EXPERIMENTAL EVALUATION OF THE THERMAL PERFORMANCE IN THE SOLAR NANOFLUID HEATING SYSTEM BY USING CUPPER AND TITANIUM OXIDE

Dr. Khalid Faisal Sultan
Lecturer
Electromechanical. Eng. Dept
University of Technology
E– mail: ksultan61@yahoo.com

ABSTRACT :-

The objectives of this article is to study performance of solar nanofluid heating system when metal(Cu(30nm) +DW) and titanium oxide (TiO_2(50nm) +DW) nanofluids was taken as the working fluid as well as the effect of nanoparticles on solar nanofluid heating system. 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 in the investigation with four particles concentration ratios (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 Cu and TiO_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. ASHRAE 93 was used to test the solar collector. The experimental results indicated that the concentration at 1%vol showed insignificant results compared with distilled water. As well as The nanofluids (Cu + DW), at concentrations 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 0.581, 10.145W/m^2.K, 0.676 and 10.907 W/m^2.K, while the nanofluid (TiO_2 + DW) 0.482,9.093 W/m^2.k ,0.567 and 9.539 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 0.449,8.013 W/m^2.K,0.504 and ,8.101 W/m^2.K respectively. Moreover use of nanofluids (Cu (30nm) +DW) and (TiO_2 (50nm) +DW) as a working fluid could improve thermal performance of evacuated tube solar collector compared with distilled water, especially at high inlet temperature. The solar collector efficiency for nanofluid (Cu (30nm) +DW) was greater than nanofluid (TiO_2 (50nm) +DW) due to small particle size for the cupper compared with titanium 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 flat plate solar collector.

Key words: Evacuated tube solar collector, Thermal performance, Metal and oxide metal ,Nanofluid

التقييم التجريبي للإداء الحرارية لنظام تسخين الموائع النانوية بالطاقة الشمسية باستخدام النحاس واوكسيد التيتانيوم مع الماء المقطر

د. خالد فيصل سلطان
مدرس
قسم هندسة الكهرو ميكانيكية
الجامعة التكنلوجية

الخلاصة

هذا البحث يتناول دراسة عملية للاداء اللاقط الشمسي الانبوبي عند استخدام موائع نانوية معدنية مثل النحاس وغير معدنية مثل اوكسيد التيتانيوم والتي تكون هذه المواد المستعملة ذات موصلية حرارية عالية مقارنة بالماء المقطر مما تجعل اداء المجمع الشمسية يكون ذي كفاءة عالية . تم في هذه الدراسة استخدام نوعين من الموائع النانوية وبحجم حبيبي مختلف وهي (Cu (30nm) + DW), (TiO_2 (50nm) + DW) وبتراكيز حجمية (0, 1, 3, 5 % vol) وبمعدل تدفق كتلي (30, 60, 90 lit/hr m^2). تم في هذه الدراسة خلط الجزئيات النانوية مع الماء المقطر كمائع اساس كما تم استخدام عامل المساحة تحت المنحني لدراسة تأثير معدل جريان الكتلي وتركيز جزئيات النانوية على كفاءة الكلية للاقط الشمسي. النتائج التجريبية بينت ان تركيز 1% vol ليس له تأثير هام مقارنة مع الماء المقطر على العكس من ان تركيز 5% vol يكون له تأثير هام على اداء اللاقط الشمسي . بينت ايضا ان المائع النانوي من النحاس والماء المقطر وبتركيز حجمي مقداره (5 % vol) ان قيم خواص الاشعاع الحراري وهي $F_R(\tau\alpha), -F_RU_L$ 0.593 , 1.168 W/m^2.k, 0.488, 1.252 W/m^2.k,بينما المائع النانوي من اوكسيد التيتانيوم مع الماء المقطر كانت كالتالي 0.437,1.025 W/m^2.k 0.480,1.140 W/m^2.k على التوالي . بينما الماء المقطر 0.442 and ,1.011 W/m^2.k,0.413,0.973 W/m^2.k علاوة على ذلك ان استخدام الموائع النانوية مثل (Cu (30nm) + DW), (TiO_2 (50nm) + DW) يحسن اداء اللاقط الشمسية وخصوصا عند درجة حرارة الدخول العالية .وكفاءة اللاقط باستخدام (Cu (30nm) + DW) تكون اكبر من كفاءة اللاقط باستخدام (TiO_2 (50nm) + DW) بسب الحجم الحبيبي الصغيرة للنحاس مقارنة مع الحجم الحبيبي لأوكسيد التيتانيوم بالإضافة الى الموصلية العالية للنحاس . كما ان النوع الحبيبي يلعب دورا كبير في اداء اللاقط الشمسي الانبوبي.

