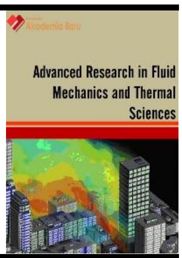
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

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



The Impact of Alumina Nanoparticles Suspended in Water Flowing in a Flat Solar Collector

Open Access

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ARTICLE INFO

Article history:
Received 1 April 2019
Received in revised form 15 May 2019
Accepted 15 May 2019
Available online 26 January 2020

Keywords:
Nusselt number; friction factor; nanofluid; solar collector

ABSTRACT

In this paper, convective heat transfer of Al_2O_3–water nanofluid flow in straight channel is numerically and experimentally studied over Reynolds number ranges of 100–1800. The Al_2O_3–water nanofluid with different volume fractions of 1%, 2% and 3% were prepared and examined. All physical properties of nanofluid which are required to evaluate the flow and thermal characteristics have been measured. In the numerical aspect of the current work, the simulation results showed that there was a good agreement with the experimental data for the friction factor and the Nusselt number. And The experimental results showed that the friction factor decreased with increasing velocity due to the low strength of cohesion between the particles with increasing velocity and increase with the increase in volume fractions due to the increase viscosity of the nanofluid and the coefficient of heat transfer also increases with the increase of the volume fractions and the flow rate. The experimental results were compared with previous experimental data and there were good agreements between the results. It can be concluded that adding 3% solid nanoparticles to water improves heat transfer by (54%) with a slight increase in friction factor can be neglected.

1. Introduction

The energy consumption demand is increasing continuously. The resources of conventional energy are still limited that may be failed to cover the requirement of energy growing population and improving the industrial activities for ever [1]. The energy performance efficiency systems have been major issue for engineers and scientists. The absorbing solar radiation for water heating was applied in flat plate solar collectors [2-3]. The low thermal conversion efficiency exhibited by conventional solar water collectors, for heat transferring and absorbing medium have led the investigators to find new concept of thermal transportability capacity and absorption. Tyagi *et al.,* [4] were concluded 10% of efficiency enhancement for direct absorbing solar collector on absolute basis compare to flat plate solar collector with utilizing alumina nanofluid. Choi [5] is the first one introduced the new materials as nanofluids that have great potential to augment thermal transportation capacity and

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absorption. Then many researchers have employed nanofluid applications as thermal absorbing media and transferring for cooling and heating systems. Theoretical, computational and experimental studies of investigators are very highly promising. Natrajan and Sathish [6] were investigated performance of carbon nanotube nanoparticles suspended in water for solar heating system and concluded that nanofluid based solar collector were more efficient compare to conventional fluid. The maximum efficiency augmentation of direct absorption solar collector was reported by Otanicar *et al.,* [7]. It was observed that the using of 0.5% volume concentration of silver/water nanofluid with (20–40 nm) enhance efficiency by 5%.
Kameya and Hanamura [8] were investigated the influence of nanoparticles solid of Nickel suspended in water to absorber heat. The coefficient of absorption found is more than that of water in range of solar radiation at 4.9 nm particle size and 1%. Yousefi *et al.,* [9] was performed an experimental study of flat plate solar collector thermal efficiency by using alumina water nanofluid at size 15 nm, 0.25%, and 2 LPM volume flow rate with 28.3% enhancement. The influence of pH variation on solar collector efficiency of carbon nanotube/water in flat plate solar collector was reported by Yosefi *et al.,* [10,11]. It was observed the pH variation value below or above the isoelectric point causes enhancement of efficiency. 4.34% entropy generation reduction and 15.33% heat transfer enhancement when solar water based CNT nanofluid was utilized by Said *et al.,* [12] theoretically. Zamzamian *et al.,* [13] were conducted an experimental study for copper nanoparticles with ethylene glycol with size diameter of 10 nm over efficiency enhancement of flat plate solar collector. It was reported that achieve optimum results of findings reveal that 0.3% and 1.5 LPM flow rate. The universal mass production techniques lack and high cost of the solid nanoparticles application in a flat plate collector for heating systems is led to study the alumina nanofluids as working fluid in this solar application [14].

