volume fraction. The results obtained from their experimental work showed that the metallic nanoparticles had improved the heat transport coefficient as compare to that of the oxide particles. **[5]** Investigated theoretically thermal efficiency of a nano-fluid based direct absorbition solar parabolic trough collector, and used aluminium nanoparticles at the volume fraction of 0.05% suspended in the base fluid Therminol-VP1. Their results showed that thermal efficiency increases compared to a conventional PTC by 10 % at low temperatures and by 5% at high temperatures. **[6]** Presented an attempt to increase the efficiency of parabolic solar collector by using copper oxide and alumina nanofluid with concentration 0.01% and the average size of nanoparticle is 20-30 nm. The maximum instantaneous efficiency was 39.4% at flow rate 60 Lit/hr with copper oxide. **[7]** Studied the performance of solar nanofluid heating system using (Cu (30nm) +DW) and (Ti$O_2(50nm) + DW$) as a nanofluids. Also he used four particles concentration ratios (0, 1, 3 and 5 % vol), mass flow rate (30, 60 and 90 lit/hr m^2) and the distilled water as working fluid. The efficiency of collector for nanofluid (Cu (30 nm) +DW) was more than nanofluid (TiO_2(50 nm) +DW) because the particle size of copper was small as compared with titanium oxide.

2. Theory:

The solar collector is formed in the shape of parabola, which is usually a mirror, or anodized Aluminum sheet depends on the applications to concentrate the radiation rays of the sun on the receiver tube that located in the focal line of the collector. The material of the absorber tube most be mild steel or copper and it is painted with black paint to improve the performance of it. The absorber tube transform the radiations into thermal energy which is carried by the working fluid that pass through the tube and use it in require application. This type of collectors can reach to 400ºC, depending upon the material that is used as a reflecting surface, absorber tube materials and heat transfer fluid. The concentrating collectors has an important factor called concentration ratio which is defined as the ratio of the aperture area of collector to the area of the absorber tube and it ranges are (20-70).

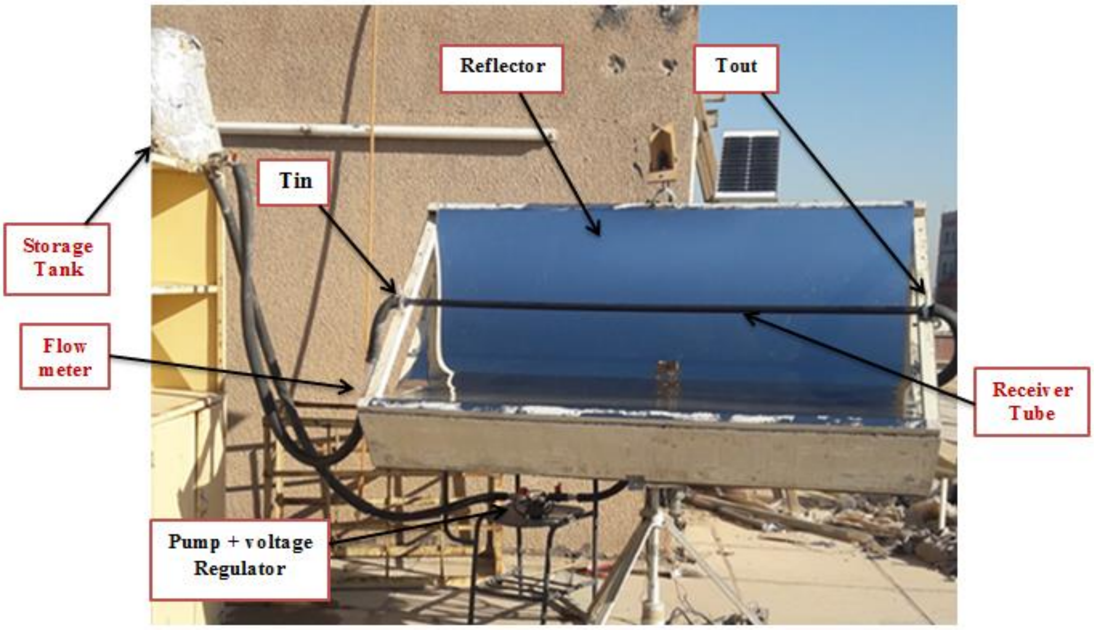

Figure (1) Parabolic Trough Solar Collector

Table (1) Specifications of Parabolic Trough Collector

ITEM	Value / Type
Collector aperture area A_a	1.755 m²
Aperture width W_a	1 m
Length to width ratio	1.755
Rim angle Φ_r	90º
Tracking mechanism type	Electro-Optical
Tracking mode	Two axis tracking
Concentration ratio with tube CR	35

Table(2) Specifications of copper tube

ITEM	Value
Length of tube L	1.835 m
Outer diameter D_o	28 mm
Inner diameter	27.2 mm
Thickness of tube	0.8 mm

3. Nano-fluid

A nano-fluid is a fluid containing nano-meter sized particles, named nanoparticles. These fluids are engineered colloidally suspensions of nano-particles in the base fluid. The nano-particles used in nano-fluid are normally made of metals, oxides, carbides, or carbon nano-tubes. Nano particles have high thermal conductivity and convective heat transfer coefficient. Knowledge of the rheological behaviour of nanofluids is found to be very critical in deciding their suitability for convective heat transfer applications.