Nomenclature :

V_p	Volume nanoparticle (m^3)
V_f	Volume of fluid (m^3)
Cp	Specific heat at constant pressure(J/kg K)
Cp_{DW}	Heat capacity of distilled water (J/kg K)
Cp_s	Heat capacity of nanoparticles (J/kg K)
Cp_{nf}	Heat capacity of nanofluid (J/kg K)
K_{nf}	Thermal conductivity of nanofluid (W/m K)
K_{DW}	Thermal conductivity of distilled water (W/m K)
Qu	Rate of useful energy gained (W)
Qcoll	Heat rate from solar collector (W)
Ac	Surface area of solar collector(m^2)
F_R	Heat removal factor
I	solar radiation(W/m^2)
U_L	Overall heat loss (W/m^2 °C)
Ta	The ambient temperature (°C)
Tfo	Outlet temperature (°C)
Tfi	Inlet temperature (°C)
m	Mass flow rate of fluid flow (Lit/s)
F '	Collector efficiency factor
hfi	Heat transfer coefficient inside the tube (W/m^2 K)
F	Fin efficiency
Ui	Overall loss coefficient of solar collector (W/m^2 K)
D	Tube outside diameter (mm)
Di	Tube inside diameter (mm)
R^2	Coefficient of determination

Greek symbols

μ_{DW}	The Viscosity of distilled water (m^2/s)
ρ_{nf}	The density of nanofluid (kg/m^3)
ρ_{DW}	The density of distilled water (kg/m^3)
μ_{nf}	The Viscosity of nanofluid (m^2/s)
$\alpha\tau$	The transmittance - absorptance product
η	Collector efficiency (%)
η_o	Initial efficiency
ηi	Instantaneous efficiency
Φ	volume fraction of nanoparticles in 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, [2013]. Renewable energy sources such as sun energy can be substituted for exceeding human energy needs, Taki et al. [2011] . Solar energy as one of the most significant forms of renewable energy sources has drawn a lot of attention as it can play a very important role in meeting a major part of our futures' need to energy, Hedayatizadeh et al. [2013]. 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 are the main disadvantages. Hence, collection 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, [2011]. Water heating by solar energy is the most important application of direct solar energy use in the world today Wongsuwan and Kumar [2005], 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, [2012]. Up to now, there are also many studies conducted with the introduction of heat exchanger into the thermo syphon SWH systems. A detailed theoretical analysis along with the experiments have been done incorporating coiled copper tube as internal heat exchanger placed inside the storage tank by Koffi et al. [2008]. Their results showed a 58% collector thermal effectiveness with a hot water temperature of 85 ^{0}C which was tested in the West African meteorological region; Jaisankar et al. [2009a, 2009b] studied on the increase in heat delivery of thermo syphon systems, as well as many studies have been carried out in the field of solar water heating to improve the thermal efficiency of SWH system, which mainly includes the water – in – glass evacuated tube SWH systems. Alshamaileh [2010]; Kumar and Rosen [2010]. 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.,[2011]; 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.,[2013]; 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 [2009] 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. [2010a, 2010b] 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. [2011] 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 copper (Cu) and titanium oxide (TiO_2) – distilled water nanofluids, mass flow rate, concentration, and nanoparticles size and type on solar collector performance more over efficiency of the collector.

2. PREPARATION OF COPPER AND TITANIUM OXIDE NANOFLUIDS

The studied nanofluids are formed by copper (Cu (30 nm)) and titanium oxide (TiO_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 nanofluid 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, resulted in uniform dispersions for the duration of the experiments. The prepared nanofluids could stay stable for 4 hours at least. figure (1) shows nanofluids containing (Cu (30 nm)) and titanium oxide (TiO_2 (50 nm)). Nanofluids with different volume fractions (Φ= 1, 3, and 5vol %) are used.

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. 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 evacuated tube solar collector, 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.

4. MEASUREMENT OF NANOFLUID THERMAL PROPERTIES :-

All physical properties of the nanofluids (Cu, TiO_2 + DW) and distilled water are needed to calculate the useful heat energy, thermal energy ,collector efficiency and the convective heat transfer . The dynamic viscosity (μ) is measured using brook field digital viscometer model DV – E. The thermal conductivity and specific heat are measured by Hot Disk Thermal Constants Analyzer and specific heat apparatus (ESD – 201). 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 practical with different volume concentrations at 0,1%, , 3%, and 5 %vol.

5. ESTIMATION OF NANOFLUID THERMO PHYSICAL PROPERTIES

Empirical relations are used in this study to estimate nanofluid physical properties which are compared with the 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 Khanafer et al.,[2011].

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

The thermal physical properties of nanofluid is calculated using equations of Kumar, R., & Rosen, [2010].

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

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

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

Recently Chandrasekar et al.[2010] presented an effective thermal conductivity model (Eq.5)

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

6. DATA ANALYSIS AND VALIDATION

The temperature, 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

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

Therefore,

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

F_R may be obtained from

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

Then the collector efficiency is obtained by using the relation,

$$\eta=\frac{Q_u}{A_c\ I} \quad (11)$$

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

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

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

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

Therefore , the plots of instantaneous efficiency (η_i) versus $\frac{\left(T_i-T_a\right)}{I}$ would be straight lines with intercept $F_R(\tau\alpha)$ and slope – $F_R U_L$. However, they are not and scattered data are expected. 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 – $F_R U_L$), [19]. Using curve fitting tool box of Mat lab, a line was fitted to experimental data of thermal efficiency versus the reduced temperature parameters, $\frac{\left(T_i-T_a\right)}{I}$, 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

