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Enhanced Heat Transfer Performance of a Flat Plate Solar Collector using CuO/water and TiO_2/water Nanofluids

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Abstract

This project focuses on evaluating the heat transfer performance of a flat plate solar collector (FPSC) with a spiral tube arrangement using TiO_2/water and CuO/water nanofluids as working fluids instead of the base fluid (water). The FPSC performance was evaluated based on the effect of the fluid type with constant fluid flow rate (1.5 lit/min) and constant nanoparticles (0.1 %) volume concentration of the nanofluids on the temperature difference between the inlet and outlet fluid streams and the FPSC thermal efficiency. The results showed that the CuO/water nanofluid as a working fluid in the FPSC exhibited higher heat transfer performance compared to TiO_2/water nanofluid as well as the base fluid (water) due to the higher thermal conductivity of CuO nanoparticles. The inlet-outlet temperature difference at 1.5 lit/min flow rate for water, CuO/water and TiO_2/water nanofluids were 6.6 °C, 7.1 °C, and 7.9 °C, respectively. Furthermore, the maximum efficiency was reported to be 55% for the CuO/water nanofluid compared to 54% and 50% for 0.1 % by vol. TiO_2/water and water, respectively. Finally, based on the raw experimental data, the empirical correlations (Nusselt number as a function of Reynolds number and Prantal number) for the base fluid (water), CuO/water nanofluid, and TiO_2/water nanofluid were obtained utilizing Statistica software.

Keywords: Renewable energy, Flat plate solar collector, Nanofluid, CuO/Water and TiO_2 /Water Nanofluids, Solar thermal energy, Water heating systems.

INTRODUCTION

The coupled challenges of the fast developments in a world population, which are doubling the world's energy needs and increasing demands for clean energy sources resulted in increased attention worldwide to the possibilities of utilizing renewable sources as a long-term solution for a secure energy future [1-4]. Compared to fossil fuels, the solar energy as one of the most available renewable energy sources is an environmentally clean source of energy and it is a very suitable energy source for solar water heating applications, which is considered the most effective approach for utilizing the solar heat [1]. Hence, in the recent years, there is a great potential in utilizing the solar energy due to the problems associated with the depletion of fossil fuels as well as the environmental concerns such as global warming and air pollution

The solar collectors are considered a special type of heat exchangers that are absorb the incoming solar radiation and convert it into heat, which is transferred to a fluid such as air, water, oil, and ethylene glycol flows through the collector [3]. The major applications of these units are solar water-heating systems in homes, solar space heating, air-conditioning, and some others industrial processes [3]. Among various types of the solar collectors, the flat-plate solar collector (FPSC) is commonly used today for the collection of low temperature solar thermal energy. Although the FPSC is simple, cheap, and most productive collector, it comparatively suffers from the low efficiency. Hence, it is very important to find new, effective, and convenient approaches to enhance the efficiency of FPSC. One of the most efficient approaches is to replace the base fluid (water) with a higher thermal conductivity fluid containing solid nanoparticles known as nanofluids [1-4].

Several experimental and numerical studies investigated the prospects of improving the efficiency of flat plate solar collectors using nanofluids. The survey focuses on the experimental and theoretical studies in which CuO/water and TiO_2/water nanofluids were used. The nanofluid term was first coined by Choi [5] which is defined as a suspension formed by mixing metallic or nonmetallic nanoparticles with a base fluid. The enhanced thermo-physical properties such a liquid thermal conductivity, liquid viscosity, and heat transfer coefficient are the unique characteristics of nanofluids. It is well known that liquids have lower thermal conductivities than metals in solid phase [6]. Ravindra Kolhe et al. (2013) [7] investigated experimentally the effect of adding the aluminum oxide (Al_2O_3) and copper oxide (CuO) nanoparticles (35-50 nm in diameter) to the base fluid (water) on the thermal efficiency of flat plate solar collector. The concentration of the nanofluids was varied between 0.3 to 0.9 %wt. In general, the nanofluids showed better thermal efficiency than water; the thermal efficiency of FPSC increases as the concentration increases for both Al_2O_3 and CuO. Moreover, they concluded that the optimal inclination angle of FPSC would be close from 50 degrees. In another experimental study, Chaji et al. 2013 [8] introduced TiO_2 nanoparticles to the base fluid (water) and evaluated the efficiency of a small flat plate solar collector. The results revealed that there is an enhancement in the efficiency of 15.7% was observed of the TiO_2/water nanofluid compared to pure water. Furthermore. Jamal et al. (2013) [9] the 0.05 and 0.1 wt% Cu/water nanofluids were synthesized by a one-step method and used as a working fluids in a flat plate solar collector. It was reported that the Cu/water nanofluid with nanoparticles weight concentration of 0.05% enhances the collector efficiency by 24% compared to the base fluid (water).

