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Experimental analysis on thermal efficiency of evacuated tube solar collector by using nanofluids

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Abstract: This research is to study performance of a evacuated tube solar collector when silver (Ag(30nm)) + distilled water and oxide titanium (ZrO_2(50nm)) + distilled water nanofluids was taken as the working fluid. With higher thermal conductivity of the working fluid the solar collector performance could be enhanced compared with that of distilled water. The two types of nanoparticles are used to investigate at different concentration (i.e. 0, 1, 3 and 5 % vol), mass flow rate (30,60 and 90 lit/hr m^2) and the based working fluid was distilled water. The effect of different nanoparticle concentrations of Ag and ZrO_2 mixed with distilled water as base fluid was examined on solar collector efficiency for different mass flow rates (30, and 90 lit/hr m^2). The area under the curve as an index was used for comparing the effects of mass flow rates and nanoparticle concentrations on the collector total efficiency. The experimental results indicated that the concentration at 1%vol showed insignificant results compared with distilled water. As well as The nanofluids (Ag + DW), at concentrations (1, and 5%vol) and mass flow rates (30, and 90 lit/hr m^2), the thermal solar characteristics values of $F_R(\tau\alpha)$, $-F_RU_L$ were 0.488, 1.168 W/m^2.k, 0.593 and 1.252 W/m^2.k, while the nanofluid (ZrO_2 + DW) 0.437,1.025 W/m^2.k ,0.480 and 1.140 W/m^2.k respectively. Whereas in the case of distilled water at mass flow rates 30 lit/hr m^2 and 90 lit/hr m^2 were 0.413,0.973 W/m^2.k,0.442 and, 1.011 W/m^2.k respectively. Moreover use of nanofluids (Ag(30nm) + + distilled water) and (ZrO_2(50nm) + distilled water) as a working fluid could improve thermal performance of flat plate collector compared with distilled water, especially at high inlet temperature. The solar collector efficiency for nanofluid (Ag(30nm) + distilled water) was greater than nanofluid (ZrO_2(50nm) + distilled water) due to small particle size for the silver compared with zirconium oxide as well as high thermal conductivity for silver. The type of nanofluid is a key factor for heat transfer enhancement, and improve performance of evacuated tube solar collector.

Keywords: Evacuated Tube Solar Collector, Thermal Performance, Metal and Oxide Metal, Nanofluid

1. Introduction

The most important benefit of renewable energy systems is the decrease of environmental pollution. The crisis of the energy cost and its demand increases exponentially with fossil energy nearing exhaustion for present and future time as well as the environmental and air pollution are being more severe, so the strong demand to use or produce a new or renewable, clean and low cost energy is raised to confront this crisis Ali [1]. Renewable energy sources such as sun energy can be substituted for exceeding human energy needs, Taki et al. [2] . Solar energy as one of the most significant forms of renewable energy sources has drawn a lot of attention as there is a belief it can play a very important role in meeting a major part of our futures' need to energy Hedayatizadeh et al. [3] . However solar energy as an eternal and widespread energy source has low density and is frequently changing as well as the gap between the time of radiation and consumption is the main disadvantage. Hence, collecting and storage of solar energy during radiation time is required for the consuming period. Water is a good material for receiving and storage of solar energy and the solar water heater (SWH) is one of the fastest growing technologies in the renewable energies sector Kumar and Rosen, [4]. Water heating by solar energy is the most important application of direct solar energy use in the world today Wongsuwan and Kumar [5], while Flat Plate Solar Water Heater (FPSWH) is a well – known technology. The thermal efficiency of the solar water heaters has improved by using some techniques Rezania, Taherian, & Ganji, [6]. Up to now, many studies have been done in order to improve the thermal efficiency of SWHs Koffi et al.[7]; Jaisankar et al.[8]; Jaisankar et al. [9]; Alshamaileh [10]; Kumar and Rosen [11]. The many ways of increasing heat transfer through heat exchangers can be divided into two categories: Passive and active methods. Contrasts to active techniques, passive methods do not need an external force. Using nanofluids as heat transfer medium is a passive method for increasing heat transfer. In spite of many scientific works studying the effect of nanofluids application on thermal efficiency of heat exchangers, there exists very limited information about the study of nanofluids effect on flat-plate solar collectors. Das et al.,[12]; expressed that the nanofluids could be utilized to enhance heat transfer from solar collectors to storage tanks and to increase the energy density. Natarajan and Sathish [13] also believed the novel approach of increasing the efficiency of solar water heater through the introduction of nanofluids instead of conventional heat transfer fluids. Tiwari et al.,[14]; investigated the effect of using Al_2O_3 nanofluid as an absorbing medium in a flat-plate solar collector theoretically. They also studied the effect of mass flow rate and particle volume fraction on the efficiency of the collector. Their results showed that using the optimum particle volume fraction 1.5% of Al_2O_3 nanofluid increases the thermal efficiency of solar collector in comparison with water as working fluid by 31.64%. Otanicar and Golden [15] reported the experimental results on solar collector based on nanofluids composed of a variety of nano particles (carbon nano tubes, graphite, and silver). The efficiency improvements were up to 5% in solar thermal collectors by utilizing nanofluids as the absorption mechanism. The experimental and numerical results demonstrated an initial rapid increase in efficiency with volume fraction, followed by a leveling off in efficiency as volume fraction continues to increase. Yousefi et al. [16,17] studied the effect of Al_2O_3 and MWCNT water nanofluid on the efficiency of a FPSC (flat plate solar collector) experimentally. The results showed that using Al_2O_3 and MWCNT water nanofluids in comparison with water as working fluid increased the efficiency up to 28.3% and 35%, respectively. Taylor et al. [18] investigated on applicability of nanofluids in high flux solar collectors. Experiments on a laboratory-scale nanofluid dish receiver suggest that up to 10% increase in efficiency is possible-relative to a conventional fluid – if operating conditions are chosen carefully for 0.125% volume fraction of graphite. Anyway, up to now just a few studies have been done on nanofluids application in SWH, especially FPSC. Since FPSCS are the most commonly used systems in the renewable energies sector, any attempt for improving the rate of energy harvest seems very effective. Considering the previous studies, nanofluid is a new candidate for this aim.