3.1 Concentration Ratio of Nanofluid

It presents the ratio of nanoparticles in the base fluid and it is calculated from **[8]**:

$$\varphi = \frac{V_{nf}}{V_{nf+p}} \quad (1)$$

Since $\rho = \frac{m}{V}$ (2)

Then $$\varphi = \frac{\left({m_p}/{V_p}\right)}{\left({m_p}/{\rho_p}\right)+\left({m_f}/{\rho_f}\right)} \quad (3)$$

3.2 Nanofluid Density

The model that is used by assuming an equipoise state between particles and fluid is obtained as follows **[8]**:

$$\rho_{nf} = \rho_f(1-\varphi) - \rho_p\,\varphi \quad (4)$$

Where,

f = subscripts,

p=stand for fluid and nano-particle respectively,

φ= Concentration of nano-particles in nano-fluid.

3.3 Nano-fluid Specific heat capacity

The nano-fluid specific heat capacity is evaluated from equation **[8]**:

$$C_{p_{nf}} = C_{p_f}(1-\varphi) - C_{p_p}\,\varphi \quad (5)$$

3.4 Nano-fluid viscosity.

Different equations had been used to evaluate viscosity of nano-fluids. In this work Einstein model **[9]** is used**:**

$$\mu_{nf} = \mu_f(1+2.5\,\varphi) \quad (6)$$

3.5 Nano-fluids thermal-conductivity

It is the most critical factor for analyzing heat transfer of nano-fluids. Multi models were found; in this work, Maxwell model **[9]** is used**:**

$$k_{nf} = k_f\,\frac{k_p+2k_f+2\varphi(k_p-k_f)}{k_p+2k_f-\varphi(k_p-k_f)} \quad (7)$$

4. Efficiency Evaluation:

The actual useful energy obtained from parabolic trough solar collector is given as **[10]:**

$$Q_{u,exp} = MC_P(T_{f,o} - T_{f,i}) \quad (8)$$

The thermal theoretical efficiency is written as **[10]:**

$$\eta_{th} = \frac{Q_{u,th}}{I_b\, A_a} \tag{9}$$

The thermal experimental efficiency is written as **[10]:**

$$\eta_{exp} = \frac{Q_{u,exp}}{I_b\, A_a} \tag{10}$$

5. Preparation technique of Nano-particles

The mixing of the nanoparticles with the water is carried out in the University of Technology in the corrosion laboratory at the materials engineering department by ultrasonic cleaner device that is shown in figure (2). The particle size of CuO and Al_2O_3 is (30-40) nm and the concentration ratio is 0.01%

Figure (2) Ultrasonic cleaner device

Table (3) Specifications of Ultrasonic cleaner

Type	**KQ3200E**
Power supply	220V, 50Hz
Operating frequency	40KHz
Ultrasonic power	150W
Washing volume	6L
Adopted standards	Q/320583GSFY008-2006

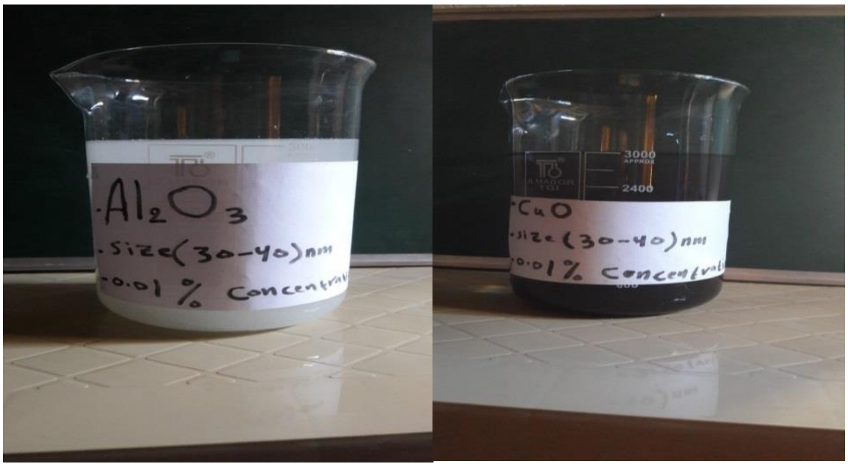

Figure (3) CuO and Al_2O_3 nanofluids

6. Results and Discussion

The results show the performance parameters of parabolic collector (output temperature, useful heat gain and efficiency).The values of solar radiation were calculated by MATLAB program **.**These experiments were performed in sunny days during (9 am-15 pm) of three fluids of parabolic trough solar collector**.**

Table (4) Results of water as a working fluid

NO	Time (hr)	T_{in} (ºC)	T_{out} (ºC)	T_{amb} (ºC)	Wind m/s	I_b (w/m²)	Q_u (w)	Eff %
1	9	20.3	27.2	27.3	0.34	385	161	23.8
2	10	22	32.8	28.5	0.9	430	250.8	33.2
3	11	25.1	41.8	30.1	1.3	512	387.7	43.1
4	12	31	54	32.4	1.1	585	534	52
5	13	38.2	57	33.9	1.7	505	436	49.3
6	14	45.5	60	34.3	1.3	445	337	43.2
7	15	47	57.3	34	2.1	386	239	35.2

Table (5) Results of CuO nanofluid as a working fluid

NO	Time (hr)	T_{in} (ºC)	T_{out} (ºC)	T_{amb} (ºC)	Wind m/s	I_b (w/m²)	Q_u (w)	Eff %
1	9	17.1	24.5	24	3.4	326	163.5	28.5
2	10	21	32.7	24.8	3.5	416	257	37.4
3	11	27	48.1	26	3.1	518	464.3	51
4	12	34.1	60	27.4	3	526	570	61.7
5	13	42.5	66	28.3	2.7	520	539	59
6	14	49.2	68	29.1	2.5	460	371	46
7	15	52.3	63	29.5	2.7	343	235.4	39.8

Table (6) Results of Al_2O_3 nanofluid as a working fluid

NO	Time (hr)	T_{in} (ºC)	T_{out} (ºC)	T_{amb} (ºC)	Wind m/s	I_b (w/m^2)	Q_u (w)	Eff %
1	9	17.4	23.8	19.2	0.44	312	141	25.3
2	10	20	30.9	20	0.97	402	245	34.7
3	11	26.7	45.6	21.3	1.1	525	422.3	45.8
4	12	33.2	58	22.6	1.6	552	553	57
5	13	39	62.5	24	1.7	541	524	55.1
6	14	45.3	62	24.8	0.82	439	373	48.4
7	15	49.5	60	25.3	1.5	368	235.2	36.5

6.1. Temperature versus time

There is a gradual increasing of output temperature of the working fluid as a result of beam solar radiation increasing. The averages values of outlet temperatures are (47.1, 52, 49) ºC for water, water based CuO and water based Al_2O_3 respectively. We note that the outlet temperature using water based CuO as a working fluid is more than the water and water based Al_2O_3 by (10.4, 6.1)% respectively.