In 2014, Ali Jabari Moghadam et al. [10] investigated the heat transfer performance of CuO/water nanofluids as a working fluid in a flat plate solar collector. The average diameter of CuO nanoparticles was about 40 nm. The mass flow rate of the fluids was varied within the range of (1-3 kg/min) and the nanoparticles volume concentration was fixed at 0.4%. At a flow rate of 1 kg min, the results showed that found that the CuO-water nanofluid enhances the collector efficiency by about 21.8% in comparison with the base fluid. The heat transfer enhancement was attributed to the enhanced thermo-physical properties of the nanofluids compared to the base fluid. In another study [11], a cylindrical solar collector with receiver helical pipe was designed and manufactured to investigate its thermal efficiency using distilled water and CuO/H_2O nanofluid as working fluids based on ASHRAE standard in collector testing. In this study, the collector efficiency was evaluated based the mass flow rate of fluid, nanoparticle mass concentration, and the effect of adding surfactant. The sodium dodecyl sulfonate (SDS) was used as a surfactant. The nanoparticles mass concentration was varied within the range of (0.1-0.4%) and the mass flow rate of fluid changed from 0.0083 to 0.033 kg/s. Compared to the base fluid (water), the results showed that CuO/water nanofluids significantly enhanced the efficiency. At a flow rate of 0.0083 kg/s, the CuO/water nanofluid with a nanoparticles concentration of 0.1 wt% exhibited an increase in the thermal efficiency by 25.6%. In addition, using the surfactant (SDS) with the nanofluid enhances the collector efficiency by 24.2% in comparison with the case without surfactant

Z. Said et al. (2015) [1] presented an experimental study of the heat transfer enhancement of a flat plate solar collector using Titanium dioxide nanofluid and polyethylene glycol dispersant compared to the base fluid (water). The nanofluids were prepared with nanoparticles volume fractions of 0.1% and 0.3% with the mass flow rates of the nanofluid varied from 0.5 to 1.5 kg/min, respectively. The results showed an increase of 76.6% in energy efficiency for 0.1% volume fraction and 0.5 kg/min flow rate, while the nanofluid of 0.1% volume fraction and 0.5 kg/min flow rate gives exergy efficiency of 16.9%. Moreover, the results revealed that the pressure drop and pumping power of TiO_2 nanofluid was very close to the base fluid for the studied volume fractions. In the same year, Michael and Iniyan et al. [12] carried out an experimental study to investigate the effect of using copper oxide/water nanofluid as the working fluid on the performance of a FPSC under natural and forced circulations. The natural circulation (thermosyphon) shows a higher enhancement of the collector performance compared to the forced circulation. Compared to the base fluid, the CuO/water nanofluid enhances the collector efficiency by 6.3%. Recently, Sujit Kumar Verma et al. (2017) [13], conducted an experimental investigation of a wide spectrum of nanofluids for studying the performance of flat plate solar collector based on different parameters and their effects on energy and exergy efficiency. The nanofluids with a particle volume concentration of 0.75% and a mass flow rate of 0.025 kg/s were considered as optimal parameters to evaluate the thermal performance of FPSC. Compared to the base fluid (water), the multivalued carbon nanotube/water exhibited the highest rise in energy efficiency of a collector that is 23.47%, followed by 16.97%, 12.64%, 8.28%, 5.09% and 4.08%, respectively for graphene/water, Copper oxide/water, Aluminum oxide/water, Titanium oxide /water, and Silicon oxide/water instead of water as the base fluid.

Several numerical studies [14,15,17,18] were also carried out to evaluate the effect of nanofluids on the performance of the FPSC. Rehena Nasrin et al. (2014) [14] performed a numerical study to the forced convective flow and heat transfer of a flat plate solar collector using different nanofluids. The solar collector has the flat-plate cover and sinusoidal wavy absorber. They used different nanofluids, which are Ag/water, Cu/water, Al_2O_3/water and CuO/water nanofluid. It was found that the best heat transfer performance was obtained with 5% solid volume fraction of Ag/water nanofluids since the Ag nanoparticles have higher thermal conductivity than other fluids as justified by the authors. Another numerical investigation of heat transfer performance of various nanofluids flow inside a flat plate solar collector was performed by E. Ekramian et al. (2014) [15]. In this study, the heat transfer coefficients and thermal efficiency of the FPSC using the base fluid (water) as well as the suggested nanofluids (Multi Wall Carbon Nano-Tube MWCNT/water, Al_2O_3/water, and CuO/water nanofluids with mass percent of 1, 2, and 3%) were predicted numerically. It was found that there is a good agreement between the numerical predictions and the experimental data. The CuO/water nanofluid exhibits higher heat transfer coefficient and thermal efficiency compared to other working fluids. It should be noted that this finding contracted that the experimental results by Sujit Kumar Verma et al. (2017) [13], in which the MWCNT/water exhibited better performance than graphene/water, Copper oxide/water, Aluminum oxide/water, Titanium oxide /water, and Silicon oxide/water instead of water as the base fluid.

