Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879

Efficiency Analysis of TiO_2/Water Nanofluid in Trough Solar Collector

Open Access

Suad Hassan Danook[1], Khamis J. Jassim[1], Adnan M. Hussein[1,*]

[1] Northern Technical University, Kirkuk, Iraq

ARTICLE INFO

Article history:
Received 30 June 2019
Received in revised form 11 November 2019
Accepted 12 November 2019
Available online 15 March 2020

ABSTRACT

The increasing demand for energy nowadays has led a number of researchers to give attention for solar energy topic. In this research, the performance of a parabolic trough solar collector has been studied theoretically and experimentally. The study used water and TiO_2/water nanofluid as working fluid with three values of volumetric flow rate (0.15-0.35-0.25) l/min. The experimental study was performed at Kirkuk city during March, April and May 2018. It was shown that the outlet temperature of the fluid, heat gain, experimental and theoretical efficiency, thermal losses of the solar collector were increased as the solar intensity increased but decreased as the volumetric flow rate increased. It was indicated that the experimental efficiency was less than the theoretical efficiency by 10%. The using of 2% of TiO_2/water nanofluid increased the solar collector efficiency by 9% at the maximum value of volumetric flow rate.

Keywords:
Efficiency; TiO_2 nanofluid; trough solar collector

1. Introduction

Solar energy is one of the main constituents of civilized societies and meets the needs of all social and industrial sectors. It is considered an economic source of energy because it is available and is relatively inexpensive compared to conventional fossil fuel-based energy. A large number of initiatives have been taken by countries around the world to promote scientific research and development activities on solar energy technology. In addition, the pollution caused by the burning of these fossil fuels has led the researchers to begin studying new energy sources. The aim was to exploit solar energy as a renewable and non-polluting energy which is free of pollutants.

Many public applications of solar complexes are heat exchangers where they convert solar energy into thermal energy to take advantage of this energy in life applications. The main part of any solar system is the solar collector, which is a system that absorbs the solar radiation and converts it into heat to use for industrial applications [1].

A new class of heat transfer enhancement is solid nanoparticles dispersed in liquid which defined as a nanofluid [2]. Nanofluid is used in solar collectors to increase the heat transfer of the fluid which consists of solid nanoparticles of metals (Ni, Cu and Ag) or ceramic compounds such as carbide, or

* *Corresponding author*
E-mail address: adnanphd2012@gmail.com (Adnan M. Hussein)

ceramic oxides such as Fe_2O_3 and TiO_2 suspended in water. The nanofluid applications are thermal engineering, improving heat transfer and improving the physical properties of water, and thus improving the efficiency of the solar collector. Cheng *et al.,* [3] conducted an experimental and theoretical study of the effect of the amount of radiation falling on the oil inside the absorber tube of the solar collector with parabola, and concluded that there was a good agreement between these two studies and the error rate between them does not exceed (2%) and the radiation losses do not exceed 153.7 w/m2. Goudarzi *et al.,* [4] conducted an experimental investigation on the simultaneous effects of CuO-H2O nanofluid and receiver helical pipe on the thermal efficiency of a cylindrical solar collector. It was found that using water-based CuO nanofluids could significantly enhance the efficiency compared with pure water, e.g., the maximum thermal efficiency was increased 25.6% with 0.1 wt% nanofluid in 0.0083 kg/s mass flow rate of fluid. Flores and Almanza [5] proposed a bimetallic absorber (copper-steel) which effectively reduced the temperature gradients and the deflections of the absorber. Lei *et al.,* [6-8] tried to decrease the temperature gradients and the absorber tube bending by using high frequency induction heating to band a new borosilicate glass to the Kovar alloy ends. The temperature gradients and thermal stress of the absorber tube can be reduced by the utilization of internal finned tubes [9] and by inserting metal foams in the absorber tube [10]. Bajestan *et al.,* 2016 [11] used nanofluid to improve heat transfer of the fluid in the solar heat exchanger. They discovered innovative ways to enhance heat transfer by using TiO_2/water nanofluid. The results indicated that the performance of the solar heat exchanger increased by (21%) when using titanium oxide as compared to water.

Regarded to the literature survey of these articles that included studying the performance of solar trough collectors, it can be seen the volume concentration of nanofluid used in the collector are not more than 1%.