The ambient temperature and wind speed on 25 th of March 2013 (clear day) measured in Baghdad latitude 34^0 North and long 33^0 East. The maximum ambient temperature was 25 ^{0}C at 1.00 Pm, while in consider variation in wind speeds is indicated. The global solar radiation was 200 W/m^2 and 800 W/ m^2 at 8.00 Am and 1.00 Pm respectively. First of all the collector was tested for distilled water as working fluid. The experimental results as shown in Figs. (6 – 12) and Table 3. These figures show the performance curves of the solar collectors under the Draft ASHRAE [2009], Standard with copper (Cu) and titanium oxide (TiO_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 (Cu + DW) and,(TiO_2+DW) at 5% vol were higher than that for distilled water due high thermal conductivity compared with distilled water. Again, the nanofluids (Cu + DW) and,(TiO_2+ DW) at 1 % vol still gave similar result with distilled water. For the nanofluids (Cu + DW), at concentrations 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 0.581, 10.145W/m^2.k , 0.676 and 10.907 W/m^2.k, while for the nanofluid (TiO_2 + DW) 0.482,9.093 W/m^2.k ,0.567 and 9.539 W/m^2.k respectively. for the case of distilled water at mass flow rates 30 lit/hr m^2 and 90 lit/hr m^2 were 0.449,8.013 W/m^2.k,0.504 and ,8.101 W/m^2.k respectively. This meant that using of nanofluids (Cu + DW) and,(TiO_2 + DW) as a working fluid was able to increase solar collector performance. Then 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 approach zero (in X_{max}).

Diffusion and relative movement of nanoparticles near tube wall lead to rapid heat transfer from wall to nanofluid, Kahani, et al.,[2013]. 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 3. 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 1.28, 1. 30 and 1.33, respectively which show the 1.56 % and 3.07% increase of second and third mass flow rate relevant to first mass flow rate. Also 'A' for three mass flow rates of nanofluid (TiO_2 + DW) at 5%vol in comparison with mass flow rate of distilled water has increased by 7.81, 10 and 11.27%, respectively. While nanofluid (Cu + DW) at 5%vol were increased by 17.96, 20.7 and 22.55% respectively. Increasing mass flow rate or using nanofluids instead of base fluid are methods for increasing collector efficiency factor (F') through increasing of heat transfer coefficient inside the tube (hfi), Duffie et al.,[1991].

$$F' = \frac{\dfrac{1}{Ui}}{W\left[\dfrac{1}{U_i\left[D+\left(W-D\right)F\right]}+\dfrac{1}{C_b}+\dfrac{1}{\pi D_i h_i}\right]}$$

Figs.(13 – 18) indicated the temperature difference between inlet and outlet solar collector and the mass flow rate for the two types of nanofluids (Cu + DW) and (TiO_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 higher compared with that of distilled water. However, at 1% vol of copper and titanium oxide nanoparticles, the insignificant results were obtained. It could be noted that for (3%vol , 5%vol) of copper and titanium 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. 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 (Cu + DW, TiO_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 (Cu (30nm) was greater than nanofluid (TiO_2 (50nm)) due to small particle size for the copper compared with titanium oxide as well as high thermal conductivity for copper. 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 (Cu (30nm)+DW) and (TiO_2 (50nm)+DW) as working fluid. The two types of nanoparticles are used in investigation 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. When the concentration of nanofluid (Cu (30nm) + DW) and (TiO_2 (50nm) + DW) increased more heat from solar collector or less heat loss was obtained then the difference between inlet and outlet temperatures of the working fluid from the evacuated tube solar collector increased. However, the concentration at 1%vol showed insignificant results compared with distilled water.
2. For the nanofluids (Cu + DW), at concentrations 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 0.581, 10.145W/m^2.k , 0.676 and 10.907 W/m^2.k, while the nanofluid (TiO_2 + DW) 0.482,9.093 W/m^2.k ,0.567 and 9.539 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 0.449,8.013 W/m^2.k,0.504 and ,8.101 W/m^2.k respectively.
3. The type of nanofluid is a key factor for heat transfer enhancement, and improvement performance of evacuated tube solar collector.
4. Use of nanofluids (Cu (30nm) + DW) and(TiO_2 (50nm) + DW) as a working fluid could improve thermal performance of evacuated tube solar collector compared with distilled water, especially at high inlet temperature.
5. The solar collector efficiency for nanofluid (Cu (30nm) + DW) was greater than nanofluid (TiO_2 (50nm) + DW) due to small particle size for the copper compared with titanium oxide as well as high thermal conductivity for copper.

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

Table .2. Thermo – physical properties of the nanofluids employed, J.P.Holman [2008].

Nano sized particles	ρ (kg/m^3)	Cp (J/kg K)	k (W/m K)	Mean diameter (nm)
Copper (Cu)	8933	385	401	30
Titanium oxide (TiO_2)	4250	686.2	8.9538	50

Table .3.The experimental results

Components	Volume fraction % vol	$\dot{m}$ Lit/hr.m^2	Model	Area under curve X100 (A)	R^2
Distilled Water (DW)	0	30	$\eta = -8.013\ X + 0.449$	1.28	0.972
	0	60	$\eta = -8.065\ X + 0.463$	1.30	0.975
	0	90	$\eta = -8.101\ X + 0.504$	1.33	0.986
Nanofluid (TiO_2 + DW)	1%vol	30	$\eta = -8.165\ X + 0.467$	1.36	0.978
	3%vol	30	$\eta = -9.034\ X + 0.471$	1.37	0.977
	5%vol	30	$\eta = -9.093\ X + 0.482$	1.38	0.983
	1%vol	60	$\eta = -9.110\ X + 0.492$	1.39	0.974
	3%vol	60	$\eta = -9.163\ X + 0.510$	1.42	0.975
	5%vol	60	$\eta = -9.223\ X + 0.536$	1.43	0.983
	1%vol	90	$\eta = -9.314\ X + 0.553$	1.45	0.993
	3%vol	90	$\eta = -9.493\ X + 0.562$	1.47	0.986
	5%vol	90	$\eta = -9.539\ X + 0.567$	1.48	0.981
Nanofluid (Cu+DW)	1%vol	30	$\eta = -10.145\ X + 0.581$	1.49	0.994
	3%vol	30	$\eta = -10.193 X + 0.592$	1.49	0.982
	5%vol	30	$\eta = -10.234\ X + 0.601$	1.51	0.990
	1%vol	60	$\eta = -10.325\ X + 0.615$	1.53	0.973
	3%vol	60	$\eta = -10.434 X + 0.622$	1.55	0.984
	5%vol	60	$\eta = -10.475\ X + 0.631$	1.57	0.972
	1%vol	90	$\eta = -10.544\ X + 0.645$	1.57	0.982
	3%vol	90	$\eta = -10.602\ X + 0.662$	1.59	0.984
	5%vol	90	$\eta = -10.907\ X + 0.676$	1.63	0.992