In this paper, the alumina nanoparticles suspended in water are used as working fluid in the flat plate solar collector experimentally. The volume fractions of nanofluid are 1%, 2% and 3% and the volume flow rates are from 10 to 110 LPM under laminar flow condition.

2. Methodology

2.1 Nanofluid Preparation

The nanoparticle of Al_2O_3 is dispersed in water as a base fluid to prepare nanofluid. The preparation of nanofluid for the study undertaken includes three different volume fractions (1%, 2% and 3%) that estimated by using Eq. (1). This is the most widely used method in the preparation of nanofluid. The electrical mixer is used to induce particles and prevent aggregation. The photographs of samples have taken as shown in Figure 1. The amount of water is 10 liters added to nanoparticles to prepare the nanofluid concentrations.

(a) (b) (c)

Fig. 1. Samples of nanofluid (a) after preparation, (b) after 2 hours and (c) after 4 hours

The most significant technique used to improve the stability of nanoparticles in water is the measurement of properties before using of samples and repeat it after tests then comparison among them [14]. Figure 1 shows a sample of nanofluid with different volume fractions, and it was noted that the nanofluid (Al_2O_3/water) that was prepared in the current study was stable during all experiments, additionally; it was observed the photographs of samples along 4 hours to check stability. There was no surfactant added to nanofluid due to prevent some influence on the nanoparticles physical properties [15].

$$\varphi = \frac{\left[\frac{m_p}{\rho_p}\right]}{\left[\frac{m_p}{\rho_p}+\frac{m_f}{\rho_f}\right]} \quad (1)$$

The pH meter is used to know a preliminary sedimentation of the nanofluids formulated, it was found that the nanoparticles were significant suspended in water. Table 1 shows the thermophysical properties of Al_2O_3/water nanofluid formulated pertinent to this study contained the specific heat Cp_{nf}, the density ρ_{nf}, the dynamic viscosity μ_{nf} and the thermal conductivity k_{nf} that adopted [16].

$$cp_{nf} = cp_p(\varphi) + (1-\varphi)\, cp_{bf} \quad (2)$$

$$\rho_{nf} = \rho_p(\varphi) + \rho_{bf}(1-\varphi) \quad (3)$$

$$k_{static} = k_f\left[\frac{(k_{np}+2k_f)-2\emptyset(k_f-k_{np})}{(k_{np}+2k_f)+\emptyset(k_f-k_{np})}\right] \quad (4)$$

$$\frac{\mu_{nf}}{\mu_f} = \frac{1}{1-34.87\left(\frac{d_p}{d_f}\right)^{-0.3}\varphi^{1.03}} \quad (5)$$

Table 1
Thermophysical properties of nanofluid and water

Volume Fractions, φ	Specific heat ($\frac{J}{kg.K}$)	Density ($\frac{kg}{m^3}$)	Viscosity ($\frac{kg.s}{m}$)	Thermal conductivity ($\frac{W}{m.K}$)
0%	4181	1000	0.001008	0.6
1%	4146.84	1026	0.0011	0.6279
2%	4112.68	1052	0.001108	0.6458
3%	4078.52	1078	0.00111	0.6641

2.2 Experimental Setup

Figure 2 shows the test rig setup used in this study. Initially with the lowest flow rate, the data is obtained in a steady state. The flow rate then increases slightly, allowing the system to return to a stable state. The system takes 15-20 minutes to reach steady state to fix the input temperature as an inlet temperature. Then increasing flow rate gradually for five steps and taking reading as temperature and inlet, outlet and surface. This procedure is repeated to ensure the reading exactly. All of these procedures are repeated with changing the volume concentrations of nanofluids.