This paper studied the performance of a parabolic trough solar collector by using water and TiO_2/water nanofluid. The influence of the nanofluid volume concentration more than 1% and the volume flow rate on the performance is indicated. All experimental tests were performed over three months.

2. Methodology

The nanofluid was prepared by mixing the TiO_2 solid nanoparticle powder with water. This method is most commonly used in the preparation of nanofluid [12]. In this method, nanoparticles are suspended in water and the electric mixer is used to prevent the aggregation of nanoparticles and obtain a solution. This method is more economical than the other methods for producing on a large-scale. The nanofluid volume concentrations were prepared with 1% and 2% respectively. Ten litres of water were added to each concentration of nanofluid. The mass of nanoparticles was measured by using a sensitive balance. It was noted that the TiO_2/water nanofluid showed significant stability along all experiments.

2.1 Test Rig Setup and Experiments

The experiment tests were performed on the solar trough collector as shown in Figure 1 during the three months of March, April and May using pure water, nanofluid with mass concentrations (1%, 2%) and three different flow rates (0.15 L / min, 0.25L / min, 0.35L / min). The following steps must be followed before and after the device is turned on: the appropriate place, the building of Kirkuk Technical College, has been selected to fix the solar collector for solar radiation gain; the solar collector including the inverter and the glass covered with the absorbent tube is cleaned. All specifications of solar collector are shown in Table 1.

Table 1
Specifications of solar collector

Focal length	0.25m
Rim angle	90°
Aperture Area	1.85 m^2
Length of parabola	1.88 m
Reflectivity of collector	0.85
Absorptivity of receiver (α)	1
Receiver material	Copper
Outer Diameter of receiver tube	0.0147m
Inner Diameter of receiver tube	0.0127 m

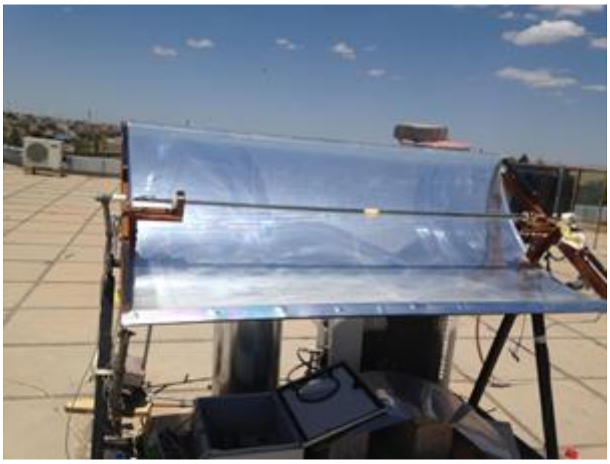


Fig. 1. Parabolic trough solar collector

Thermocouples were fixed and connected to the data logger to measure temperatures. Readings were taken of the temperature and volumetric flow rate as measured by the thermocouples and volumetric flow meter equipment. It took place from 9 a.m. to 3 p.m. and was saved to Microsoft Excel for analysis.

3. Calculations

3.1 Governing Equations

The solar radiation angle can be evaluated by the position of the sun in any area on the Earth's surface and from these angles [10]. Azimuth Angle (δ) and the Altitude Angle (α)

$$\delta = 23.45 \sin\left[\frac{360}{370}\,(ND - 80)\right] \quad (1)$$

$$\alpha = Sin^{-1}[\cos(\delta)\cos(\Phi) + \sin(\delta)\sin(\Phi) \quad (2)$$

The solar radiation falling on the solar collector may be evaluated by [13]

$$I_b = I_{DN} * \cos\theta 1 \quad (3)$$

The angle of fall is calculated from equation [13]

$\cos\theta_1 = \sin\delta \sin\Phi \cos\beta - \sin\delta \cos\Phi \sin\beta \cos\delta + \cos\delta \cos\beta \cos\Phi \cos\omega + \cos\delta \sin\Phi \sin\beta \cos\gamma \cos\omega$
$\cos\delta \sin\beta \sin\delta \sin\delta$ (4)

The energy gained directly from the solar radiation that falling on the parabolic trough to pass through the receiving focus line and calculated from the following equation [13].