Wail Sami et al. (2015) [16] presented previous studies related to the use of the nanofluid as working fluids instead of the base fluids and evaluate their performance in flat-plate solar collectors. Based on the review, the authors concluded the following: (1) the performance of the flat plate solar collectors effectively enhanced using the nanofluids, (2) the highest collector efficiency was reached using the nanofluids based on carbon nanostructures, (3) at high temperature, the surfactant stability in the nanofluids requires more in depth investigation, and (4) the cost, viscosity, stability, and pumping power are the main challenges facing the nanofluid technology. Recently, Nang Khin Chaw Sint. et al. (2017) [17] analyzed the efficiency of a flat plate solar collector using CuO/water nanofluid as a working fluid. The collector efficiency for a domestic solar water heating system was calculated using MATLAB software. The weather conditions of a city in Myanmar was considered in this study. The results showed that the nanoparticles volume concentration up to 2% enhances the collector efficiency, while a marginal effect of the nanoparticle size on the efficiency was observed. As a summary, the CuO/water nanofluid exhibited better collector efficiency with the nanoparticles concentration up to 5% compared with that of water under the same ambient, radiant, and operating conditions. More recently, Maouassia A. et al. (2017) [18] illustrated a numerical study of using TiO_2 nanoparticles to simulate the efficiency of flat plate solar collector under laminar and forced convections conditions. The dynamic and thermal properties were evaluated based on different (1, 3, 5, and 10 %) and Reynolds number range of 25-800 and the effectiveness of TiO_2/water nanofluids was compared to conventional coolant (water). The results presented by the following parameter: average temperature; pressure drop coefficient, and Nusselt number. Finally, the authors concluded that heat transfer enhanced by increasing both nanoparticles concentration and Reynolds number.

Based on the above literature, it is clear that there are relatively few studies carried out for investigating numerically and experimentally the thermal performance of FPSC using TiO2/water and CuO/water nanofluids. This is in addition to some contradictions in reporting the effectiveness of these nanoparticles, especially for CuO. The conventional FPSC was used in all the research work available in the literature. Therefore, the aim of this study is to compare the performance of FPSC with a spiral pipe arrangement using TiO2/water and CuO/water nanofluids relative to the base fluid (water) under outdoor conditions. The comparison will be done at a volume concentration of 0.1 % and a flow rate of 1.5 Lpm. Based on the results, the nanofluid with the best performance will be considered for a detailed study in comparison with water.

EXPERIMENTAL WORK

Experimental Setup:

The schematic of experimental set-up is illustrated in Fig. (1) and Fig. (2) show the photos of experimental set-up. The schematic diagram in Fig (1) illustrates that the solar radiation passes through the glass cover to absorbing plate and tubes, which are painted with matt black painting to enhance the absorption of short-wavelength sun radiation and reduce long wavelength radiation loss from the absorbing surface. This solar radiation converts to thermal energy that is stored in a heat transfer fluid. The fluid circulates in a closed system through a tank and submersible water pump.