Fig.1 Show nanofluids for TiO_2 + distilled water , Cu + distilled water and distilled water

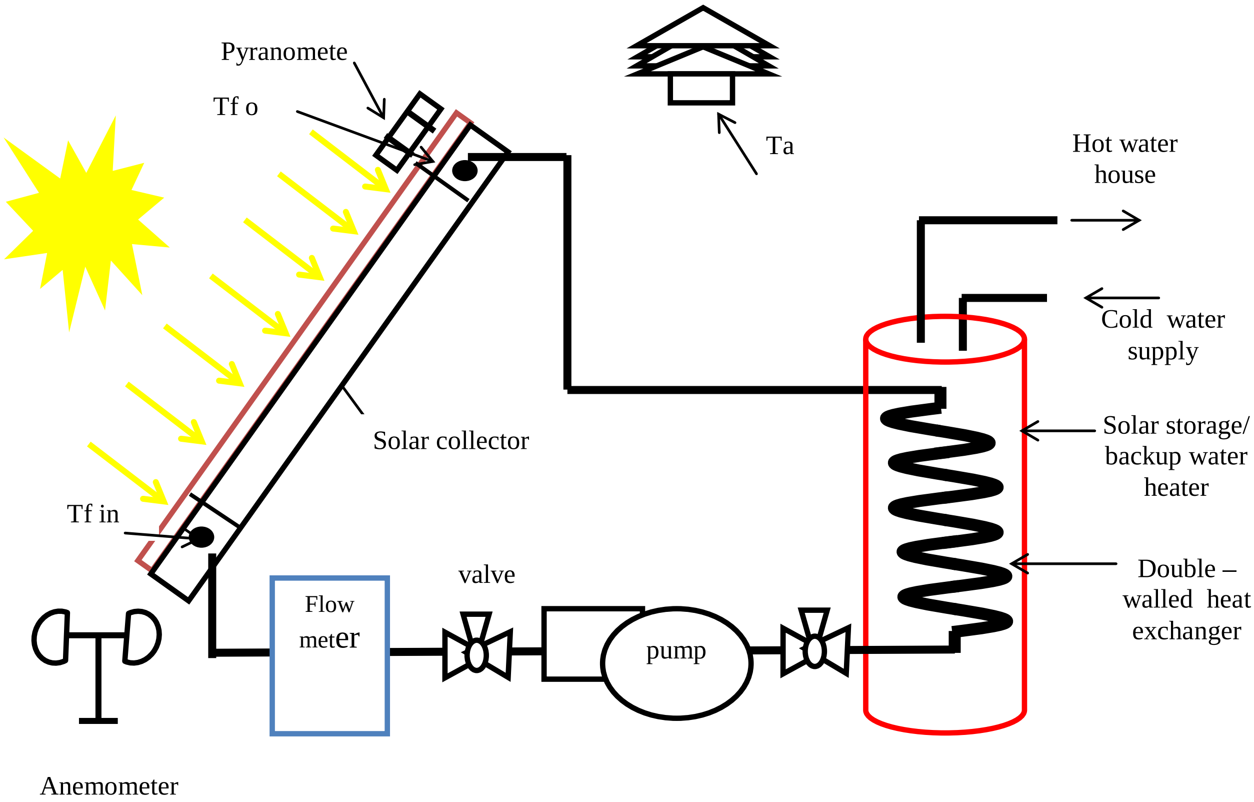

Fig 2. The experimental set up schematic

Fig 3. The experimental evacuated tube solar collector

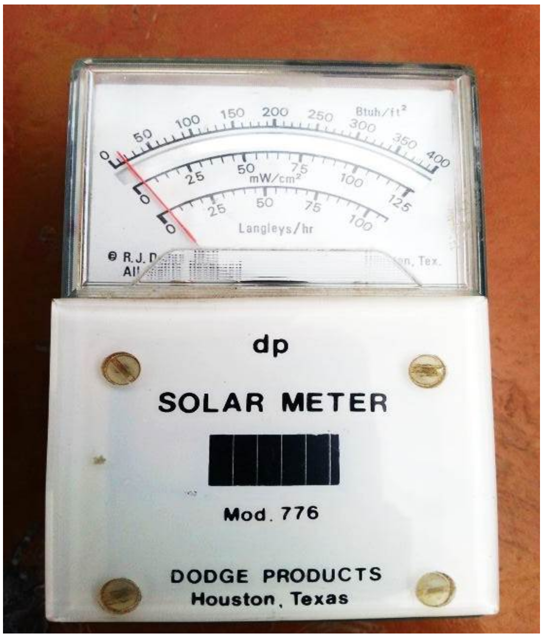

Fig 4. Solar power meter

Fig 5. Anemometer

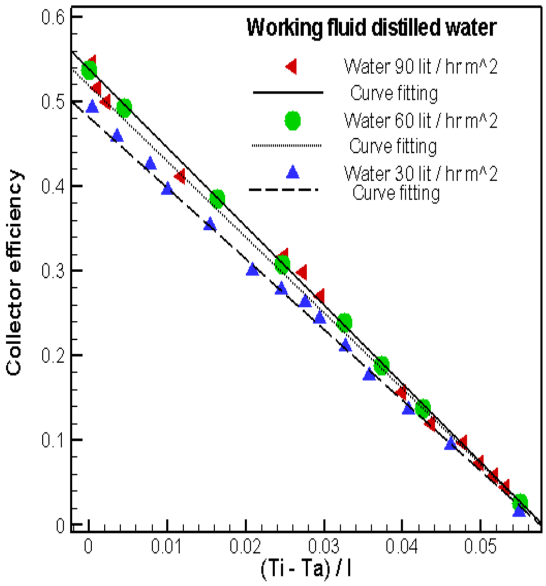

Fig.6 Collector efficiency for three mass flow rate of water as working fluid in

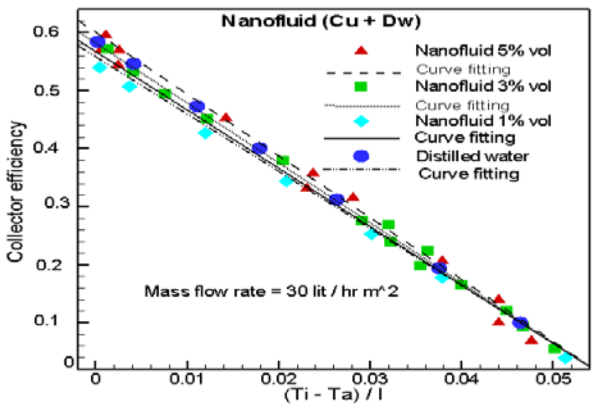

Fig 7. Collector efficiency for mass flow rate 30 lit/ hr m^2 at different Φ for nanofluid (Cu + DW)