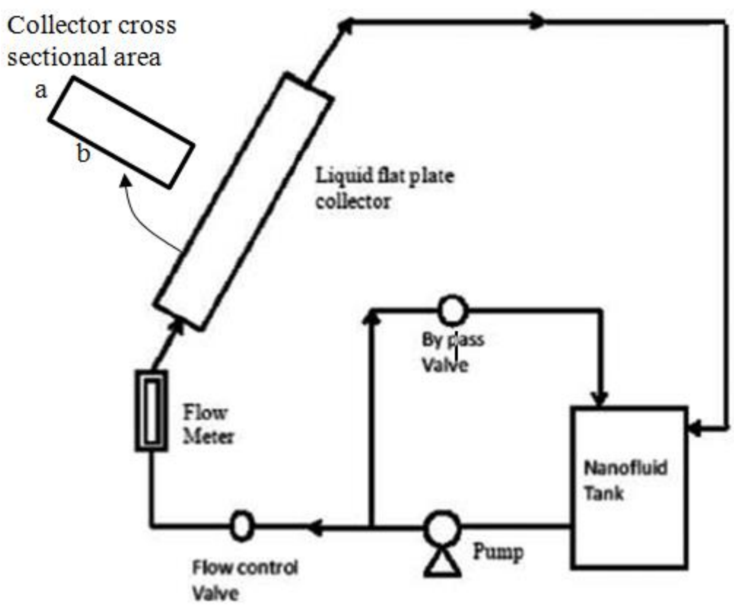


Fig. 2. Schematic of the experimental setup

2.3 Experimental Procedure

The setup of experimental test includes the test section, thermocouples, flow meter, manometer and pump. A 0.5 pump with horse power has been used to pump the working fluid from tank of 10 liters capacity to the test section. Calibration has been conducted for thermocouples as shown in Figure 3.

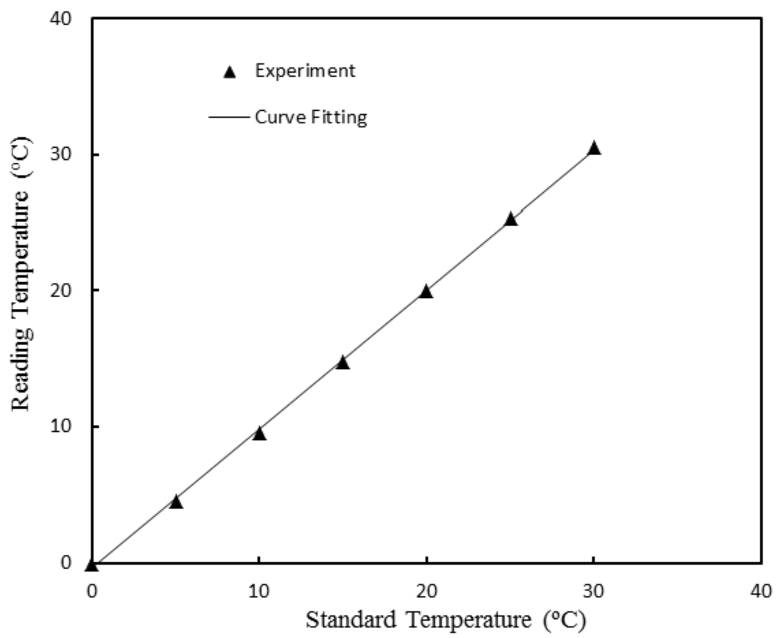


Fig. 3. Calibration data of thermocouples

The power from solar radiation is heated the top wall of the test section, and the bottom walls was insulated. Insulation layers of fiber-glass (with 5 cm thick) have been fixed around the test section to prevent heat loses. A flow meter has been fixed between the inlet of the developing section and the pump to measure the fluid flow rate. A U-tube manometer was connected at the test section outlet and inlet for pressure drop measuring along collector. Five thermocouples type T have been fixed at the outlet, inlet and along the test section for measuring temperatures. It can be noted that the thermocouples temperature agrees with that standard temperature from the mercury thermometer with deference of error is approximately 1%.