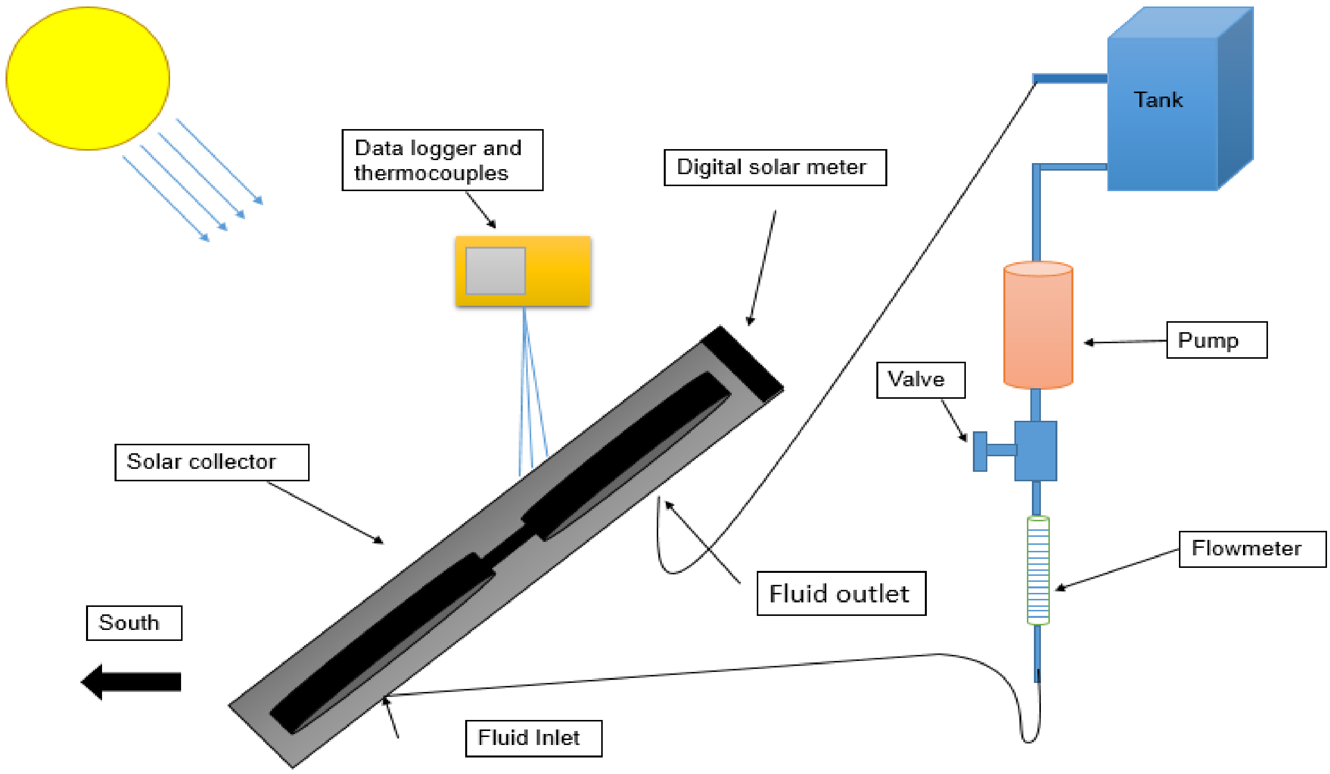

Figure 1: The schematic of flat plate solar collector experimental setup.

Figure (2): Experimental set-up of flat plate solar collector.

The FPSC consists of box made from wood with dimensions of $\{1.07\ \mathrm{m}, 0.57\ \mathrm{m}, 0.1\ \mathrm{m}\}$. The specifications of FPSC are presented in Table (1). The transparent glass was fixed on the top of the FPSC that contains the absorber plate and the flow tube. The wood was used in the industry of enclosure as a heat insulator with thermal conductivity of $\{0.19\ \mathrm{w/m.c}\}$.

Table (1) the specification of flat plate solar collector components

Component	Dimension	Remarks
Collector	1.07m x 0.57 m x 0.1 m	Gross area= 0.6099 m^2
Absorber plate	1.07m x 0.57 m x 0.002 m	Material: black painted Galvanized plate
Transparent cover	3 mm thick	Material : window glass
Number of pipe coils	diameter =0.015875 m	Material: copper Length pipe = 15 m Number of coils = 12
Bottom insulation	0.3 m thick	Material : glass wool
Edges insulation	0.15 m thick	Material : glass wool

The Nanofluid Preparation:

In this research, dry powder of CuO and TiO_2 nanoparticles of 99.9 % purity and average size (20-60) nm purchased from (Nanografi Nano Technology, Turkey base company) are dispersed in deionized water as base fluid for the nanofluid preparation. The CuO and TiO_2 nanoparticles were selected to prepare the water-based nanofluids in this study due to their good chemical stability and the enhanced thermal properties compared to the base water. The properties of the CuO *and* TiO_2 nanoparticles are listed in Table (2).

To enhance the heat transfer performance of the conventional fluids, it is necessary to obtain a good dispersion and stability of the nanoparticles in the base water. There are two techniques of preparing the nanofluids which are two step and one step methods. In the tow-step method, the nanoparticles or nanotubes are first prepared in a form of dry powder by various methods as physically, chemically, and laser based techniques. The produced nanoparticle is mixed with water and then are sonicated to get uniform and stable suspension [19]. A special type of surfactants may be used to get well dispersion of the nanoparticles in the base fluid. This depends on the depend on the boundary properties among nanoparticle and base fluid [20]. However, it was reported that adding surfactants may result in decreasing the thermal performance of the nanofluids due to the formation of the bubbles [13]. This method is widely applied for producing nanofluid since the commercial availably of nanoparticle powders for the time being. This method is limited by the nanoparticles agglomeration during the process, packing, and transport, causing problems in the subsequent dispersing in fluid step. On the other hand, the one-step method utilized to diminish the agglomerating of nanoparticles during the drying, storage, and transportation processes, leading to difficulties in the following dispersion stage of the two-step method [20].