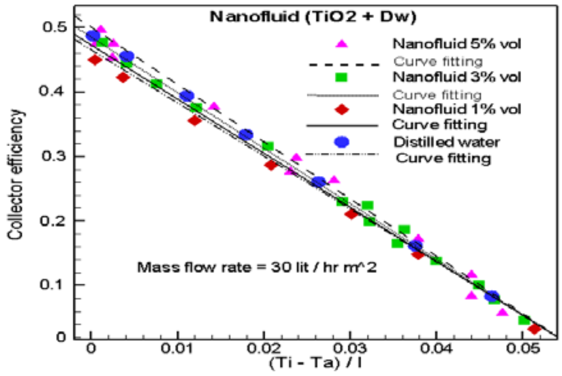

Fig 8. Collector efficiency for mass flow rate 30 lit/ hr m^2 at different Φ for nanofluid (TiO_2 + DW)

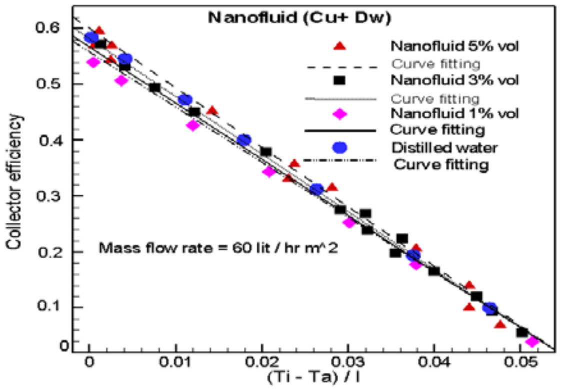

Fig 9. Collector efficiency for mass flow rate 60 lit/ hr m^2 at different Φ for nanofluid (Cu +DW)

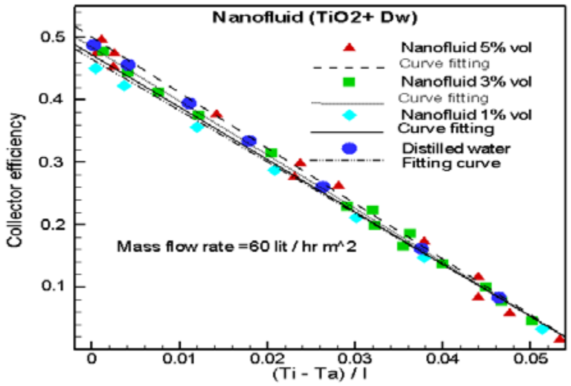

Fig 10. Collector efficiency for mass flow rate 60 lit/ hr m^2 at different Φ for nanofluid (TiO_2 +DW)

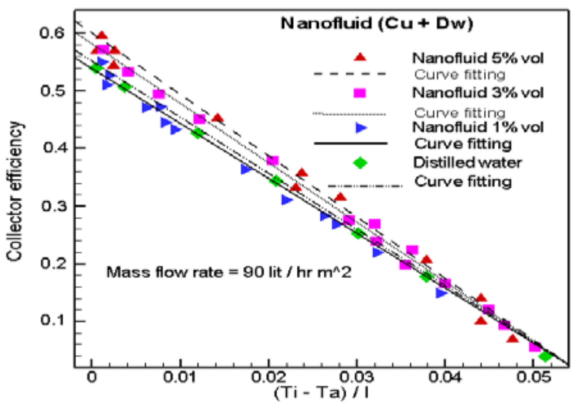

Fig 11. Collector efficiency for mass flow rate 90 lit/ hr m^2 at different Φ for nanofluid (Cu +DW)