$$Qu)_{exp} = m^{o} Cp_{f} (T_{f,i}-T_{f,o}) \quad (5)$$

$$(Qu)_{th} = A_a F_R \left(I_a - \frac{U_l A_{r,int}(T_{fi}-T_a)}{A_a} \right) \quad (6)$$

$$A_a = (w-D_{r,ext})^{*} \quad (7)$$

$$A_{r,ext=} D_{r,ext} \pi L \quad (8)$$

3.2 Efficiency of Collector

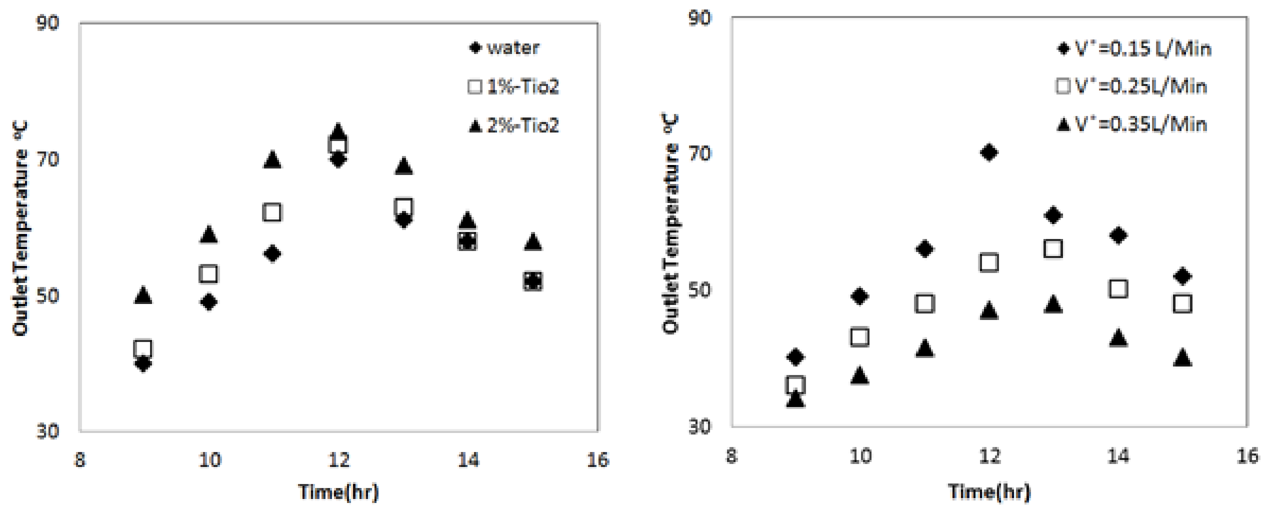
The efficiency of the system can be calculated by dividing the useful energy (acquired) by the fluid of the solar collector by the total radiation intensity falling on the system multiplied by the area of the absorption plate [14,16].

$$\eta_{th} = \frac{(Qu)_{th}}{I_b A_a} \quad (9)$$

$$\eta_{exp} = \frac{(Qu)_{exp}}{I_b A_a} \quad (10)$$

4. Result and Discussion

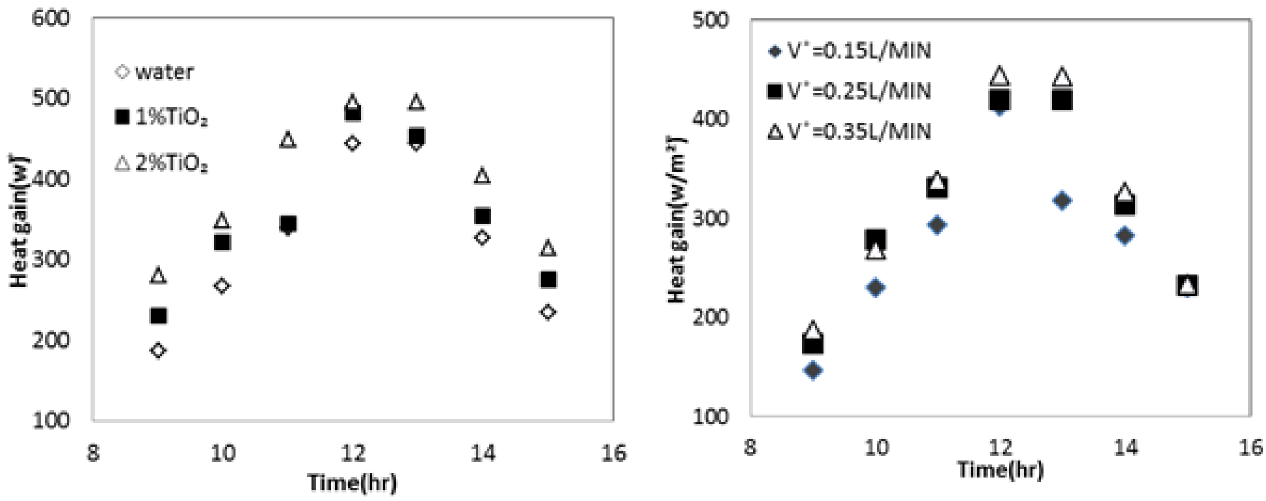
Figure 2 shows the effect of nanofluid volume concentrations and volume flow rate on the outlet temperature form 9a.m to 3p.m on tenth April 2018. It can be seen that the outlet temperature is increasing gradually from 9a.m till the mid-day then decreasing step by step as shown in Figure 2(a). On the other hand, the values of the outlet temperature under minimum flow rate are highest as compared to other outlet temperature under other flow rates. Moreover, the maximum outlet temperature is decreasing from 72°C to 48°C as increase in volume flow rate from 0.15l/min to 0.35l/min respectively. It can be noted that the outlet temperature is increasing gradually from 9a.m till the mid-day then decreasing step by step as shown in Figure 2(b). Furthermore, the values of the outlet temperature when using 2% nanofluid have highest values than 1% nanofluid and water. Likewise, the maximum outlet temperature is 75°C for 2% nanofluid but is 70°C for 1% nanofluid then is 66°C for pure water.