2.4 Governing Equations

The non-dimensional governing equations of laminar flow, steady state, two-dimensional, non-compressible, homogeneous mixture of nanoparticles and based fluid are [19]

Continuity equation

$$\frac{\partial U}{\partial X} + \frac{\partial U}{\partial Y} = 0 \tag{6}$$

Momentum equation

$$\left(U\frac{\partial U}{\partial X} + V\frac{\partial V}{\partial Y}\right) = -\frac{dp}{dx} + \frac{1}{Re}\left(\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2}\right) \tag{7}$$

$$\left(U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y}\right) = -\frac{dp}{dx} + \frac{1}{Re}\left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\right) \tag{8}$$

Energy equation

$$\left(U\frac{\partial \theta}{\partial X} + V\frac{\partial \theta}{\partial Y}\right) = \frac{1}{Re\,Pr}\left(\frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2}\right) \tag{9}$$

2.5 Data Reduction

The receiving heat by the nanofluids from solar radiation on the flat plate collector can be evaluated as [17]

$$Qc = cp_{nf}\,\rho_{nf}\,UA(T_{out} - T_{in}) \tag{10}$$

It can be expressed the average coefficient of heat transfer as follows [17].

$$h_{nf}(exp) = \frac{cp_{nf}\,\rho_{nf}\,U\,A(T_{out} - T_{in})}{\pi\,a\,L\,(T_s - T_b)} \tag{11}$$

Nusselt number may be estimated as follows [17].

$$Nu_{nf}\,(\mathrm{exp}) = \frac{h_{nf}\,(\mathrm{exp})\,D_h}{k_{nf}} \tag{12}$$

where D_h is the straight channel hydraulic diameter which can be defined as [18]

$$D_h = \frac{2a\,b}{a+b} \tag{13}$$

The frication factor (f) can be expressed as [18]

$$f = \frac{\frac{2\,\Delta p}{\frac{L}{D}\cdot\rho.U^2}}{4} \tag{14}$$

The heat transfer coefficient or Nusselt number represents heat transfer to a system can be evaluated by using Shah-London equation under laminar flow condition [16].

$$Nu_{av} = 1.953\,(Re_{D_h}\,pr\,\frac{D}{L})^{1/3} \tag{15}$$

The angle of solar radiation can be evaluated depending on 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)

$$\delta = 23.45\sin\left[\frac{360}{370}\,(ND - 80)\right] \tag{16}$$

$$\alpha = Sin^{-1}[\cos(\delta)\cos(\Phi) + \sin(\delta)\sin(\Phi) \tag{17}$$

The solar radiation falling on the solar collector may be evaluated by [11]

$$I_b = I_{DN*}COS\theta 1 \tag{18}$$

The angle of fall is calculated from equation [11].

$$\cos\theta_{1=}\ \sin\delta\sin\Phi\cos\beta - \sin\delta\cos\Phi\sin\beta\cos\delta + \cos\delta\cos\beta\cos\Phi\cos\omega + \cos\delta\sin\Phi\sin\beta\cos\gamma\cos\omega\cos\delta\sin\beta\sin\delta\sin\delta \tag{19}$$

The energy gained directly from the solar radiation can be estimated by the following equation [11].

$$Qu)_{exp} = m^{o}\,Cp_{f}\,(T_{f,i}-T_{f,o}) \tag{20}$$

$$(Qu)_{th} = A_a\,F_R\left(\ I_a - \frac{U_l A_{r,int}(T_{fi}-T_a)}{A_a}\right) \tag{21}$$

$$A_{a=}\ (W-D_{r,ext})*L \tag{22}$$

$$A_{r,ext=}\ D_{r,ext}\ \pi\ L \tag{23}$$

The efficiency of the system can be evaluated as:

$$\eta_{th} = \frac{(Qu)_{th}}{I_b\,A_a} \tag{24}$$

$$\eta_{exp} = \frac{(Qu)_{exp}}{I_b\,A_a} \tag{25}$$

3. Uncertainty Analysis

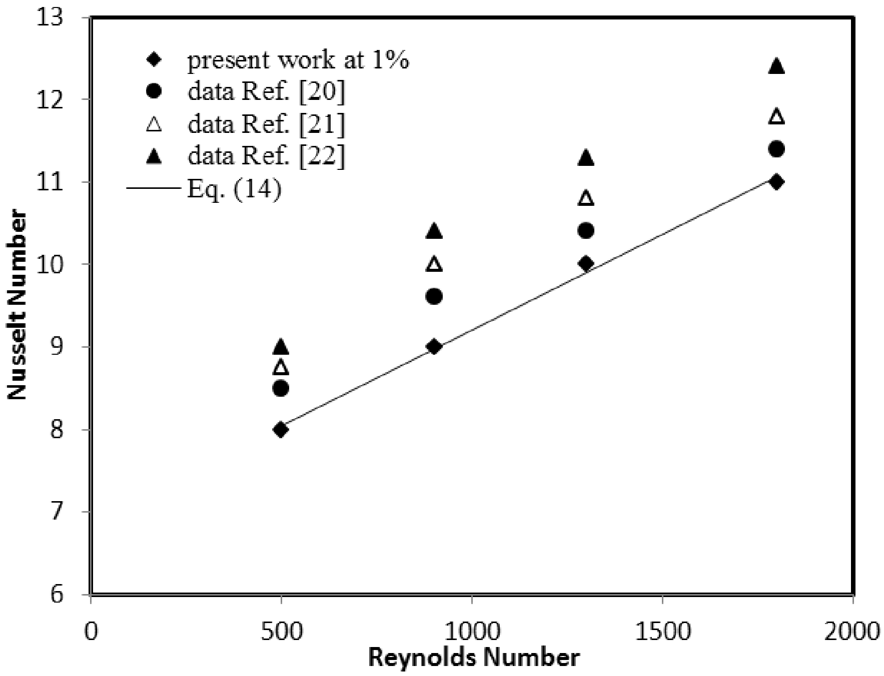
A complete thermocouples system calibration has been conducted. Along temperature measurement tests the value ±0.1°C is estimated to represent the uncertainty of the temperature reading [2]. The fluid manometer is a mechanical device to measure the pressure under laboratory and steady state conditions. A U-tube manometer employed Mercury (Hg) with a specific gravity (S) of 13.6 for the manometer fluid. The pressure drop uncertainty through the collector is calculated to be $U_h = \pm 0.001$ m. The volume flowrate is estimated depending the flowmeter reading and the uncertainty associated found as $U_{\dot{m}} = \pm 0.5$ Kg/s. Nusselt number is estimated and the uncertainty associated is found as $U_{Nu} = \pm 0.22$. Reynolds number (Re) through the collector is estimated and the uncertainty associated is found as $U_{Re} = \pm 3.456$.