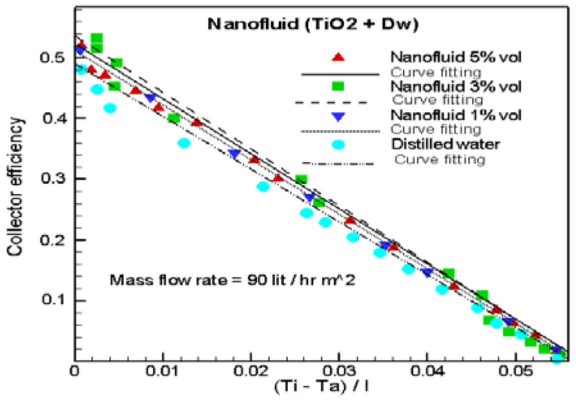

Fig 12. Collector efficiency for mass flow rate 90 lit/ hr m^2 at different Φ for nanofluid (TiO_2 +DW)

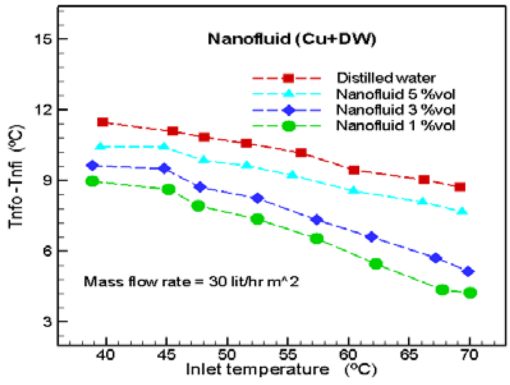

Fig 13. Variation of temperature between inlet and outlet collector solar for (Cu + DW) at different Φ

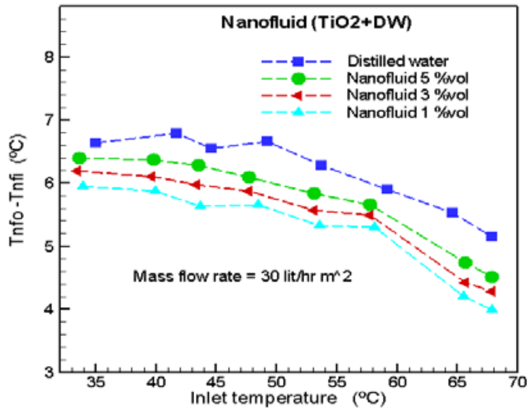

Fig 14. Variation of temperature between inlet and outlet collector solar for (TiO_2 + DW) at different Φ

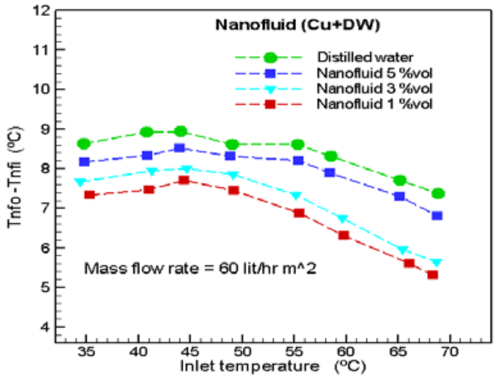

Fig 15. Variation of temperature between inlet and outlet collector solar for (Cu + DW) at different Φ

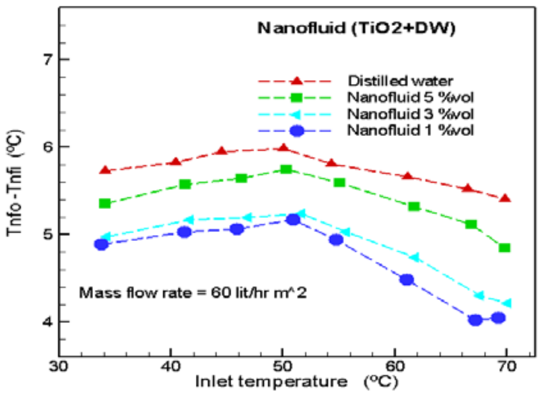

Fig 16. Variation of temperature between inlet and outlet collector solar for (TiO_2 + DW) at different Φ

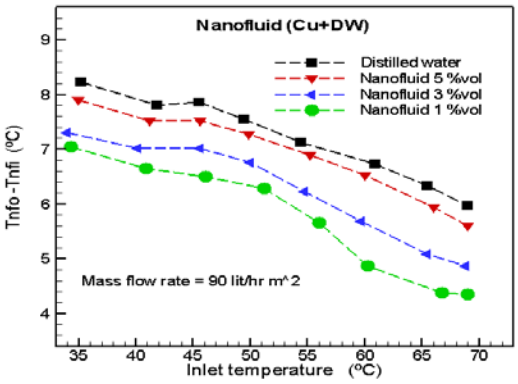

Fig 17. Variation of temperature between inlet and outlet collector solar for (Cu + DW) at different Φ