In the present study, the main purpose of this work is to study the effect of silver (Ag) and zirconium oxide (ZrO_2) – distilled water nanofluids, mass flow rate, concentration, and nanoparticle size on solar collector performance more over efficiency of the collector.

2. Preparation of Silver and Zirconium Oxide Nanofluids

The studied nanofluid is formed by silver (Ag (30 nm)) and zirconium oxide (ZrO_2 (50 nm)) nanoparticles and Two – step method was applied by by dispersing pre – weighed quantities of dry nanoparticles in base fluid. In a typical procedure, the pH of each nanofluids a mixture was measured .The mixtures were then subjected to ultrasonic mixing [100 kHz, 300 W at 25 – 30 ^{0}C, Toshiba, England] for two hour to break up any particle aggregates. The acidic pH is much less than the isoelectric point [iep] of these particles, thus ensuring positive surface charges on the particles. The surface enhanced repulsion between the particles, which resulted in uniform dispersions for the duration of the experiments. The prepared nanofluids could stay stable for 4 hours at least. The figure (1) shows nanofluids which containing (Ag (30 nm)) and zirconium oxide (ZrO_2 (50 nm)). Nanofluids with different volume fractions (Φ= 1, 3, and 5vol %) are used.

***Fig 1.** Show nanofluids for ZrO_2 + distilled water ,Ag+ distilled water and DW*

3. Experimental Setup with Twenty Riser Tubes

In Fig (2) the schematic view of set up is shown. Three temperature measurements are required for solar collector testing i.e. ambient air temperature and the nanofluid temperature at the collector inlet and outlet. The surrounding air temperature measured by temperature sensor. The specification of evacuated tube solar collector indicated in details are summarized in Table 1. Fig (3) reveal evacuated tube solar collector used in the experiments.

Table 1. *Specification of solar collector with 20 riser.*

GTC – Solar Specification			
Out tank material	**White color steel**	**Capacity**	**120 L**
Vacuum tube	47x1500 mm series glass tube	Insulation	High density pressure
Frame material	40 degree gavernzied steel	Series No	0811JS
Inner tank material	SUS 3042b food grade 0.41mm	Manufacture date	NOV.18th.2008

It is a glazed (one cover) solar collector that is exposed to south with tilt angle 48° are inlet and outlet of heat transfer fluid to the FPSC, respectively. Two mercury bar thermometers at the inlet and outlet of solar collector measured the temperature of heat transfer nanofluid , respectively with accuracy of 0.1 °C. The bulbs of thermometers were placed inside the tubes completely. Simultaneously, temperatures of the three mentioned points were also measured by PT100 sensors for gaining higher accuracy. Pump [Bosch 2046 – AE], German carried distilled water and nanofluid through the collector, two control valves after pump and solar storage. Mass flow rate was measured directly by flow meter type Dwyer series MMA mini – Master flow meter. To fulfill the quasi – steady state conditions, it was tried to have a slow change in inlet fluid temperature, hence a heat exchanger was applied. Solar radiation (I) was measured by a TES 1333 solar power meter (Houston Texas) as shown in Fig. (4) with accuracy typically within ±10 W/m^2 and resolution 0.1 W/m^2. The Prova AVM – 03 anemometer as shown in Fig. (5) also provided the accurate measurements of wind velocity with ± 3.0% accuracy.