To weigh the Nano powder very accurately, a sensitive balance (Make-Sartorius, model-234-IS, resolution-01 mg) was used. The mass in grams of the nanoparticles required for preparation of nanofluid with different volume concentration is calculated using the following equation [21]:

$$Vol\,\%(\phi) = \frac{m/\rho}{100ml\ water + m/\rho} \qquad \textbf{(1)}$$

This equation calculates the mass of CuO and $\mathrm{TiO_2}$nanoparticles dispersed into 100 ml of water, volume consternations of (0.1 % Vol.).were prepared and used in the study. Ultrasonic sonic mixing was applied for one and half hour to disperse the weighed amount of CuO and$\mathrm{TiO_2}$nanoparticles in de-ionized water using ultrasonic mixing (made-QSONICA-Sonicators,power-500 W frequency 20 ±3KHz).

Table 2: Physical properties of copper oxide (CuO) and Titanium oxide ($\mathrm{TiO_2}$) nanoparticles.

No.	Technical properties	CuO	$\mathrm{TiO_2}$
1	Purity %	99.99	99.99
2	Average particle size (nm)	20-60	20-60
3	Specific surface area (m^2/g)	35	50
4	Bulk density (g/cm^3)	0.8	0.3
5	True density (g/cm^3)	6500	4500
	Color	black	white
6	Morphology	nearly spherical	nearly spherical

Experiments:

The experiments were conducted during May and June 2017 from 10 AM to 12:30 PM. Two nanofluids (CuO/water and TiO_2/water) were proposed and their results were compared with the base fluid (water). The flow rate of the fluids is kept constant at 1.5 lit/min and the nanoparticles volume concentration of the nanofluids was 0.1%. The thermocouple readings of the inlet, outlet, and the fixed points as well as the solar radiation intensity on the FPSC were taken every five seconds. However, five minutes' intervals were considered in recording the solar radiation intensity and the thermocouples readings.

The Base Fluid Experiments: The deionized water was used as a reference base fluid, which is introduced into the FPSC setup at. The experiments were carried out on May 29, 2017 at a fluid flow rate of 1.5 lit/min. The weather temperature was recorded to be about 41.7 °C during the run with a small variation. For a fair comparison, it should be noted that all the experiments were performed under the same experimental conditions with changing the fluid type.

The TiO_2/ Water Experiments: The base water was replacing by TiO2/water nanofluids. At the beginning, the TiO_2/water nanofluids with volume fraction concentration of 0.1%. was used as a working fluid at different flowrate of 1.5 lit/min to be compared with the base fluid at the same conditions. The nanofluid experiments were performed on June 8, 2017 at the same experiments conditions mentioned previously. 0.1 % Volume concentration of TiO_2/water nanofluids at a flow rate of 1.5 lit/min. The maximum ambient temperature of about 43.7 °C was recorded for TiO_2 nanofluids.

The CuO/Water Nanofluid Experiments: The CuO/water nanofluids was used as a working fluid with a volume fraction concentration of 0.1% and a flow rate of 1.5 lit/min under the same experimental condition of the base fluid experiment. The experiments were conducted on June 4, 2017 .The maximum weather temperature was 41.1 °C.

RESULTS AND DISCUSSION

Incident Solar Radiation Results

All the experiments were carried out on selected days during summer 2017 in Iraq based on the weather conditions as the clear sky. The incident solar radiation was measured and the collected data are included in fourteen figures (as an example, three of them Fig. 3, 4, and 5 are shown in this paper for water, CuO/water nanofluid and TiO_2/water nanofluid). During the experiments, it can be observed that the incident solar radiation increases within the period of (10AM-12:30 PM) with some fluctuations due to the presence of clouds from time to time