(a) Volume concentration (b) Volume flowrate

Fig. 2. Outlet temperature with time

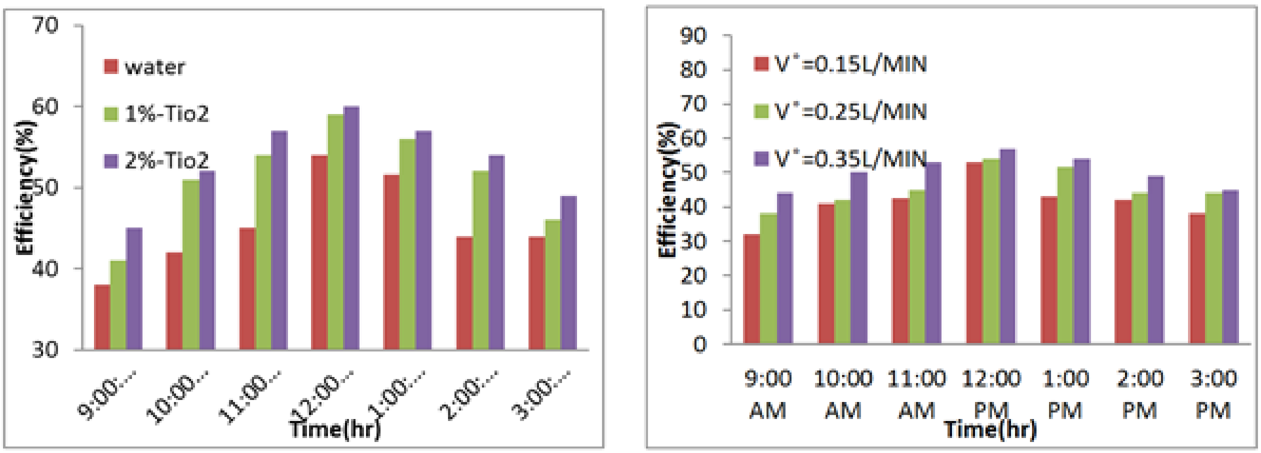
Figure 3 indicates the effect of nanofluid volume concentrations and volume flow rate on the heat gain form 9a.m to 3p.m on tenth April 2018. It was noted that the heat gain is increasing gradually from 9a.m till the mid-day then decreasing step by step as shown in Figure 3(a). Likewise, the values of the heat gain under minimum flow rate are highest as compared to other heat gain under other flow rates. Moreover, the maximum heat gain is decreasing from 443W to 413W as increase in volume flow rate from 0.15l/min to 0.35l/min respectively. It was cleared that the heat gain is increasing gradually from 9a.m till the mid-day then decreasing step by step as shown in Figure 3(b). Furthermore, the values of the heat gain when using 2% nanofluid have highest values than 1% nanofluid and water. Likewise, the maximum heat gain is 510W for 2% nanofluid but is 480W for 1% nanofluid then is 420W for pure water.