4. Results

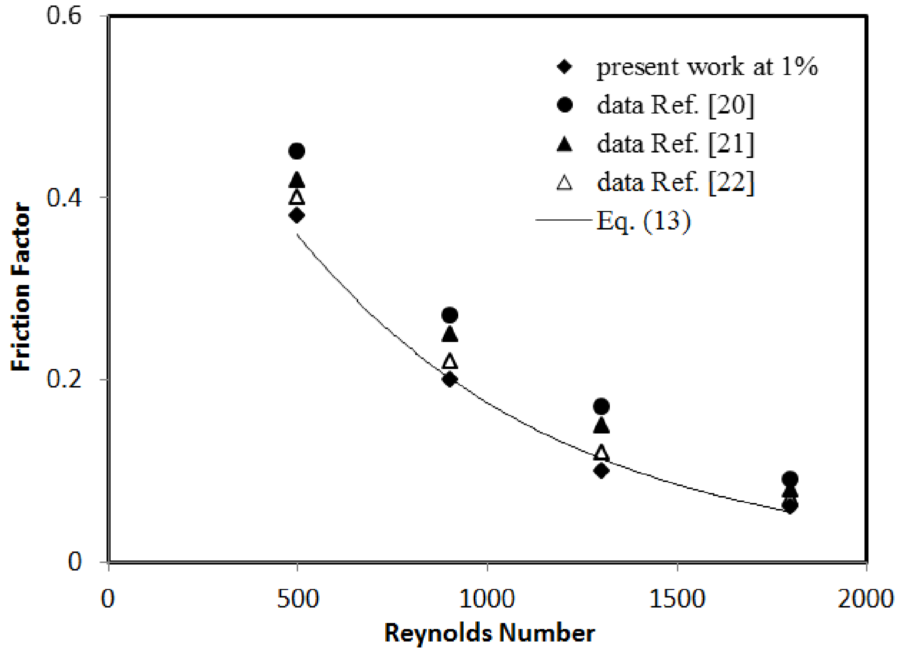
4.1 Validation

In order to verify the accuracy of the results of experimental results, Nusselt number, friction factor were compared with the theoretical results of the previous research. The average Nusselt number for the laminar flow of nanofluid through the solar collector was calculated and compared with the researchers' data [20-22]. The results showed that Nusselt number is increased with increase of Reynolds number as shown in Figure 4(a).

The friction factor results under laminar flow condition are compared to other researchers [20-22] as shown in Figure 4(b). It was shown that the friction factor decreases with increasing of Reynolds number, while increasing with increasing of nanofluid volume fractions.



(a)



(b)

Fig. 4. Validation of (a) Nusselt number and (b) friction factor

4.2 Heat Transfer

Figure 5 shows the relation between Nusselt number and Reynolds number of nanofluid with a different velocity of (5.1-18 mm/s) and nanoparticles diameter (30 nm). It was observed that Nusselt number is increasing as increase in Reynolds number and nanofluid volume concentrations. Distilled water (fai = 0%) has the lowest Nusselt number due to low thermal conductivity of distilled water. It can be clearly showed the heat transfer enhance by 12% for 3% nanofluid volume concentration as compared to water as base fluid. The enhancement percentage of heat transfer under taken is agreed to the data of previous researcher [23].

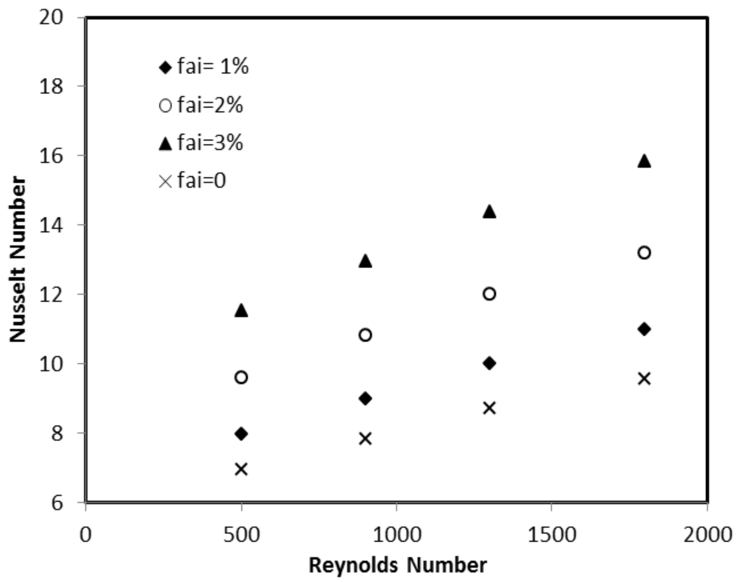


Fig. 5. Experimental results of Nusselt number

Figure 6 shows the friction factor at different velocity ranges from (5.1 - 18 mm/s) and nanofluid volume concentrations from 1% to 3%. It was indicated that the friction factor decreases with the increase of volume flowrate. It can be noted that the friction factor increases with the increase in the nanofluid volume concentrations due to increase of viscosity resistance. These results are agreed to data of [24].