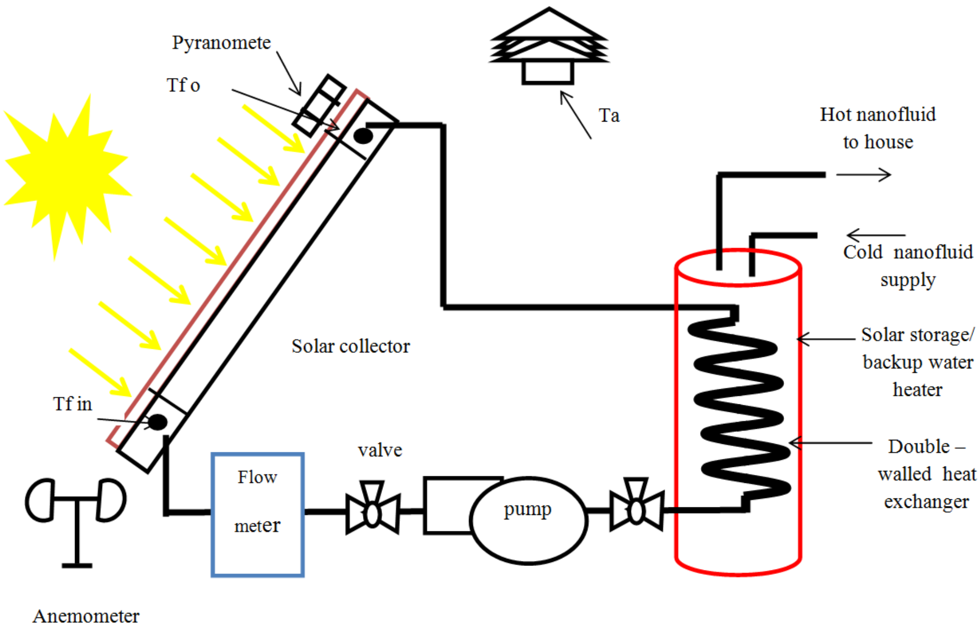

Fig 2. *The experimental set up schematic*

Fig 3. *The experimental evacuated tube solar collector*

Fig 4. *Solar power meter*

Fig 5. *Anemometer*

4. Measurement of Nanofluid Thermal Properties

All physical properties of the nanofluids (Ag, ZrO_2 + DW) and distilled water needed to calculate the useful heat energy, thermal energy ,collector efficiency and the convective heat transfer are measured. The dynamic viscosity (μ) is measured using brook field digital viscometer model DV – E. The thermal conductivity, specific heat and density are measured by Hot Disk Thermal Constants Analyzer (6.1), specific heat apparatus (ESD – 201) as well as the measurement of density was carried out by weighing a sample and volume. The thermal properties of nanofluids dynamic viscosity (μ) , thermal conductivity, specific heat and density are measured with different volume concentrations at 0,1%, , 3%, and 5 %vol.

5. Estimation of Nanofluid Thermo – Physical Properties

The empirical relation used in this study to comparison with the practical measurements for nanofluid properties. The thermo physical properties of nanofluid were calculated at the average bulk temperature of the nanofluid by the following equations.

The volume fraction (Φ) of the nanoparticles is defined by[19].

$$\varphi = \frac{v_p}{v_p + v_f} = m\frac{\pi}{6}d_p^{-3} \tag{1}$$

Density [20].

$$\rho_{nf} = \Phi\,\rho_{nf} + (1-\Phi)\,\rho_{Dw} \tag{2}$$

Viscosity [20].

$$\mu_{nf} = (1-\Phi)\,\mu_{Dw} + \Phi\mu_{Dw} \tag{3}$$

Specific heat [20].

$$Cp_{nf}\,\rho_{nf} = \Phi(\rho_s\,Cp_s) + (1-\Phi)(\rho_{Dw}Cp_{Dw}) \tag{4}$$

Recently Chandrasekar et al.[21] presented an effective thermal conductivity model (Eq.5)

$$\frac{k_{nf}}{k_{Dw}} = \left[\frac{Cp_{nf}}{Cp_{Dw}}\right]^{-0.023}\left[\frac{\rho_{nf}}{\rho_{Dw}}\right]^{1.358}\left[\frac{\mu_{Dw}}{\mu_{nf}}\right]^{0.126} \tag{5}$$

Table 2. *Thermo – physical properties of the nanofluids employed [22].*

Nano sized particles	ρ (Kg/m^3)	Cp (J/kg k)	k (W/m k)	Mean diameter (nm)
silver (Ag)	10500	235	429	30
Zirconium oxide (ZrO_2)	5890	278	22.7	50

6. Data Analysis and Validation

The temperature distribution, useful heat energy and the collector efficiency were calculated by using the equations (6) to (13) which were derived from [7], [8], [1] and [9]. To obtain the relationship between the temperature and the mass flow rate (m), the equation for useful heat energy (Qu), as:

$$Q_u = A_c F_R\left[I\alpha\tau - U_L\left(T_f - T_a\right)\right] \tag{6}$$

The heat energy is converted into thermal energy of water in the pipes, as:

$$Q = \dot{m}\,Cp\left(T_{f\,o} - T_{f\,i}\right) \tag{7}$$

Then

$$\dot{m}\,Cp\left(T_{f\,o} - T_{f\,i}\right) = A_c F_R\left[I\alpha\tau - U_L\left(T_f - T_a\right)\right] \tag{8}$$

Therefore,

$$\left(T_{f\,o} - T_{f\,i}\right) = \left(\frac{A_c F_R}{\dot{m}\,Cp}\right)\left[I\alpha\tau - U_L\left(T_f - T_a\right)\right] \tag{9}$$

F_R may be obtained from

$$F_R = \frac{\dot{m}\,Cp}{A_c U_L}\left[1 - \exp\left(\frac{U_L F' A_c}{\dot{m}\,Cp}\right)\right] \tag{10}$$

Then the collector efficiency is obtained by using the relation,

$$\eta = \frac{Q_u}{A_c I} \tag{11}$$

Substitution of Eqs. (7) and (9) in Eq. (10) yields,

$$\eta = F_R \left[\alpha\tau - \frac{U_L\left(T_f - T_a\right)}{I} \right] \tag{12}$$

Since F_R, $\alpha\ \tau$ & U_L are constant,

$$\eta\ \alpha \left[\frac{\left(T_f - T_a\right)}{I} \right] \tag{13}$$

Therefore , the plots of instantaneous efficiency (η_i) versus $\frac{(T_i - T_a)}{I}$ would be straight lines with intercept $F_R(\tau\alpha)$ and slope $-F_RU_L$. In spite of these difficulties, long – time performance estimate of many solar heating systems, collectors can be characterized by the intercept and slope (i.e., by $F_R(\tau\alpha)$, and $-F_RU_L$) [23]. Using curve fitting tool box of Mat lab, a line was fitted to experimental data of thermal efficiency versus the reduced temperature parameters, $\frac{(T_i - T_a)}{I}$, for each case. Goodness of fitting was determined by R^2. Finally the area under curves as index of collector total efficiency was used for comparing the cases.