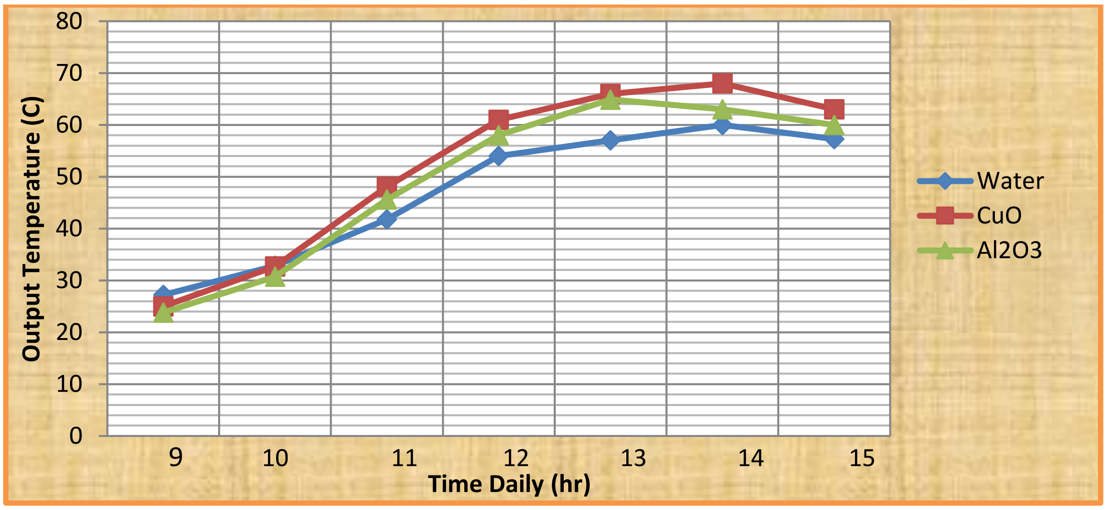

Figure (4) Output temperature versus time

6.2 Heat gain versus time

There is a gradual increasing in useful heating gain because of solar radiation increasing. The averages values of useful heat gains from the solar collector are (335, 372, 357) watt for water, water based CuO and water based Al_2O_3 respectively. We note that the useful heat gain using water based CuO as a working fluid is more than the water and water based Al_2O_3 by (11, 4.2)% respectively.

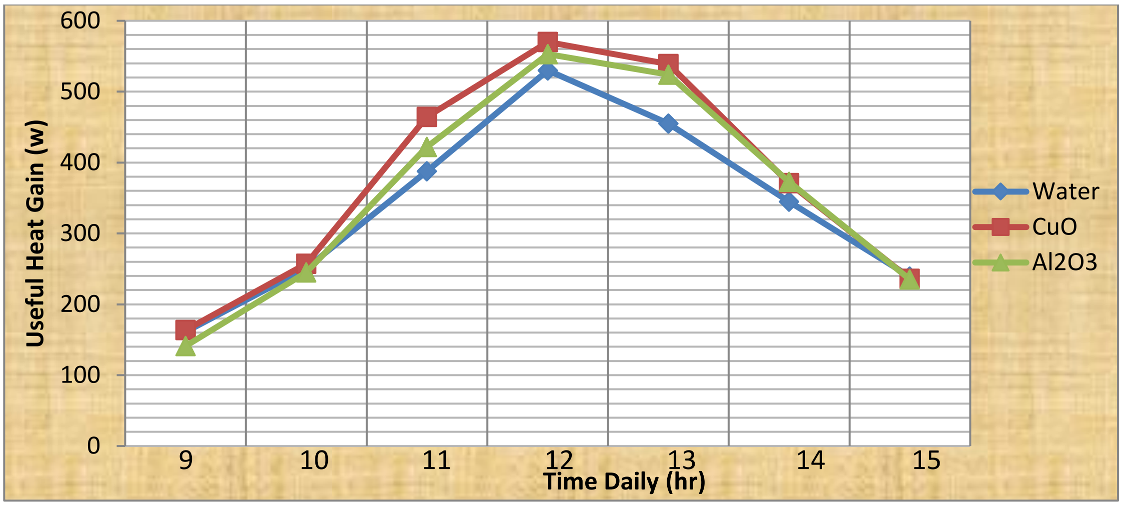

Figure (5) Useful heat gain versus time

6.3 Efficiency versus time

There is a gradual increasing in the efficiency of the solar collector as a result of solar radiation increasing**.** The averages values of efficiencies from the solar collector are 40%, 46.2% and 43.3 for water, water based CuO and water based Al_2O_3 respectively. We note that the efficiency of the solar collector when used water based CuO as a working fluid is more than the water and water based Al_2O_3 by (15.5, 6.7) % respectively**.**