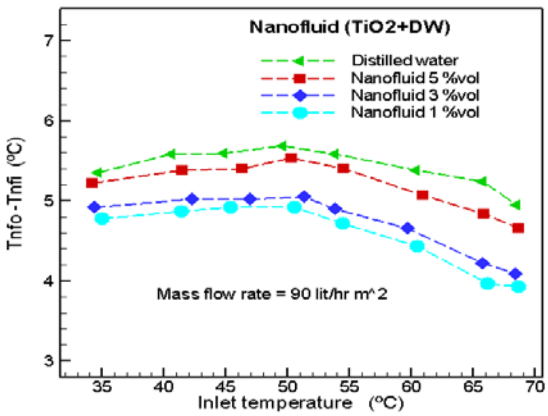

Fig 18. Variation of temperature between inlet and outlet collector solar for for (TiO_2 + DW) at different Φ

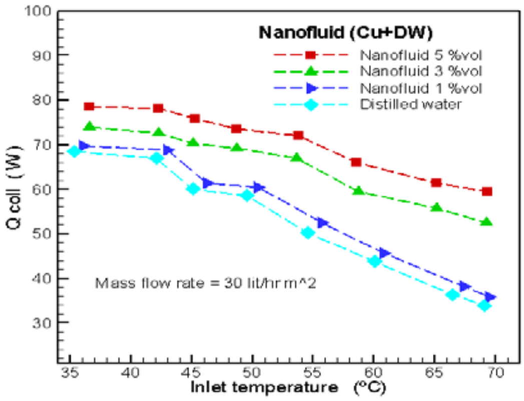

Fig 19. Variation of useful heat gain from collector solar at various Φ for nanofluid (Cu + DW)

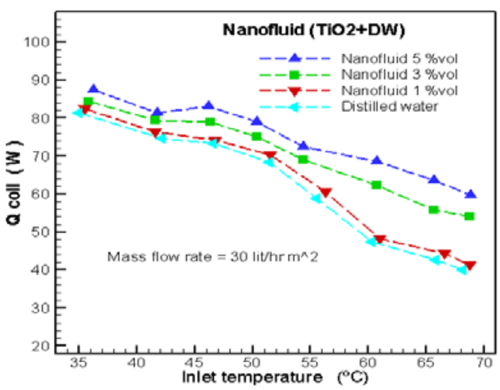

Fig 20. Variation of useful heat gain from collector sola at various Φ for nanofluid (TiO_2 + DW)

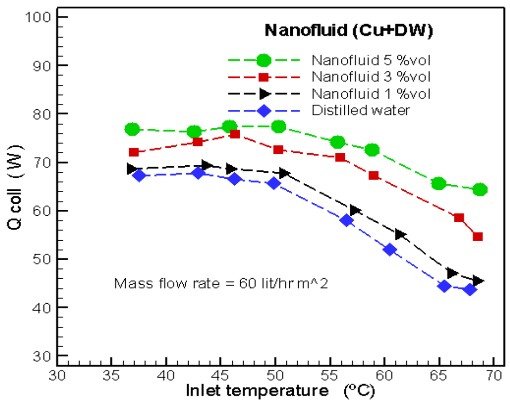

Fig 21. Variation of useful heat gain from collector solar at various Φ for nanofluid (Cu + DW)

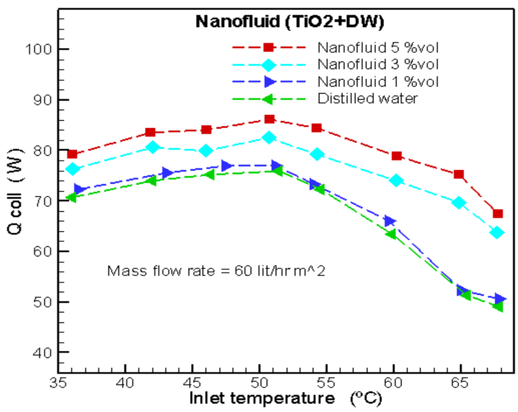

Fig 22. Variation of useful heat gain from collector sola at various Φ for nanofluid (TiO_2 + DW)

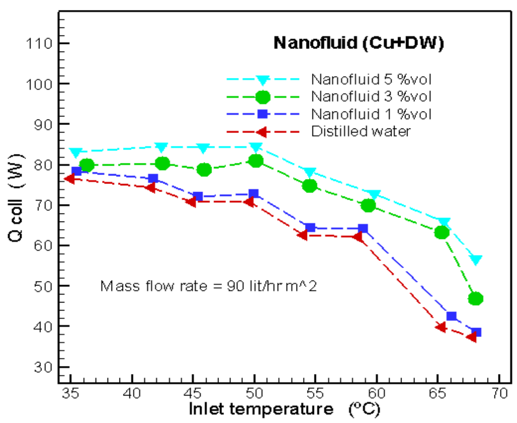

Fig 23. Variation of useful heat gain from collector solar at various Φ for nanofluid (Cu + DW)

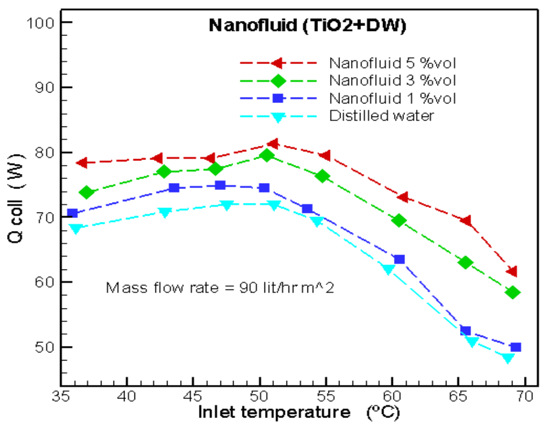

Fig 24. Variation of useful heat gain from collector solar at various Φ for nanofluid (TiO_2 + DW)

REFERENCES :-

Ali, M. H. "Analysis Study of Solar Tower Power Plant & Its Configuration Effects on Its Performance in Iraq (Baghdad City)". Modern Applied Science, 7(4), 55 – 69, 2013.