7. Results and Discussion

At first of all the collector was tested for distilled water as working fluid. The experimental results as shown in Figs.(7 – 12) and Table 3. It can be seen the performance curves of the solar collectors under the ASHRAE Standard with silver (Ag) and zirconium oxide (ZrO_2) nanofluids at concentrations (0,1, 3 and 5%vol) and mass flow rates (30,60 and 90 lit/hr m^2). It was found that the collector efficiency of the nanofluids (Ag+ DW) and,(ZrO_2+DW) at 5% vol were higher than that for distilled water due high thermal conductivity compared with distilled water. Again, the nanofluids (Ag + DW) and,(ZrO_2 + DW) at 1%vol still gave similar result with distilled water. The nanofluids (Ag + DW), at concentrations (1, and 5%vol) and mass flow rates (30, and 90 lit/hr m^2), the thermal solar characteristics values of $F_R(\tau\alpha)$, $-F_RU_L$ were 0.488,1.168 W/m^2.k, 0.593 and 1.252 W/m^2.k, while the nanofluid (ZrO_2+DW) were 0.437,1.025 W/m^2.k ,0.480 and 1.140 W/m^2.k respectively. Whereas in the case of distilled water at mass flow rates 30 lit/hr m^2 and 90 lit/hr m^2 were 0.413,0.973 W/m^2.k, 0.442 and ,1.011 W/m^2.k respectively. This meant that using of nanofluids (Ag + DW) and,(ZrO_2 + DW) as a working fluid were able to increase solar collector performance. Then the evacuated tube solar collector could operate at higher temperature compared with distilled water. Since slopes of models are negative, one can see that increasing (Ti – Ta), causes the efficiency to zero (in X_{max}).

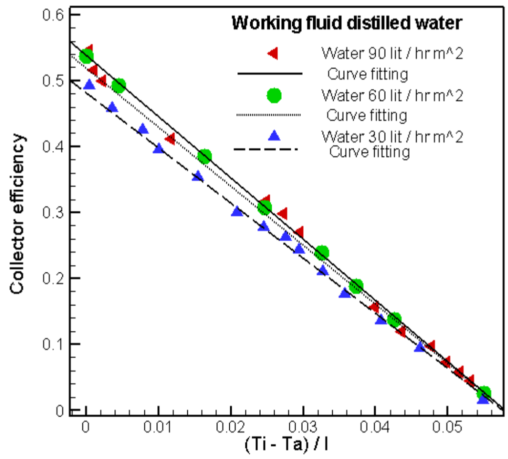

Fig 6. *Collector efficiency for three mass flow rate of water as working fluid in*