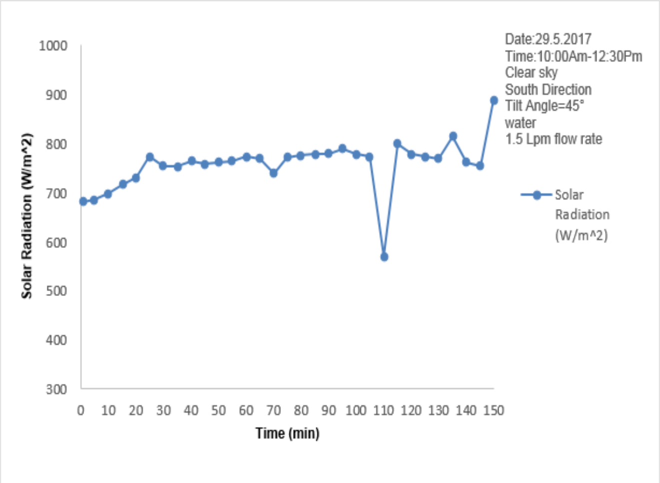

Figure 3: Incident Solar Radiation on May 29, 2017**.**

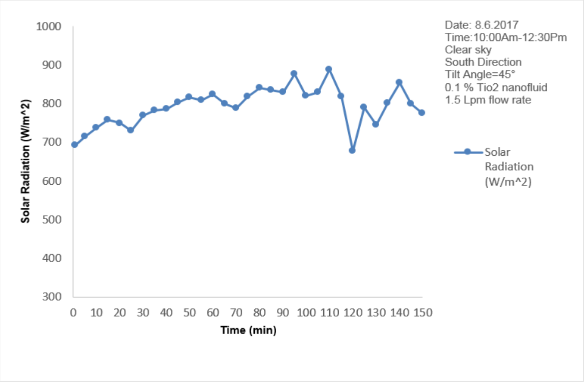

Figure 4: Incident Solar Radiation on June 8, 2017

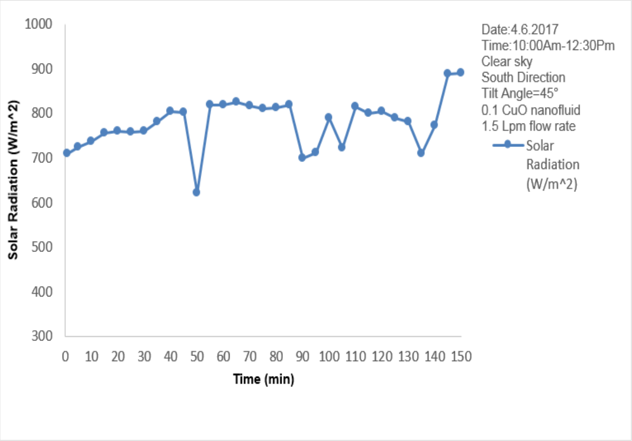

Figure 5: Incident Solar Radiation on June 4, 2017

Temperature Difference Results

The effects of the fluid (water and the nanofluids) flow rate, the nanofluid types, and the nanoparticles volume concentration of the nanofluids on the outlet-inlet temperature difference of the flat plate solar collector. These effects will be discussed in more details in the following sections.

The Fluid Type Effect-The Base Fluid (Water), CuO/Water, and $\mathbf{TiO_2}$ / Water Nanofluids : The effect of fluid type on the outlet-inlet temperature difference of the FPSC is demonstrated in Fig. (6). At 1.5 lit/min, the experimental results indicated that the temperature differences of about 6.6 °C, 7.1 °C, and 7.9 °C for water, TiO_2, and CuO was reported. From Fig. (6) and these readings were reported when the solar radiation reaches its highest value approximately about 788 W/cm^2 (at 11:35 AM), 788 W/cm^2 (at 11:10 AM), and 811 W/cm^2 (at 11:15AM) for water, TiO_2, and CuO, respectively. Hence, the 0.1 % volume concentration CuO/water nanofluid exhibited higher temperature difference than that of both 0.1 % volume concentration TiO_2/water nanofluid and the base fluid (water). The TiO_2/water nanofluid has a higher temperature difference compared to water. The heat transfer enhancement of the nanofluids is attributed to the enhanced thermophysical properties such as thermal conductivity and heat transfer coefficient caused by adding the CuO and TiO_2 nanoparticles to water. In addition to the above reason, it was noted that adding nanoparticles to the water has many advantages: (1) results in a decrease in the heat capacity of the water so that less energy is required for the nanofluid in comparison with water; in other words, the temperature difference of the nanofluids is larger than that of water if the same amount of heat is provided, (2) the heat transfer area is increased by mixing a little amount of the nanoparticles with the base fluid (water), and (3) the mass migration phenomenon of the nanoparticles in the nanofluid working media further improves the heat transfer enhancement. On the other hand, the higher temperature difference of the CuO/water nanofluid in comparison with TiO_2/water nanofluid is due to the higher thermal conductivity of CuO nanoparticles

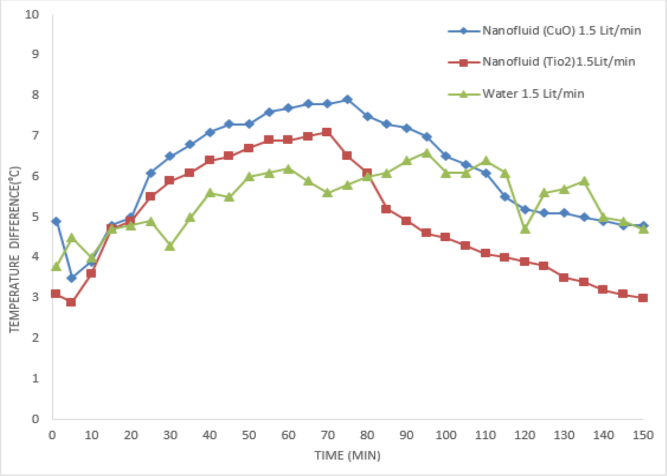

Figure 6: The inlet-outlet temperature difference vs. time at 1.5 lit/min flow rate for water, CuO/water, and TiO_2/water nanofluids with nanoparticles volume concentration of $(\emptyset = 0.1\%)$.