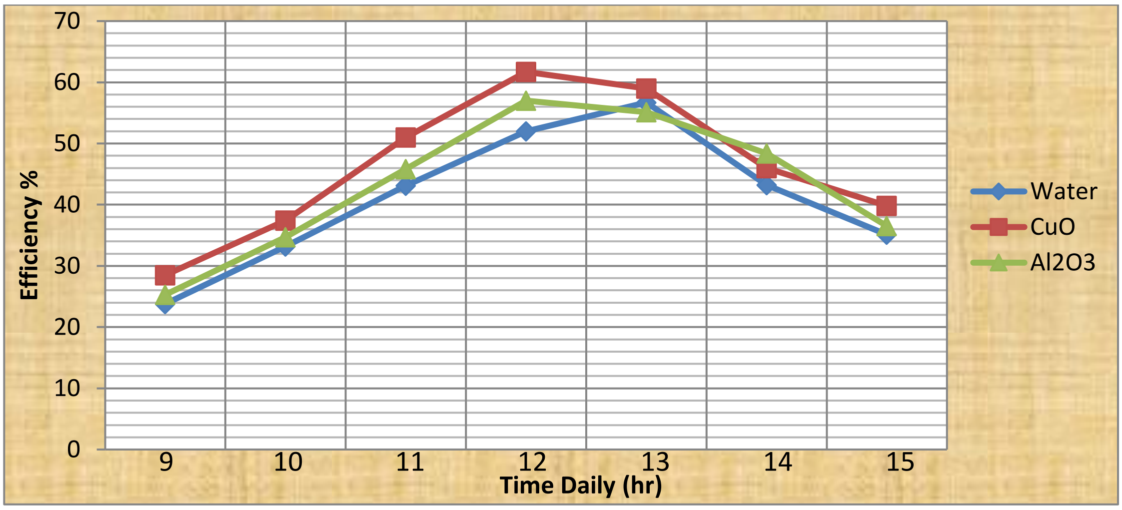

Figure (6) Efficiency versus time

6.4 Comparative between experimental and numerical results

The numerical simulation was taken for four hours only (9am, 11am, 13pm and 15pm), therefore it is results should be compared with the same flow rate and time. There are differences between experimental and numerical results.

The average of numerical output temperature is more than the experimental by (9.6, 12.1, 11)% for water, water based CuO and water based Al_2O_3 respectively.