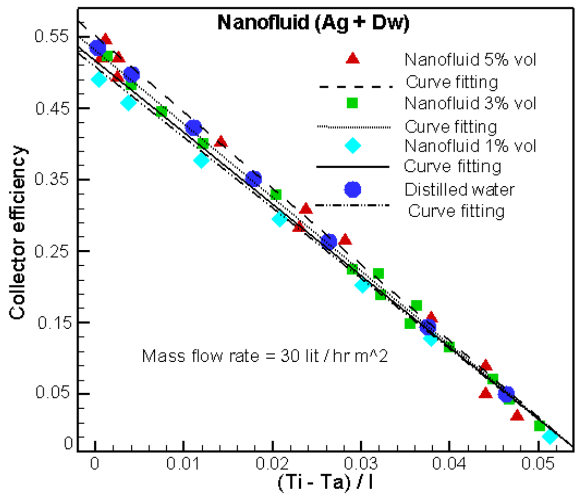

Fig 7. *Collector efficiency at different Φ for nanofluid (Ag + DW)*

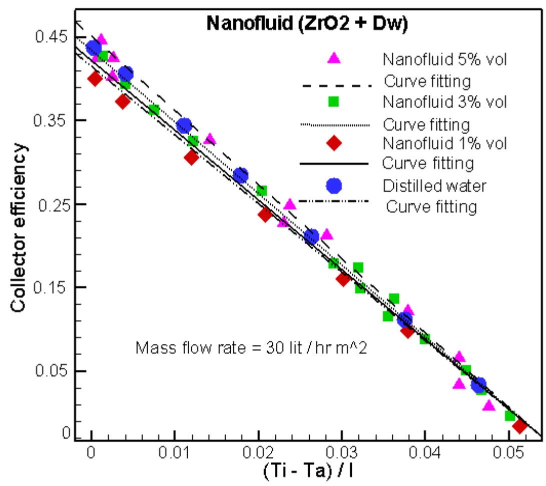

Fig 8. *Collector efficiency at different Φ for nanofluid (ZrO2 + DW)*

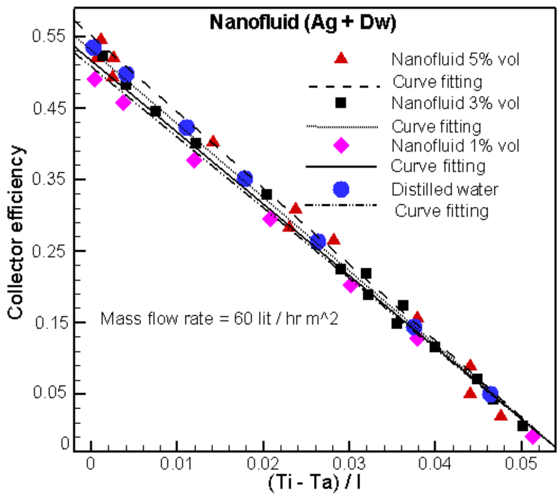

Fig 9. *Collector efficiency at different Φ for nanofluid(Ag +DW)*

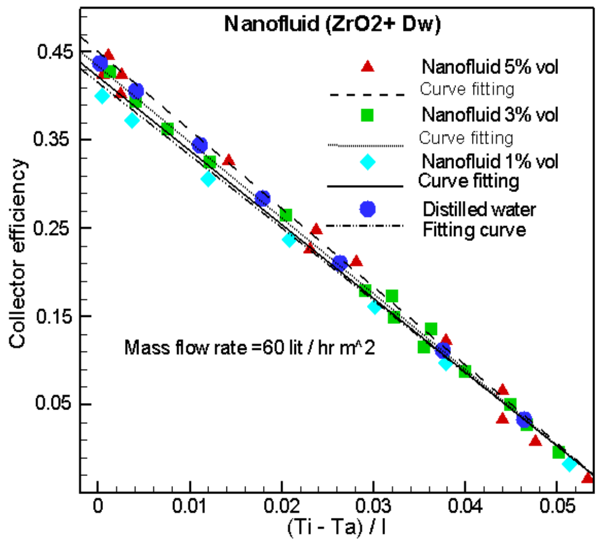

Fig 10. *Collector efficiency at different Φ for nanofluid(ZrO2 +DW)*

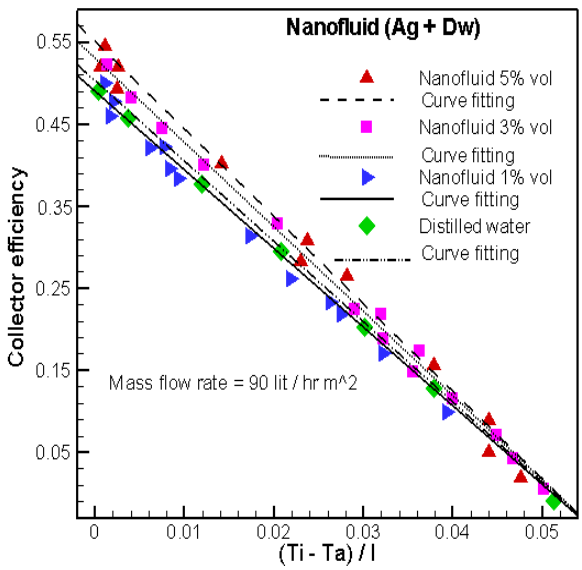

Fig 11. *Collector efficiency at different Φ for nanofluid(Ag +DW)*

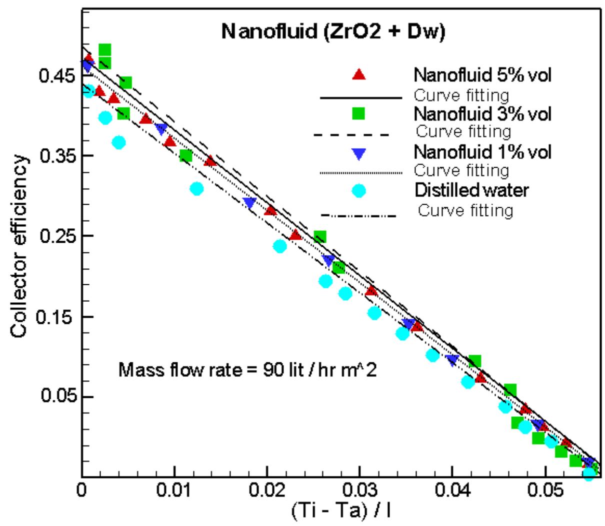

Fig 12. *Collector efficiency at different Φ for nanofluid(ZrO2 +DW)*

Diffusion and relative movement of nanoparticles near tube wall lead to rapid heat transfer from wall to nanofluid [24]. The slopes became steeper for nanofluids comparing to water which shows the effect of using nanofluids in enhancement of the collector heat removal factor (F_R). Another parameter for comparing the collector efficiency is ‘A’ (Area under the curve×100) that has been brought in Table 2. It represents the entire range of the collector efficiency (from X = 0 to X_{max}). Amounts of ‘A’ for three mass flow rate of distilled water are 1.29, 1. 31 and 1.33, respectively which proves the 1.55 % and 3.1% increase of second and third mass flow rate relevant to first mass flow rate. Also ‘A’ for three mass flow rates of nanofluid (ZrO_2 + DW) at 5%vol in comparison with mass flow rate of distilled water has increased by 6.20, 8.39 and 10.52%, respectively. While nanofluid (Ag + DW) at 5%vol were increased by 17.82, 19.09 and 21.05% respectively. Increasing mass flow rate or using nanofluids instead of base fluid are methods for increasing collector efficiency factor through increasing of heat transfer coefficient inside the tube (hfi) [23].

Figs.(13 – 18) indicated the temperature difference between inlet and outlet solar collector and the mass flow rate for the two types of nanofluids (Ag + DW) and (ZrO_2 + DW) with volume fraction (1, 3 and 5%vol) and distilled water, respectively. Since higher the concentration of nanoparticles, higher thermal conductivity of the working fluid was obtained then the fluid could get more heat rate from the solar collector. It could be seen that when the nanofluid concentration was increased, the temperature difference between inlet and outlet would be lower compared with that of distilled water. However, at 1% vol of silver and zirconium oxide nanoparticles, the insignificant results were obtained. It could be noted that for (3%vol , 5%vol) of silver and zirconium nanoparticles, especially for low mas flow rate (30 lit/hr m^2) and high inlet temperature, the temperature difference was more deviated from that of distilled water. This meant that the two types of nanofluids could get more heat rate thus the heat loss from the collector was less compared with that of distilled water. It was un doubtful that when the mass flow rate and the inlet temperature increased the temperature difference decreased.