Efficiency of Flat Plate Solar Collector

The thermal efficiency is calculated based on the procedure explained in Ref. [22] and mathematically is expressed as:

$$\eta = F_R\left[(\tau\alpha) - \frac{U_L(T_i - T_a)}{G}\right] \qquad \textbf{(2)}$$

where

F_R: - heat removal factor

$\tau\alpha$: - transmittance- absorptance product

T_i: - inlet fluid temperature of solar collector (°C)
T_a: - ambient temperature (°C)
G: - radiation intensity (W/m^2)

U_L : - solar collector overall heat loss coefficient ($W/m^2.°C$).

To calculate the thermal efficiency of the FPSC, it is required to find the following parameters: the solar collector overall heat loss coefficient and the heat removal factor. The following equation can be used to determine the solar collector overall heat loss coefficient [22]:

$$U_L = U_{top} + U_{bottom} + U_{egdes} \qquad \textbf{(3)}$$

Based on the above equation, the top overall heat loss coefficient of the FPSC is expressed by [22]:

$$U_{to.} = \frac{1}{\frac{Ng}{\frac{c}{T_p}}\left[\left[\frac{T_p - T_a}{Ng + f}\right]\right]^{0.33} + \frac{1}{h_w}} + \frac{\sigma(T_p^2 + T_a^2)(T_p + T_a)}{\left[\frac{1}{\varepsilon_p + 0.05\,Ng(1 - \varepsilon_p)}\right] + \left[\frac{2Ng + f - 1}{\varepsilon_g}\right] - Ng} \qquad \textbf{(4)}$$

Where Ng= number of glass covers

T_p: - average plate temperature (°C)
T_a: - average ambient temperature (°C)
ε_p= absorber plate emissivity

ε_g = glass emissivity

σ: - Stefan-Boltzmann constant = 5.65*10^{-8} $W/m.K^{-4}$

$f = (1 - 0.04\,h_w + 0.0005\,h_w^2)\,(1 + 0.09\,Ng)$

$C = 365.9\,(1 - 0.0083\,\beta + 0.0001298\,\beta^2)$

h_w = The heat transfer coefficient of wind is given by the following equation [22]:

$$h_w = \frac{8.6 * V^{0.6}}{L^{0.4}}$$

Where L is the collector length (m) and V is the wind velocity (m/s).

The bottom overall heat loss coefficient of the FPSC can be calculated by the following equation [22]:

$$U_{bot.} = \frac{1}{\frac{t_{ba.}}{k_{ba.}} + \frac{1}{h_{c,b-a}}} \qquad \textbf{(5)}$$

where

$t_{ba.}$= thickness of back insulation (m)

$k_{ba.}$= conductivity of back insulation ($W/m.k$) for play wood.

$h_{c,b-a}$= convection heat loss coefficient from back to ambient ($W/m^2.k$)

Finally, the edge overall heat loss coefficient energy of the FPSC is given by [22]:

$$U_{ed} = \frac{1}{\frac{t_{ed.}}{k_{ed.}} + \frac{1}{h_{c,ed.-a}}} \qquad \textbf{(6)}$$

where

$t_{ed.}$= thickness of edge insulation (m)

$k_{e.}$= conductivity of back insulation ($W/m.k$) for play wood

$h_{c,ed-a}$= convection heat loss coefficient from edge to ambient ($W/m^2.k$)

It should be noted that the typical values of the edge heat loss coefficient are ranging between 1.5 – 2.0 $W/m^2.k$.

The following equation is used to calculate the heat removal factor [22]:

$$F_R = \frac{\dot{m}\,C_p}{A_c U_L}\left[1 - exp\left[-\frac{U_L\,F'\,A_c}{\dot{m}\,C_p}\right]\right] \qquad \textbf{(7)}$$

where

C_p: Specific heat at constant pressure ($J/kg.k$)
A_c: Surface area of solar collector (m^2)
ṁ: mass flow rate of fluid flow (kg/sec).

F': Collector efficiency factor.

The collector efficiency factor can be calculated from the following equation [22]:

$$F' = \frac{\frac{1}{U_L}}{w\left[\frac{1}{U_L[D_o + (w - D_o)F]} + \frac{1}{C_b} + \frac{1}{\pi D_i h_{fi}}\right]} \qquad \textbf{(8)}$$

Where

w: distance between pipes (m)
h_{fi} : heat transfer coefficient inside absorber pipe ($W/m^2.°C$)
D_o: tube inside diameter (m)
D_i: tube outside diameter (m)
C_b: Bond conductance

For straight fin with rectangular profile, the fin efficiency is formulated as [22]:

$$F = \frac{\tanh[m(w-D)/2]}{m(w-D)/2} \quad \textbf{(9)}$$

Where D is the riser tube outside diameter (m) and w is the distance between riser tubes (m) and $m = \sqrt{\frac{U_L}{K.\delta}}$ [where m is the air mass and $\boldsymbol{\delta}$ is the plate thickness (m)].