(a) Volume concentration (b) Volume flowrate

Fig. 3. Heat gain with time

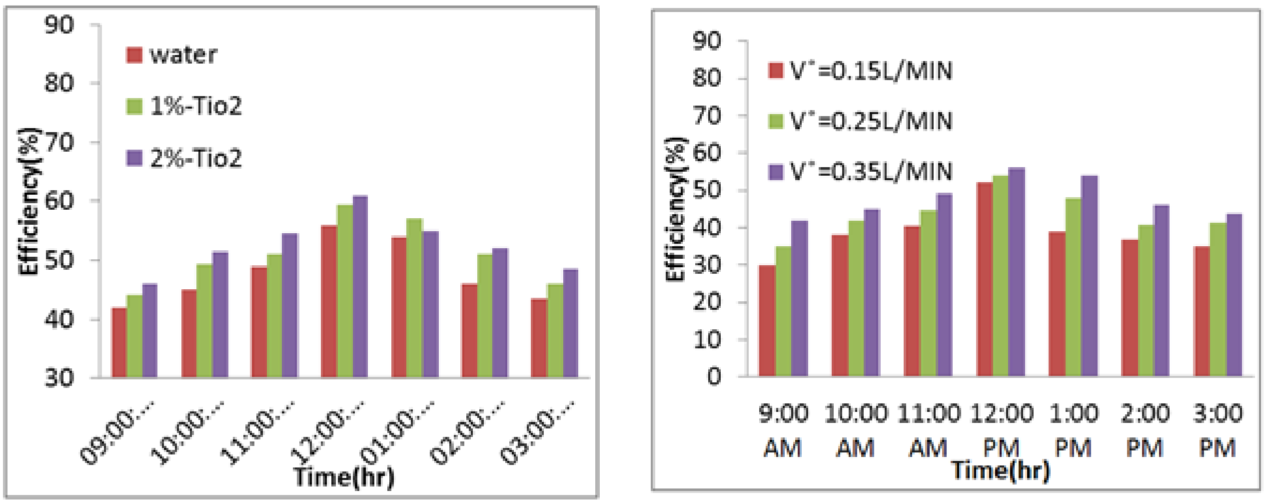
Figure 4 shows the theoretical efficiency changing with nanofluid volume concentrations and volume flow rate form 9a.m to 3p.m on twentieth April 2018. As shown in Figure 4(a) the efficiency is increasing gradually from 9a.m till the mid-day then decreasing step by step. The highest efficiencies values are under minimum flow rate as compared to other values of efficiencies under other flow rates. Likewise, the maximum efficiency is decreasing from 60% to 52% as increase in volume flow rate from 0.15l/min to 0.35l/min respectively. It can be seen that the outlet temperature is increasing gradually from 9a.m till the mid-day then decreasing step by step. Figure 4(b) shows that the values of the efficiencies when using 2% nanofluid have highest values than 1% nanofluid and water.