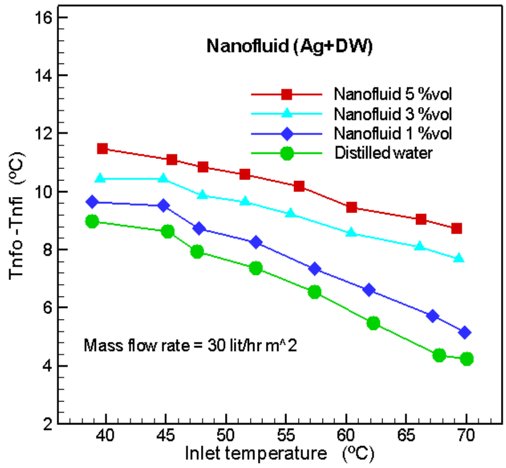

Fig 13. Variation of temperature between inlet and outlet Collector solar for (Ag + DW) at different Φ

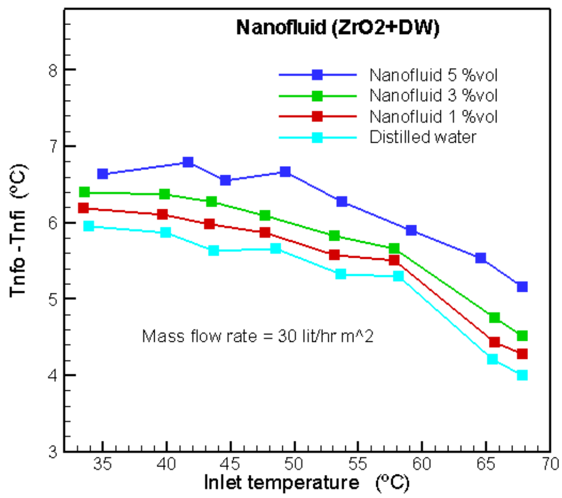

Fig 14. Variation of temperature between inlet and outlet Collector solar for (ZrO2 + DW) at different Φ

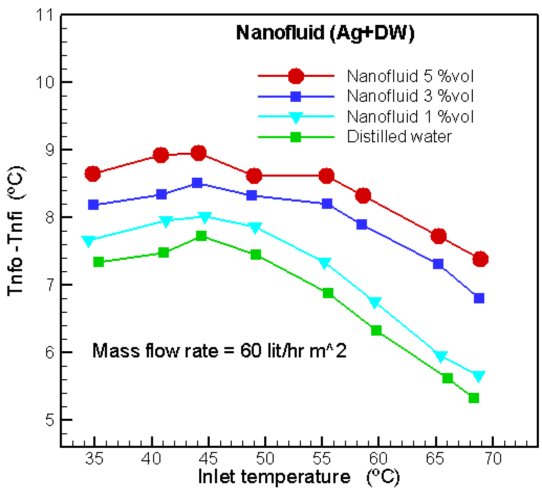

Fig 15. Variation of temperature between inlet and outlet Collector solar for (Ag + DW) at different Φ

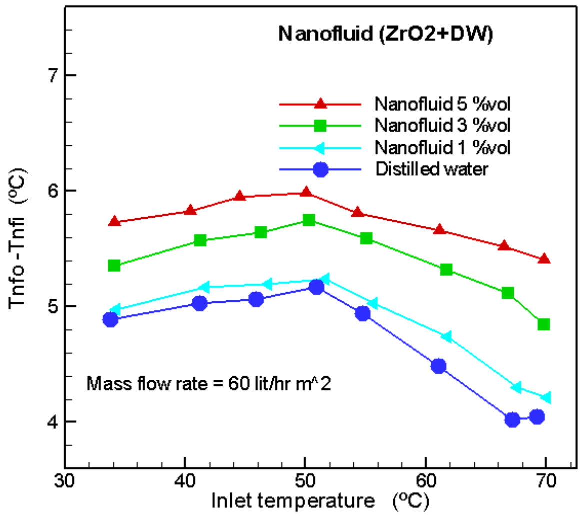

Fig 16. Variation of temperature between inlet and outlet Collector solar for (ZrO2 + DW) at different Φ

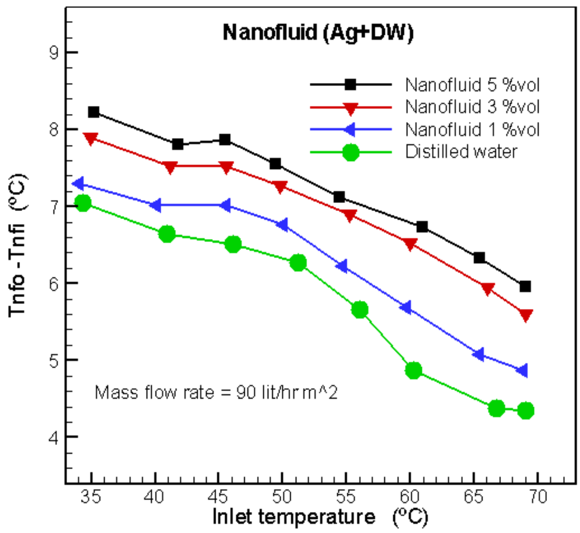

Fig 17. Variation of temperature between inlet and outlet Collector solar for (Ag + DW) at different Φ

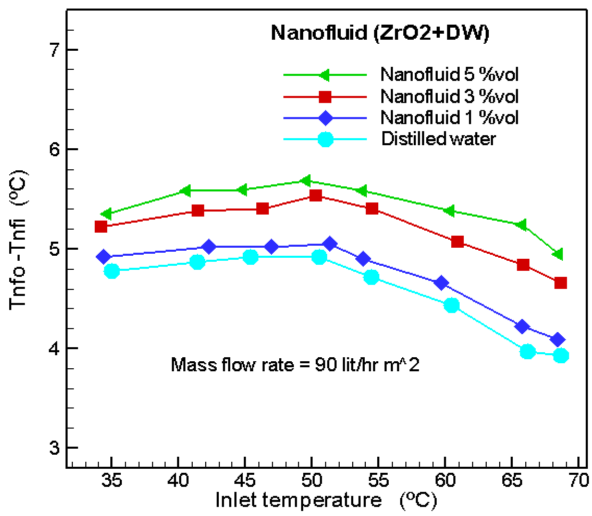

Fig 18. Variation of temperature between inlet and outlet Collector solar for (ZrO2 + DW) at different Φ