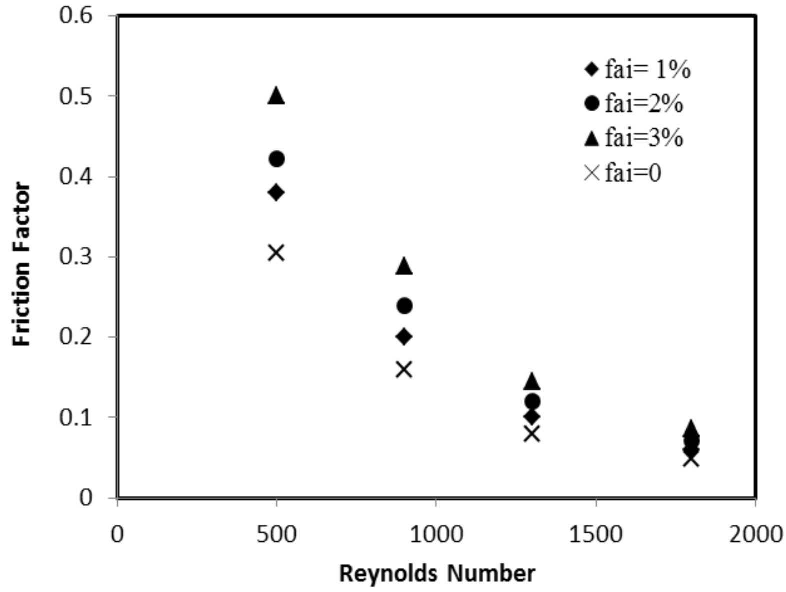


Fig. 6. Experimental results of friction factor

4.3 Thermal Efficiency

Figure 7 indicates the inlet, outlet and ambient temperatures through the flat solar collector using Al2O3/water nanofluid. It was noted that temperatures are increased along the day hours for 1% nanofluid volume concentrations. It was noted that the maximum temperature measured at the noon (12.00 o'clock) when using 1% alumina nanofluid and environment.

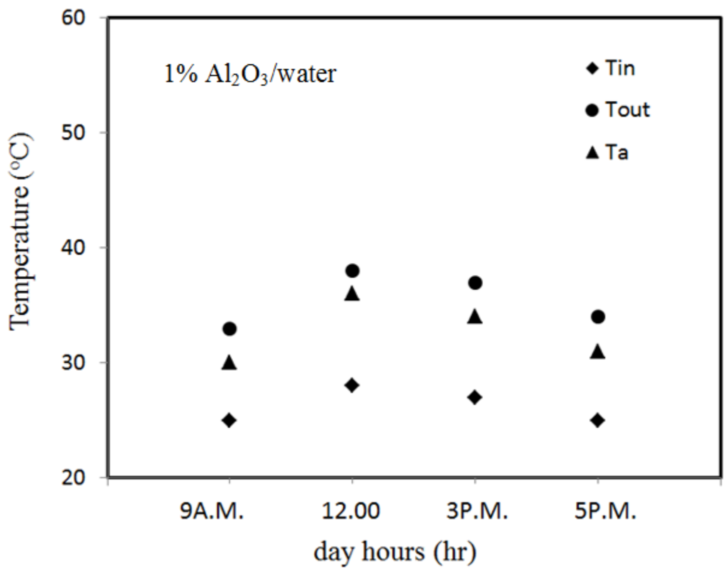


Fig. 7. Temperature at inlet, outlet and ambient along the day hours (21/May/2017)

Figure 8 illustrates the solar collector heat gain along the day hours. It can be noted that the maximum heat gain happened at the noon (12.00 o'clock). The heat gain is increased with increasing of the nanofluid volume concentrations. The reason is the maximum solar intensity applied on the solar collector.