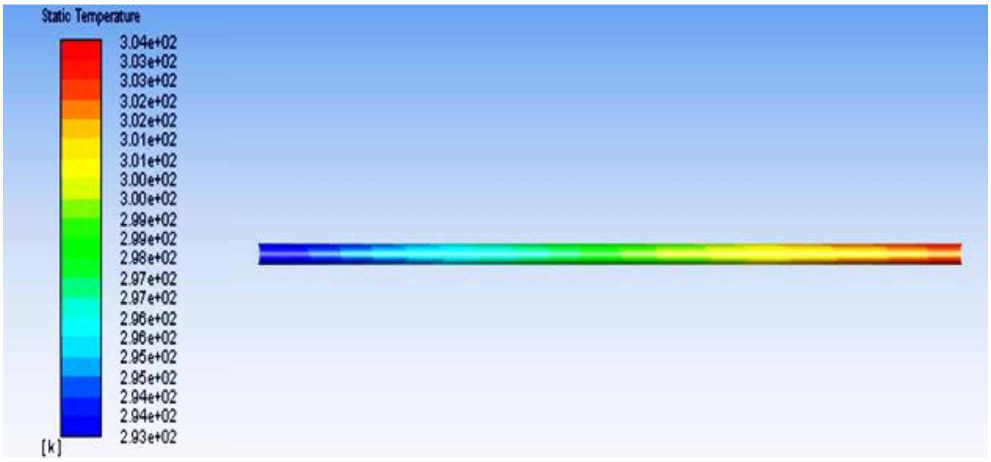

Figure (7) Temperature of water at 9 am

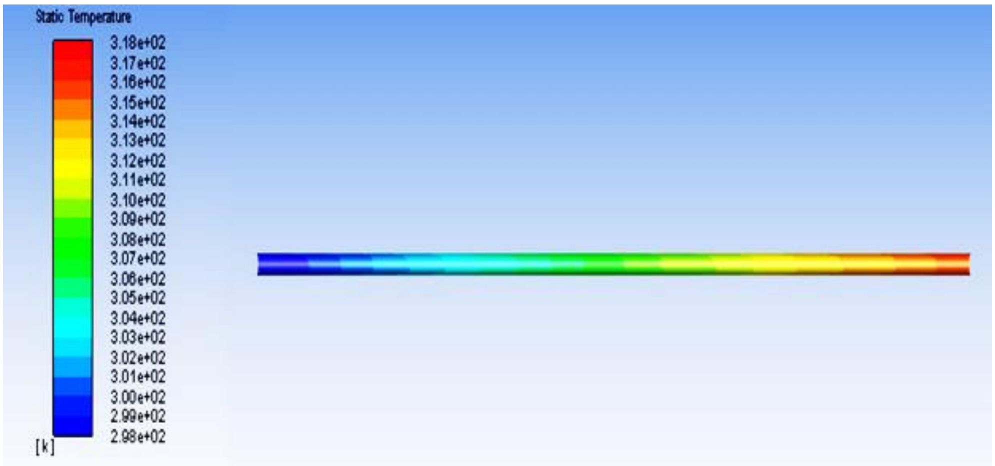

Figure (8) Temperature of water at 11 am

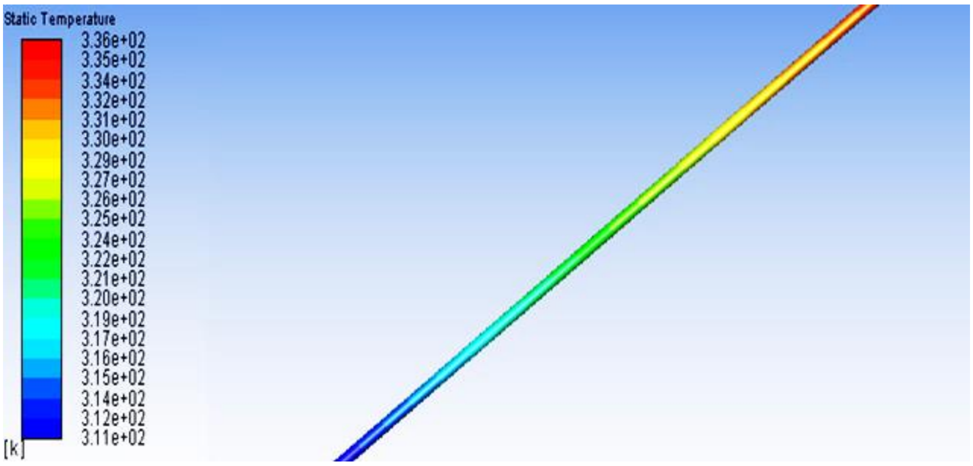

Figure (9) Temperature of water at 13 am

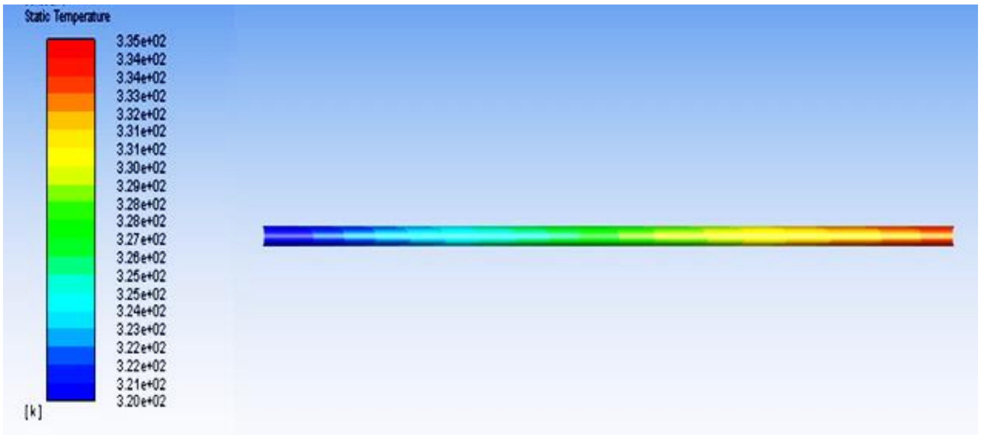

Figure (10) Temperature of water at 15 pm

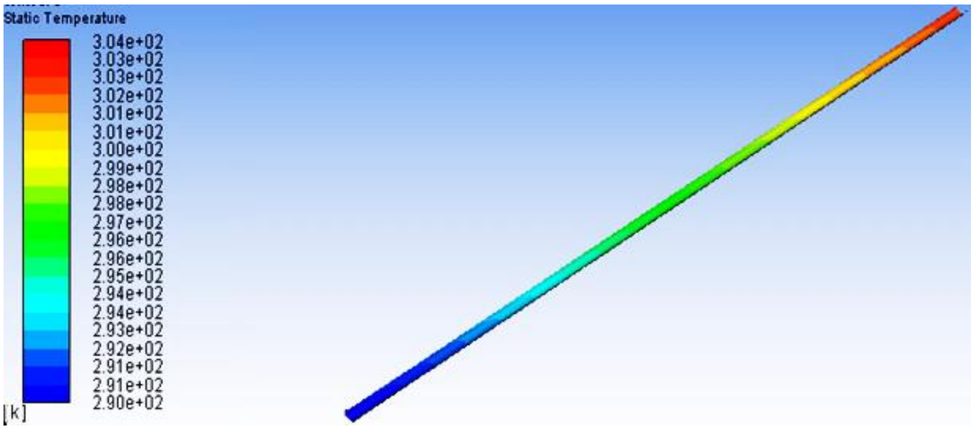

Figure (11) Temperature of water based CuO at 9am