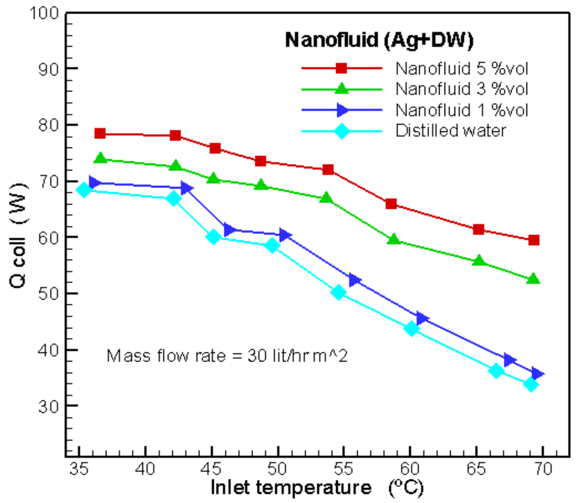

Fig 19. *Variation of useful heat gain from Collector solar At various Φ for nanofluid (Ag + DW)*

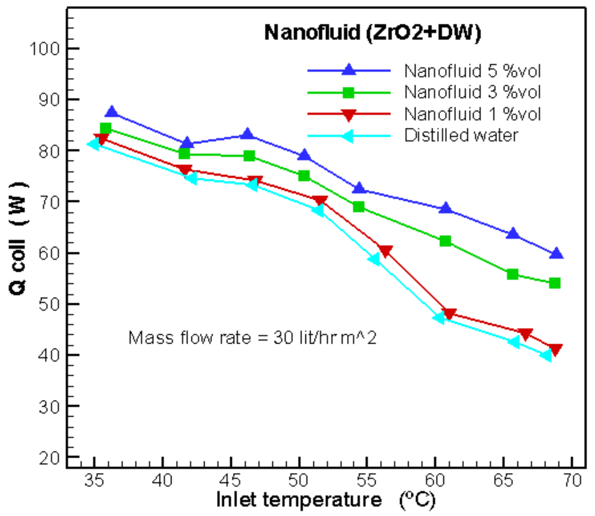

Fig 20. *Variation of useful heat gain from Collector sola At various Φ for nanofluid (ZrO2 + DW)*

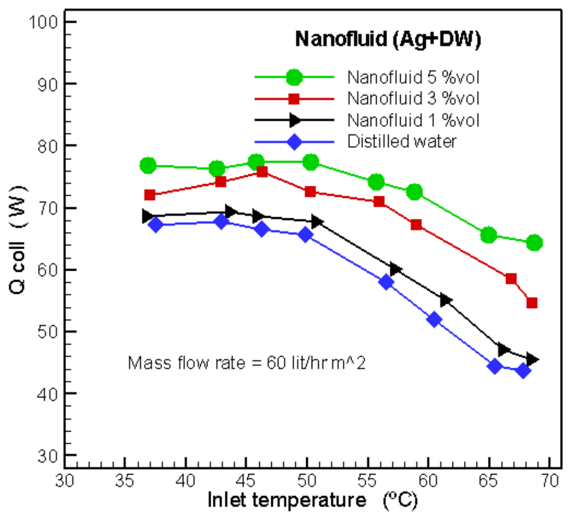

Fig 21. *Variation of useful heat gain from Collector solar At various Φ for nanofluid (Ag + DW)*

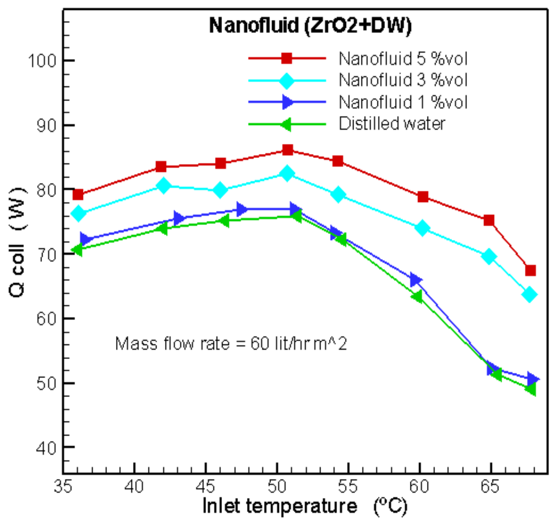

Fig 22. *Variation of useful heat gain from Collector sola At various Φ for nanofluid (ZrO2 + DW)*

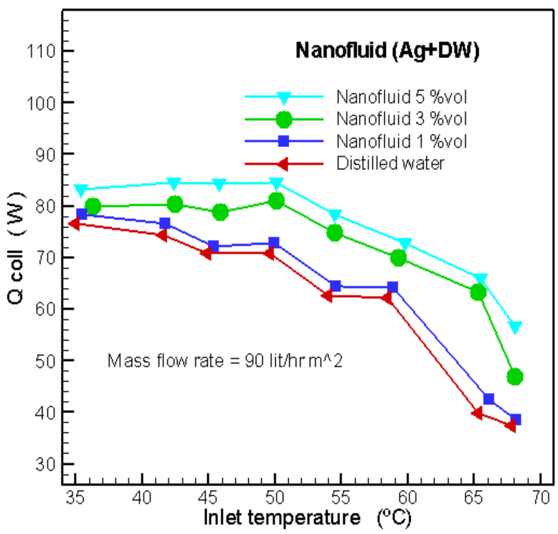

Fig 23. *Variation of useful heat gain from Collector solar At various Φ for nanofluid (Ag + DW)*