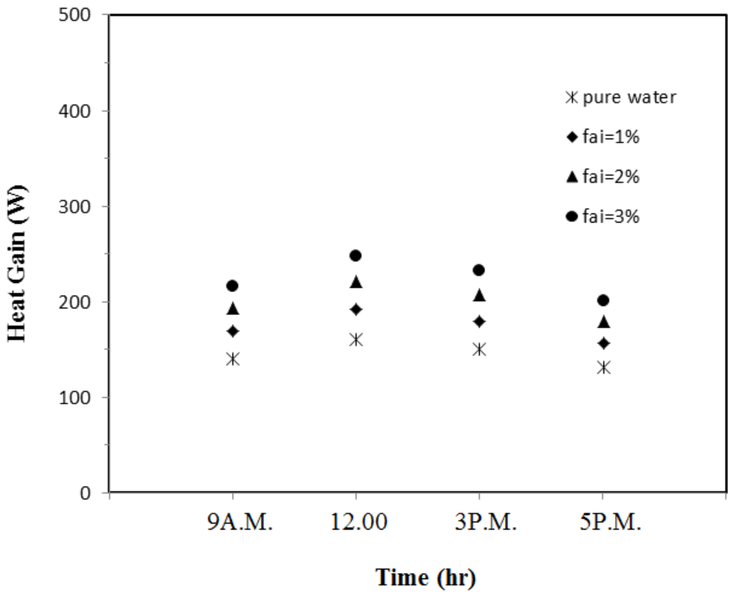


Fig. 8. Solar collector heat gain along the day hours (21/May/2017)

Figure 9 shows the effect of nanofluid volume concentrations on solar collector efficiency. It can be seen that the efficiency increases as the nanofluid volume concentrations increase from 33% to 50 as compared to the base fluid. The increase of nanofluid volume concentrations is led to increase the absorption capability that enhance the heat transfer and heat gain then increase of thermal efficiency. when particle agglomeration starts at higher concentration, slowed down of Brownian motion among water and solid nanoparticles, that causes to convection heat transfer reduction between water and solid nanoparticles [25].

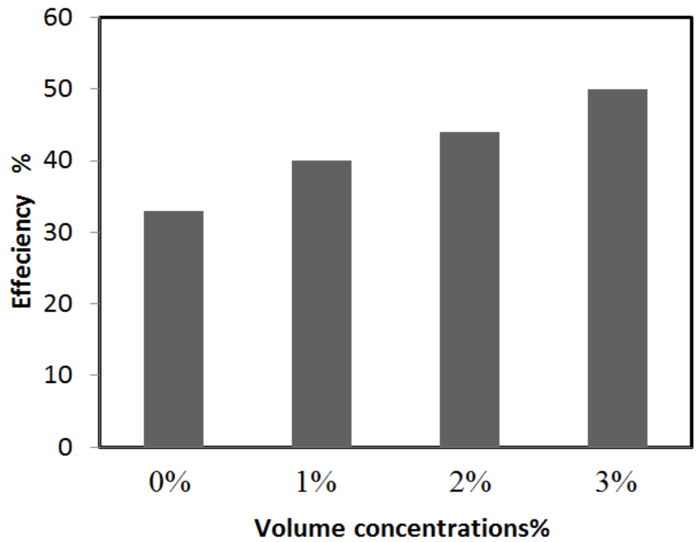


Fig. 9. The effect of nanofluid volume concentrations on solar collector efficiency

5. Conclusions

Nanotechnology allows the production of nanoparticles suspension of these particles in liquids create a new type of fluid heat transfer. Nanofluid has a significant role in thermal engineering. This article provides an overview of recent developments in the study of solar collector and heat transfer with using of nanostructures. Nanofluids contain small amounts of nanoparticles that have much higher thermal conductivity than the base fluid. The enhanced thermal conductivity of nanofluid depends on the volume concentrations and the type of nanoparticles. The outstanding nanoparticles increase the heat transfer performance of conventional fluid. The coefficient of friction factor decreases with the increase of Reynolds number and increases with the increase of nanoparticles concentrations, while the heat transfer coefficient increases with increasing of Reynolds number and nanofluid volume concentrations. The heat transfer enhancement is observed with increasing of nanofluid volume concentrations and volume flow rates. The heat gain of solar collector is increased with increasing of nanofluid volume concentration and at the noon. The overall efficiency of the solar system is assessed with and without nanofluid. The use of different concentrations of nanofluid is significant of the solar collector efficiency.

Acknowledgement
The help and support of authors by Northern Technical University is great acknowledged.

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