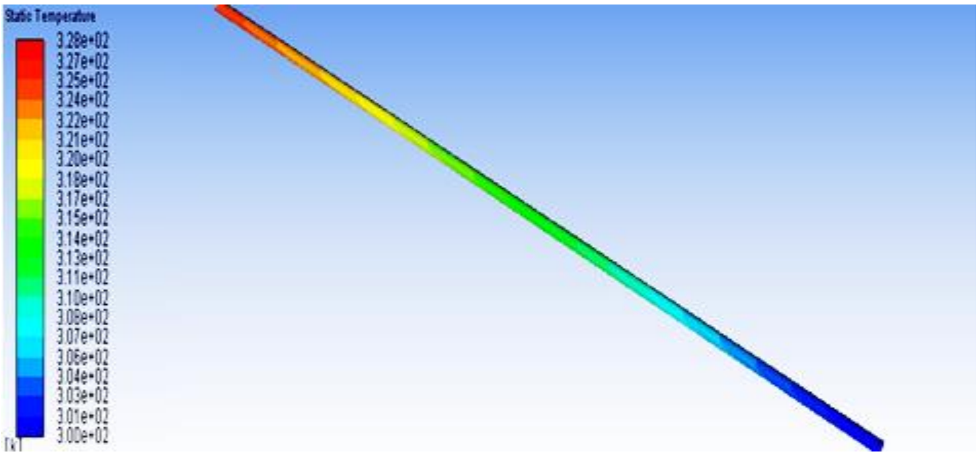

Figure (12) Temperature of water based CuO at 11am

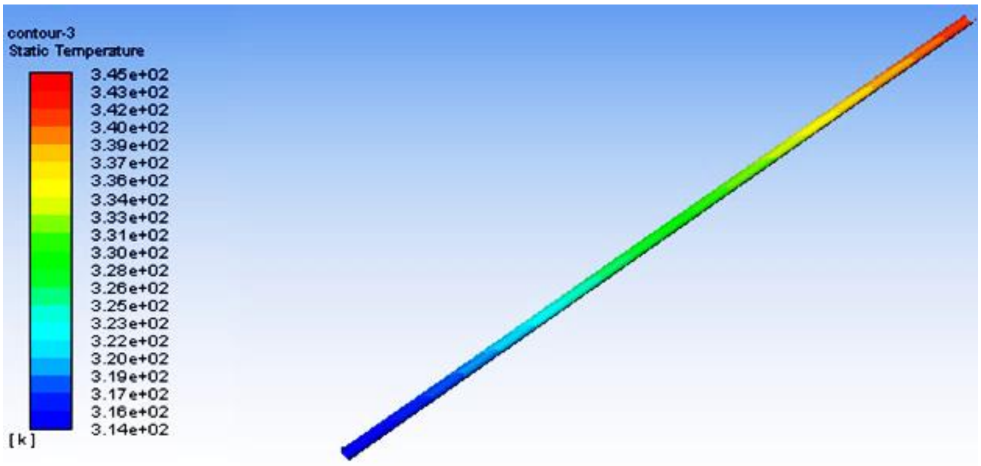

Figure (13) Temperature of water based CuO at 13pm

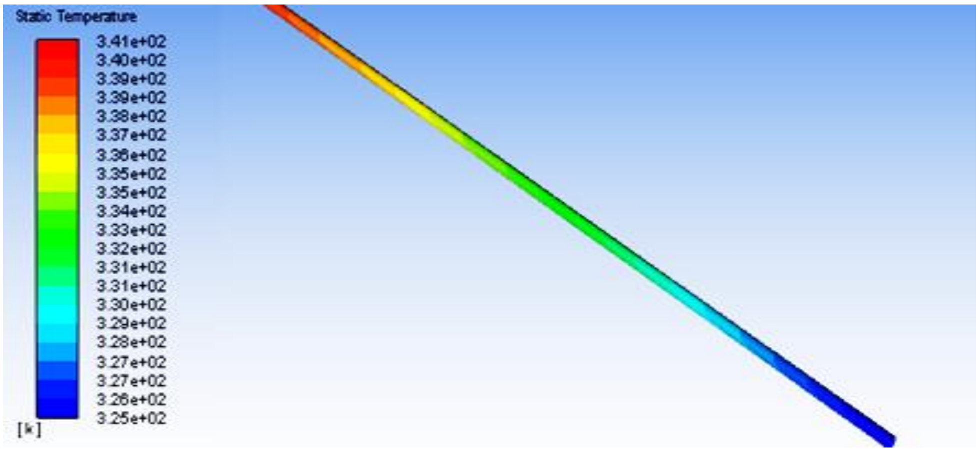

Figure (14) Temperature of water based CuO at 15pm

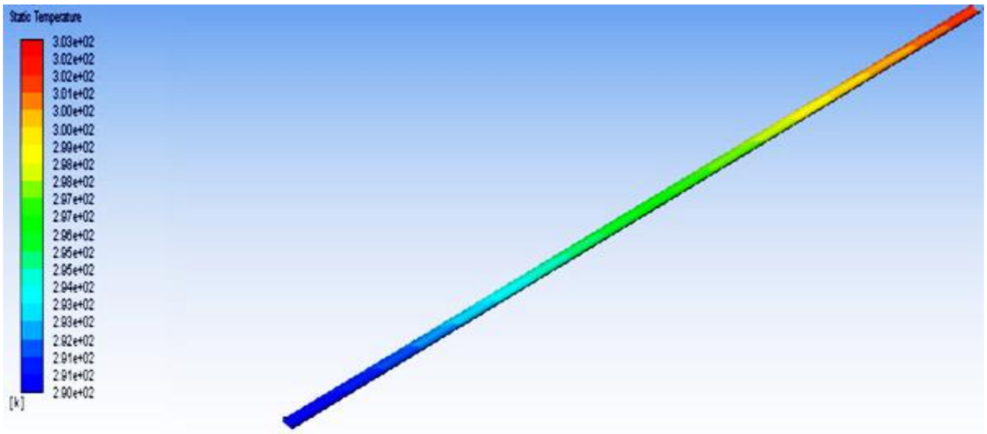

Figure (15) Temperature of water based Al_2O_3 at 9am