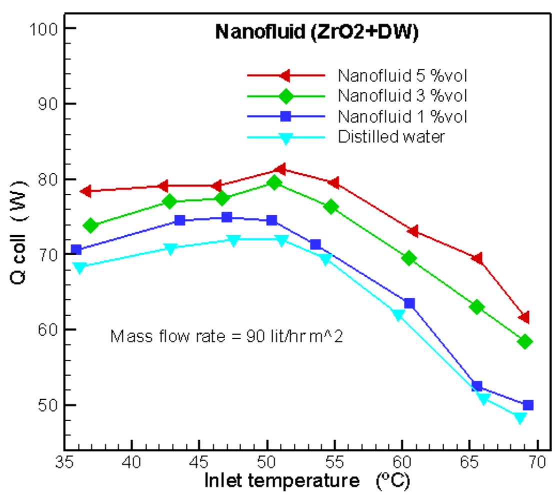

Fig 24. *Variation of useful heat gain from Collector solar At various Φ for nanofluid (ZrO2 + DW)*

Table 3. *The experimental results*

	Volume fraction % vol	$\dot{m}$ Lit/hr.m^2	Model	Area under curve X100 (A)	R^2
Distilled Water (DW)	0	30	$\eta = -0.973\ X + 0.413$	1.29	0.992
	0	60	$\eta = -0.989\ X + 0.435$	1.31	0.982
	0	90	$\eta = -1.011\ X + 0.442$	1.33	0.996
Nanofluid (ZrO_2+DW)	1%vol	30	$\eta = -1.025\ X + 0.437$	1.35	0.988
	3%vol	30	$\eta = -1.044\ X + 0.442$	1.36	0.977
	5%vol	30	$\eta = -1.064\ X + 0.449$	1.37	0.983
	1%vol	60	$\eta = -1.070\ X + 0.456$	1.38	0.994
	3%vol	60	$\eta = -1.078\ X + 0.463$	1.41	0.985
	5%vol	60	$\eta = -1.085\ X + 0.469$	1.42	0.993
	1%vol	90	$\eta = -1.09\ 0X + 0.472$	1.44	0.99
	3%vol	90	$\eta = -1.114\ X + 0.475$	1.46	0.996
	5%vol	90	$\eta = -1.140\ X + 0.480$	1.47	0.992
Nanofluid (Ag+DW)	1%vol	30	$\eta = -1.168\ X + 0.488$	1.49	0.994
	3%vol	30	$\eta = -1.175\ X + 0.492$	1.5	0.991
	5%vol	30	$\eta = -1.198\ X + 0.512$	1.52	0.995
	1%vol	60	$\eta = -1.212\ X + 0.534$	1.53	0.985
	3%vol	60	$\eta = -1.222\ X + 0.555$	1.55	0.992
	5%vol	60	$\eta = -1.231\ X + 0.563$	1.56	0.991
	1%vol	90	$\eta = -1.236\ X + 0.578$	1.57	0.979
	3%vol	90	$\eta = -1.239\ X + 0.585$	1.59	0.983
	5%vol	90	$\eta = -1.252\ X + 0.593$	1.61	0.983

The useful heat gains from the solar collectors at various inlet temperature, mass flow rate (30, 60 and 90 lit/hr m^2) and volume fraction (1, 3 and 5%vol) are shown in Figs (19 – 24). The changes were similar to those shown in Figs. (13 – 18). Moreover the nanofluids (Ag + DW, ZrO_2 + DW) at 5%vol showed better performance compared with distilled water while the nanofluid at 1%vol gave similar results with distilled water. The solar collector efficiency for nanofluid (Ag(30nm) was greater than nanofluid (ZrO_2(50nm)) due to small particle size for the silver compared with oxide zirconium as well as high thermal conductivity for silver. The type of nanofluid is a key factor for heat transfer enhancement, and improve performance of evacuated tube solar collector.

8. Conclusion

The thermal enhancement of solar collector performance was investigated with nanofluids (Ag(30nm)+DW) and (ZrO_2(50nm)+DW) as working fluid. The two types of nanoparticles are used in investigate with four particles concentration ratios (i.e. 0, 1, 3 and 5 % vol) and the based working fluid was distilled water. The summary results are as follows:

1. The nanofluids (Ag + DW), at concentrations (1, and 5%vol) and mass flow rates (30, and 90 lit/hr m^2), the thermal solar characteristics values of $F_R(\tau\alpha)$, $- F_R U_L$ were 0.488, 1.168 W/m^2.k , 0.593 and 1.252 W/m^2.k, while the nanofluid (ZrO_2 + DW) 0.437,1.025 W/m^2.k ,0.480 and 1.140 W/m^2.k respectively. Whereas in the case of distilled water at mass flow rates 30 lit/hr m^2 and 90 lit/hr m^2 were o.413,0.973 W/m^2.k,0.442 and ,1.011 W/m^2.k respectively .
2. Use of nanofluids (Ag(30nm) and ZrO_2(50nm)) as a working fluid could improve thermal performance of evacuated tube solar collector compared with distilled water, especially at high inlet temperature.
3. The solar collector efficiency for nanofluid (Ag(30nm) was greater than nanofluid (ZrO_2(50nm)) due to small particle size for the silver compared with oxide zirconium as well as high thermal conductivity for silver.

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