(a) Volume concentration (b) Volume flowrate

Fig. 4. Theoretical thermal efficiency

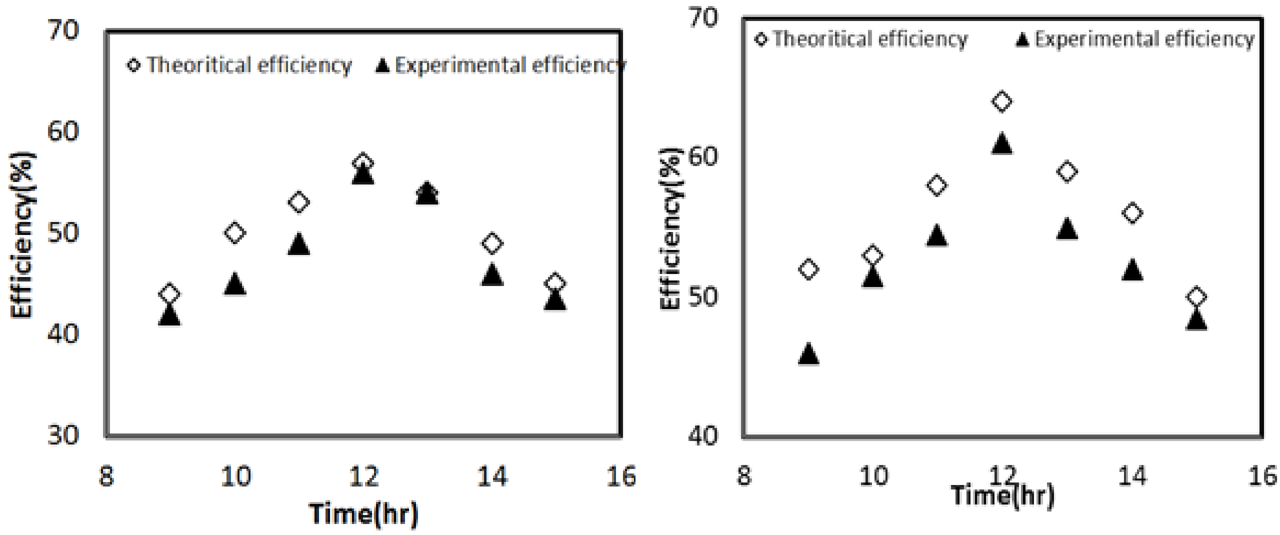
Similar behavior of experimental efficiency appeared in Figure 5 and the effect of nanofluid volume concentrations and volume flow rate shown from 9a.m to 3p.m on tenth April 2018. The highest values of efficiency are under minimum flow rate as compared to other values of efficiencies under other flow rates. Figure 5(a) illustrates the maximum efficiency that decreasing from 57% to 49% as increase in volume flow rate from 0.15l/min to 0.35l/min respectively. It can be noted that the outlet temperature is increasing gradually from 9a.m till the mid-day then decreasing step by step. Figure 5(b) shows that the values of the efficiencies when using 2% nanofluid have highest values than 1% nanofluid and water.



(a) Volume concentration (b) Volume flowrate

Fig. 5. Theoretical thermal efficiency of the solar collector with daylight hours

Figure 6 indicates that both the theoretical and experimental efficiency against the time along day. It was observed that the theoretical efficiency values are largest as compared to the experimental efficiency for nanofluids and pure water. The deviation among them is not more than 15% for both pure water and nanofluids. The reason is the perfect assumptions and conditions of the theoretical calculation and the errors that generated from experimental tests.



(a) Pure water (b) TiO_2/Water nanofluid

Fig. 6. Theoretical and experimental efficiency of the solar collector

4.1 Comparison of Results with Other Researchers

The experimental efficiency of the solar collector, ranging from 42 to 56%, was achieved by using water as the operating fluid. This is an approach to the results of Hamad *et al.,* [15] where its practical efficiency ranged from (42-58%). This compatibility of the two studies is in good agreement as show in Figure 7.

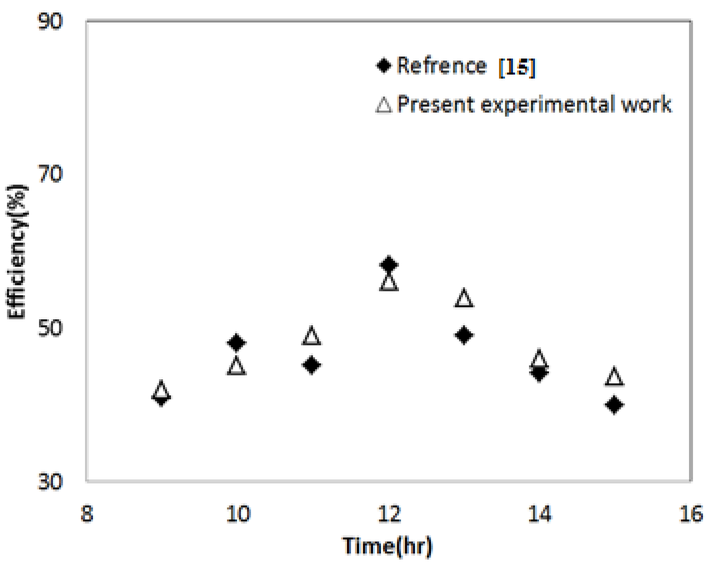


Fig. 7. Comparison between the present experimental efficiency and Hamad *et al.,* [15]

5. Conclusions

The fluid temperature outside the solar collector is directly proportional to the intensity of the solar radiation and the volume of the volumetric flow at daylight hours up to midday. The value of heat energy gained and heat losses is directly proportional to the intensity of solar radiation and volumetric flow rate during daylight hours up to midday Addition of TiO_2 / water to the solar collector improves its efficiency by 9% using 2% of the nanofluid and 6% when using 1% of the same fluid at the highest volumetric flow. The highest error ratio between theoretical and practical efficiency does not exceed (10%). The value of the heat transfer coefficient is proportional to the volumetric flow rate of the fluid and thermal efficiency.