In this study, the density (ρ_{nf}) and special heat capacity ($c_{p,nf}$) of nanofluid were calculated and listed in Table (3) based on empirical correlations proposed by Pak [23] and Xuan [24] as follows:

$$C_{p,nf} = \frac{(1-\phi)\rho_{bf}C_{p.bf} + \phi\rho_p C_{p.np}}{\rho_{nf}} \quad \textbf{(10)}$$

$$\rho_{nf} = (1-\phi)\rho_{bf} + \phi\rho_{np} \quad \textbf{(11)}$$

Table (3): Thermo physical properties of base fluid and nanoparticles.

No.	Property	CuO	TiO_2	Water
1	$c_p[J.kg^{-1}.k^{-1}]$	535.6	689	4197
2	$\rho[kg.m^{-3}]$	6500	4500	997.1
3	$k[W.m^{-1}.K^{-1}]$	20	8.4	0.669
4	$d_p(nm)$	30	30	-

Table (4) presents the FPSC efficiency as a function of the fluid type at 1.5 lit/min. The 0.1 % vol. CuO/water nanofluid exhibited higher efficiency (55%) compared to 54% and 50% for 0.1 % by vol. TiO_2/water and the base fluid (water), respectively. This is attributed to the higher thermal conductivity of CuO compared to TiO_2 and water. These observations are in good agreement with the reported data in the literature [1-3-8-12].

Table 4: The Efficiency of Flat Plate Solar Collector using Different Fluids.

Number of Experimental	Type of fluid	Mass flow rate	Efficiency %
1	water	1.5 Lit/min	50
2	Nanofluid (TiO_2-0.1%)	1.5 Lit/min	54
3	Nanofluid (CuO-0.1%)	1.5 Lit/min	55

Empirical Correlations

Finally, from the raw experimental data, the following steps can formulate the empirical correlations or power-law correlations for heat transfer coefficient ($Nu = a\,Re^b\,Pr^{1/3}$) of the base fluid (water) and nanofluids using STATISTICA program (version 10). Using the experimental data, the non-dimensional relationships (Nusselt number as a function of Reynolds number and Prantal number) were obtained utilizing Statistica software as shown in Table (5). For water, the constants ($n_1$and n_2) of the correlation $Nu = n_1\,Re^{n_2}\,Pr^{0.3}$ at constant flow rates (1.5 lit/min) was calculated by taking the average values of the estimated constants for each run. While for the nanofluids, the average values of the constants were considered at 0.1% nanoparticles volume concentration and a flow rate of 1.5 lit/min. The power of the Prantal number was taken to be 0.3 for all the experiments. The empirical correlations were tested by calculating the Nusselt numbers using the values of the Reynolds number and Prantal number. The results were compared with the calculated Nusselt numbers from the below equation and the level of confidence was about [95.0 %]. The Nusselt number for the base fluid and the nanofluids are defined by the following equations:

$$Nu = \frac{h\,D}{K} \quad \textbf{(12)}$$

Table 5: The Dimensionless Relationship from Experimental Work

($Model: Nu = n_1\,Re^{n_2}\,Pr^{0.3}$)

Number of Experimental	Type of fluid	Mass flow rate	Dimensionless Relationship
1	water	1.5 Lit/min	$\boldsymbol{Nu = .926e^{-3}\,Re^{1.1446}\,Pr^{0.3}}$
2	Nanofluid (Tio2-0.1%)	1.5 Lit/min	$\boldsymbol{Nu = .00182\,Re^{1.072973}\,Pr^{0.3}}$
3	Nanofluid (CuO-0.1%)	1.5 Lit/min	$\boldsymbol{Nu = .982e^{-3}\,Re^{1.118938}\,Pr^{0.3}}$

CONCLUSIONS

This project focused on enhancing the heat transfer performance of FPSC with a spiral tube arrangement by replacing the base fluid (water) with CuO/water and TiO_2/water nanofluids. The effect of the fluid type on the inlet-outlet temperature difference as well as the thermal efficiency of FPSC was investigated. Based on the experimental results, the following conclusions can be drawn:

1. The CuO/water nanofluid as a working fluid in the FPSC exhibited higher heat transfer performance compared to TiO_2/water nanofluid as well as the base fluid (water) due to the higher thermal conductivity of CuO nanoparticles.
2. The maximum efficiency was reported to be 55% for 0.1% particle volume concentration of the CuO/water nanofluid at a flow rate of 1.5 lit/min.
3. The outcomes of this kind of the research work provides the solar thermal energy investigators with the required knowledge to further enhancing the performance of the water heating systems.

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