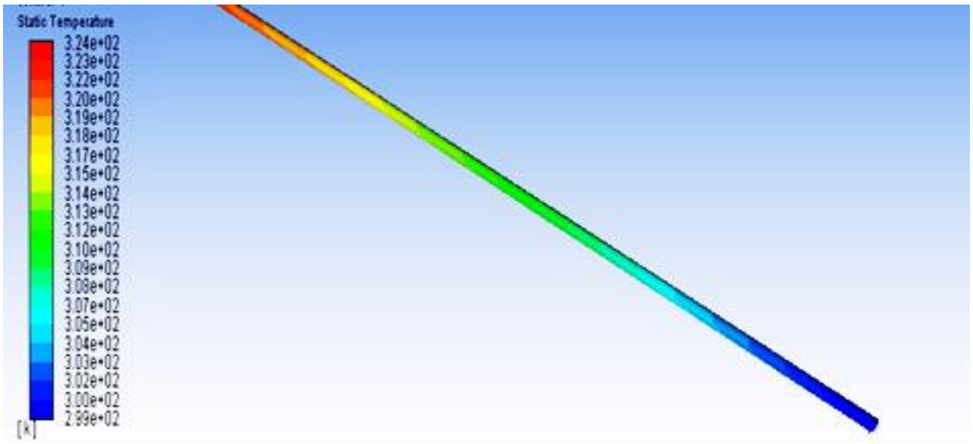

Figure (16) Temperature of water based Al_2O_3 at 11am

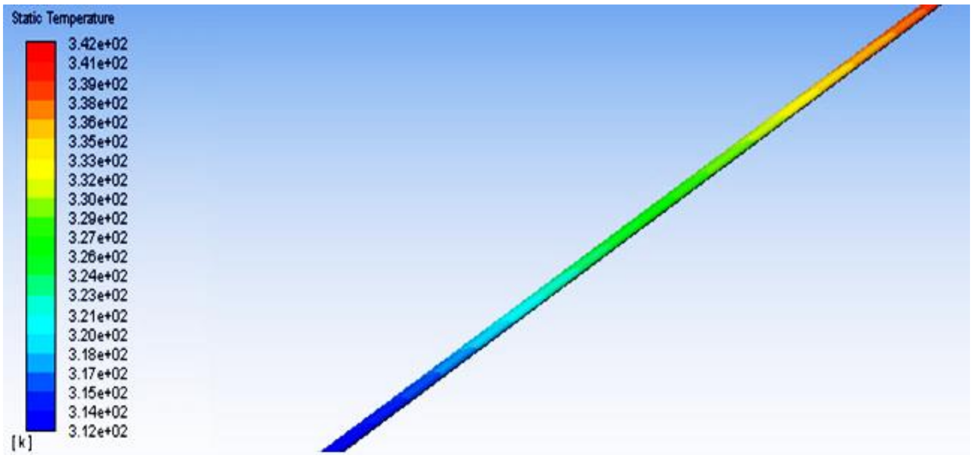

Figure (17) Temperature of water based Al_2O_3 at 13pm

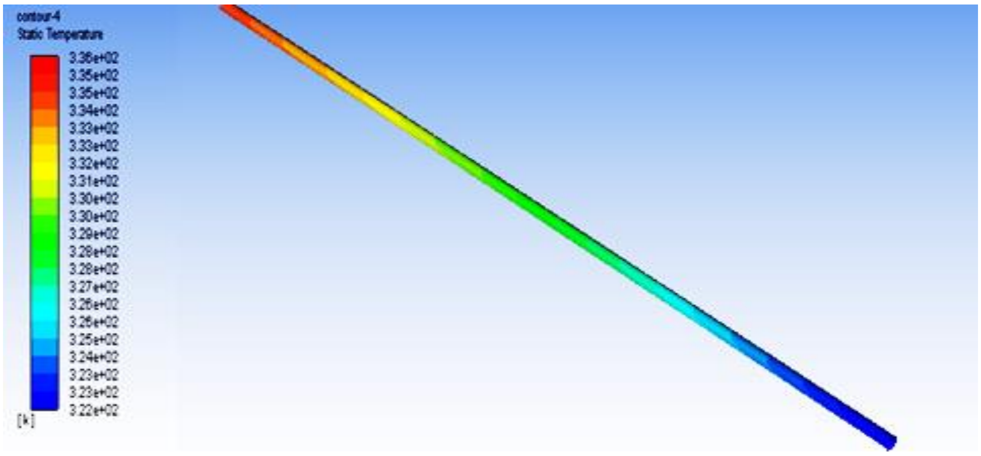

Figure (18) Temperature of water based Al_2O_3 at 15pm

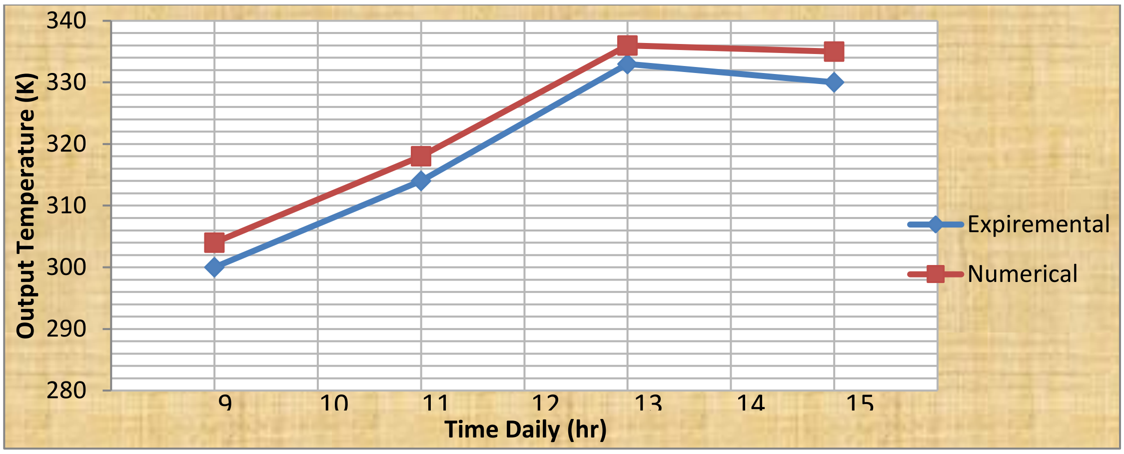

Figure (19) Difference between Experimental and Numerical output temperature for water