Acknowledgement
The help and support of authors by Northern technical university is great appreciation.

References

[1] Faizal, M., Rahman Saidur, Saad Mekhilef, A. Hepbasli, and I. M. Mahbubul. "Energy, economic, and environmental analysis of a flat-plate solar collector operated with SiO 2 nanofluid." *Clean Technologies and Environmental Policy* 17, no. 6 (2015): 1457-1473.
[2] Ahmed, Hamdi E., Mirghani Ishak Ahmed, and Mohd Zamri Yusoff. "Heat transfer enhancement in a triangular duct using compound nanofluids and turbulators." *Applied Thermal Engineering* 91 (2015): 191-201.
[3] Cheng, Z. D., Y. L. He, Jie Xiao, Y. B. Tao, and R. J. Xu. "Three-dimensional numerical study of heat transfer characteristics in the receiver tube of parabolic trough solar collector." *International Communications in Heat and Mass Transfer* 37, no. 7 (2010): 782-787.
[4] Goudarzi, K., E. Shojaeizadeh, and F. Nejati. "An experimental investigation on the simultaneous effect of CuO–H2O nanofluid and receiver helical pipe on the thermal efficiency of a cylindrical solar collector." *Applied Thermal Engineering* 73, no. 1 (2014): 1236-1243.
[5] Flores, Vicente, and Rafael Almanza. "Behavior of the compound wall copper–steel receiver with stratified two-phase flow regimen in transient states when solar irradiance is arriving on one side of receiver." *Solar Energy* 76, no. 1-3 (2004): 195-198.
[6] Lei, Dongqiang, Zhifeng Wang, and Jian Li. "The calculation and analysis of glass-to-metal sealing stress in solar absorber tube." *Renewable Energy* 35, no. 2 (2010): 405-411.
[7] Lei, Dongqiang, Zhifeng Wang, and Jian Li. "The analysis of residual stress in glass-to-metal seals for solar receiver tube." *Materials & Design* 31, no. 4 (2010): 1813-1820.
[8] Lei, Dongqiang, Zhifeng Wang, Jian Li, Jianbin Li, and Zhijian Wang. "Experimental study of glass to metal seals for parabolic trough receivers." *Renewable Energy* 48 (2012): 85-91.
[9] Muñoz, Javier, and Alberto Abánades. "Analysis of internal helically finned tubes for parabolic trough design by CFD tools." *Applied energy* 88, no. 11 (2011): 4139-4149.
[10] Wang, Pusci, D. Y. Liu, and C. Xu. "Numerical study of heat transfer enhancement in the receiver tube of direct steam generation with parabolic trough by inserting metal foams." *Applied energy* 102 (2013): 449-460.
[11] Ebrahimnia-Bajestan, Ehsan, Mohammad Charjouei Moghadam, Hamid Niazmand, Weerapun Daungthongsuk, and Somchai Wongwises. "Experimental and numerical investigation of nanofluids heat transfer characteristics for application in solar heat exchangers." *International Journal of Heat and Mass Transfer* 92 (2016): 1041-1052.
[12] Hussein, Adnan M., Rosli Abu BAKAR, Kumaran Kadirgama, and Karada Viswanatha Sharma. "HEAT TRANSFER ENHANCEMENT WITH ELLIPTICAL TUBE UNDER TURBULENT FLOW TiO2-WATER NANOFLUID." *Thermal Science* 20, no. 1 (2016).
[13] Garg, H. P. *Solar energy: fundamentals and applications*. Tata McGraw-Hill Education, 2000.
[14] Holman, J. P. "Heat transfer tenth edition." (2010).
[15] Hamad, Faik Abdul Wahab. "The performance of a cylindrical parabolic solar concentrator." *Solar Energy* 5, no. 2 (1987): 1-19.
[16] Hashim, Ghasaq Adheed, and NA Che Sidik. "Numerical study of harvesting solar energy from small-scale asphalt solar collector." *Journal of Advanced Research Design* 2, no. 1 (2014): 10-19.