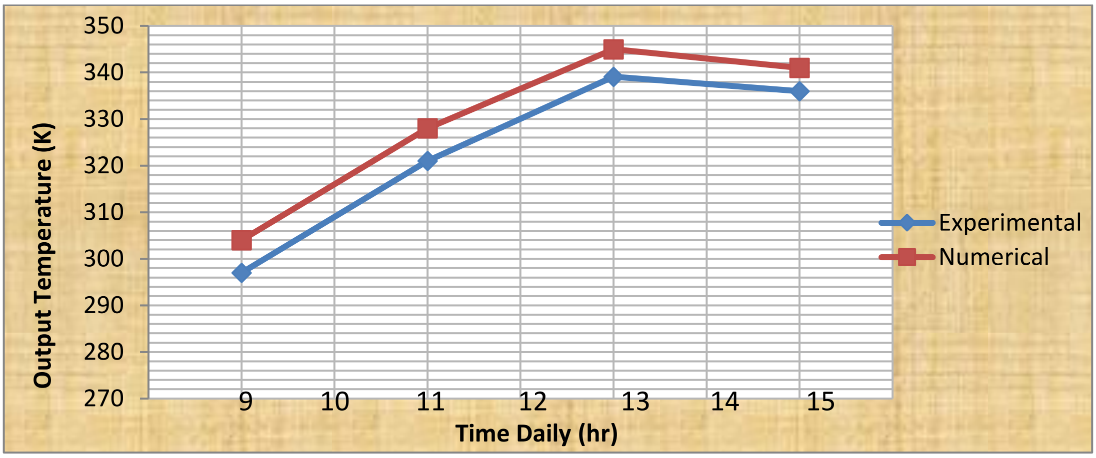

Figure (20) Difference between Experimental and Numerical output temperature for water based CuO

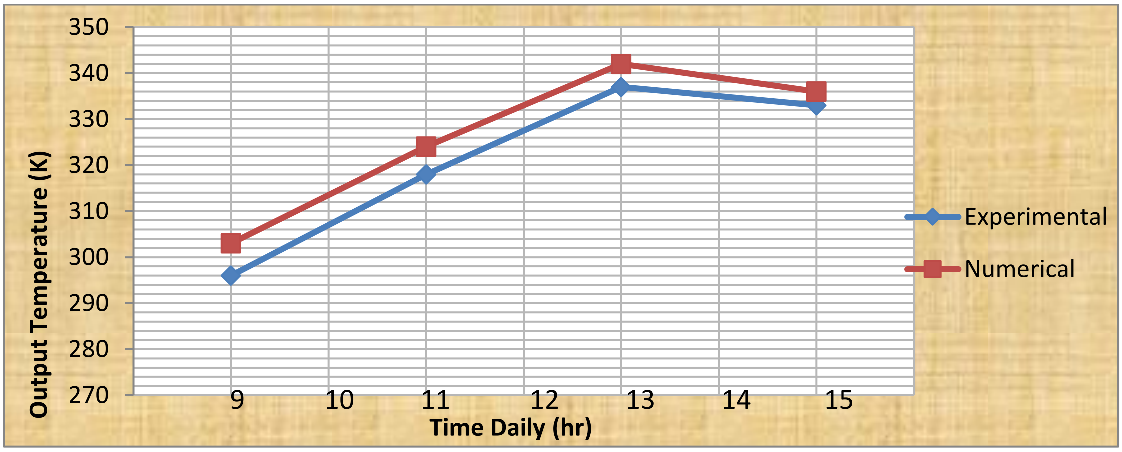

Figure (21) Difference between Experimental and Numerical output temperature for water based Al_2O_3

7. Conclusion

The main goal of this work is to improve the performance of the Parabolic Trough Solar Collector by using water, distilled water based copper oxide CuO and distilled water based Aluminum oxide Al_2O_3 with concentration ratio 0.01% and with mass flow rate 20 Lt/hr without tracking system. The experimental results are shows that:

1- By using water based CuO as a working fluid and compare the results with results of water:

The output temperature is improved by 10.4%, useful heat gain is improved by 11% and the collector efficiency is improved by 15.5%.

2- By using water based Al_2O_3 as a working fluid and compare the results with results of water:

The output temperature is improved by 4%, useful heat gain is improved by 6.5% and the collector efficiency is improved by 8.2%.

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الخلاصة

المركزات الشمسية وسيلة مهمة لأستخدام طاقة الشمس. هنالك عدة انواع من المركزات الشمسية. في العمل الحالي محاولة تجريبية لتحسين الاداء الحراري للجامع الشمسي ذو القطع المكافيء بأستخدام ثلاثة موائع مختلفة (ماء، ماء مقطر مع جزيئات اوكسيد النحاس النانوية، ماء مقطر مع جزيئات الالومينا النانوية) مع نسبة تركيز 0.01 %، وسرعة جريان 20 لتر/ساعة، وبدون استخدام نظام التتبع مع محاكاة رقمية. الاختبار التجريبي تم في مدينة بغداد في قسم الهندسة الكهروميكانيكية في الجامعة التكنولوجية خلال ايام شهر تشرين الاول 2017 خلال وقت النهار (9 صباحا – 15 مساءا). النتائج المحسوبة للموائع الثلاثة كما يلي:

- استخدام (CuO + ماء مقطر) يزيد معدل درجات الحرارة الخارجة بنسبة 10.4% ومعدل المكاسب الحرارية زاد بنسبة 11% ومعدل الكفاءات زاد بنسبة 15.5%.
- استخدام (Al_2O_3 + ماء مقطر) يزيد معدل درجات الحرارة الخارجة بنسبة 4% ومعدل المكاسب الحرارية زاد بنسبة 6.5 % ومعدل الكفاءات زاد بنسبة 8.2%.

هذه النتائج تبين ذلك، استخدام المائع (ماء مقطر + CuO) يعطي أفضل اداء بالمقارنة مع المائعين الاخرين المستخدمين في هذا العمل.

الكلمات المفتاحية: الجامع الشمسي ذو القطع المكافيء، تأثير النانو فلود، الطاقة الشمسية، تحسين كفاءة الجامع الشمسي المقعر ذو القطع المكافيء.