Alshamaileh, E. "Testing of a new solar coating for solar water heating applications. Solar Energy", 84,1637 – 1643, 2010.

Chandrasekar M., Suresh S., Chandra Bose A., Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al_2O_3/ water nanofluids. Exp. Thermal and Fluid Sci.34 , 210, 2010.

Das, S. K., Choi, S. U. S., Yu, W., & Pradeep, T. "Nanofluid Science and Technology". John Wiley & Sons, Inc., Publication, 2007.

Draft ASHRAE Standards, Proposed standards77 – 93,Third Public Review (May 2009).

Duffie, J. A., & Beckman, W. A. "Solar engineering of thermal processes". Wiley publication Hedayatizadeh, M., Ajabshirchi, Y., Sarhaddi, F., Safavinejad, A., Farahat, S.,1991.

Hedayatizadeh, M., Ajabshirchi, Y., Sarhaddi, F., Safavinejad, A., Farahat, S., & Chaji, H. "Thermal and Electrical Assessment of an Integrated Solar Photovoltaic Thermal (PV/T) Water Collector Equipped with a Compound Parabolic Concentrator (CPC)". International Journal of Green Energy, 10(5), 494 – 522 ,2013.

Jaisankar, S., Radhakrishnan, T. K., & Sheeba, K. N. " Experimental studies on heat transfer and friction factor characteristics of thermosyphon solar water heater system fittedith spacer at the trailing edge of twisted tapes". Applied Thermal Engineering, 29, 1224 – 1231 ,2009a.

Jaisankar, S., Radhakrishnan, T. K., & Sheeba, K. N. " Experimental studies on heat transfer and friction factor characteristics of forced circulation solar water heater system fitted with helical twisted tapes". Solar Energy, 83, 1943 – 1952 ,2009b.

J.P.Holman, Heat transfer,8th ed. 2008.

Kumar, R., & Rosen, M. A. "Integrated collector – storage solar water heater with extended storage unit". Applied Thermal Engineering, 31, 348 – 354 , 2011.

Koffi, P. M. E., Andoh, H. Y., Gbaha, P., Toure, S., & Ado, G. "Theoretical and experimental study of solar water heater with internal exchanger using thermo siphon system". Energy Conversion and Management, 49, 2279 – 2290 ,2008.

Kumar, R., & Rosen, M. A.. Thermal performance of Integrated collector – storage solar water heater with corrugated absorber surface. Applied Thermal Engineering, 30, 1764 – 1768,2010.

Khanafer K, Vafai K, A Critical syntesis of thermophysical Characteristics of Nanofluids, International Journal of Heat and Mass transfer(Under Press), 2011.

Kahani, M., Zeinali Heris, S., & Mousavi, S. M." Comparative study between metal oxide nanopowders on thermal characteristics of nanofluid flow through helical coils". Powder Thechnology, 246, 82 – 92 ,2013.

Natarajan, E., & Sathish, R. "Role of nanofluids in solar water heater". The International Journal of Advanced Manufacturing Technology,23,1876 – 8 ,2009.

Otanicar, T., & Golden, J. "Comparative environmental and economic analysis of conventional and nanofluid solar hot water technologies". Environ. Sci. Technol., 43, 6082e7,2009.

Rezania, A., Taherian, H., & Ganji, D. D. "Experimental Investigation of a Natural Circulation Solar Domestic Water Heater Performance Under Standard Consumption Rate". International Journal of Green Energy, 9(4), 322 – 334, 2012.

Taki, M., Ajabshirchi, Y., Behfar, H., & Taki, M. "Experimental Investigation and Construction of PV Solar Tracker Control System Using Image Processing". Modern Applied Science, 5(6), 237 – 244,2011.

Tiwari, A., K. Pradyumna Ghosh, P., Sarkar, J. "Solar Water Heating Using Nanofluids –A Comprehensive Overview And Environmental Impact Analysis". International Journal of Emerging Technology and Advanced Engineering, 3(Special Issue 3), 221 – 224. . 2013.

Taylor, R. A., Phelan, P. E., Otanicar, T. P., Walker, C. A., Nguyen, M., Trimble, S., & Prasher, R. "Applicability of Nanofluids in High Flux Solar Collectors". Renewable and Sustainable Energy, 3(2), 023104,2011.

Wongsuwan, W., & Kumar, S. "Forced circulation solar water heater performance prediction by TRNSYS and ANN". International Journal of Sustainable Energy, 24(2), 69 – 86 ,2005.

Yousefi, T., Veysy, F., Shojaeizadeh, E., & Zinadini, S. An experimental investigation on the effect of Al2O3-H2O nanofluid on the efficiency of flat-plate solar collectors. *Renewable Energy*, *39*, 293 – 298 ,2012a.

Yousefi, T., Veysy, F., Shojaeizadeh, E., & Zinadini, S. "An experimental investigation on the effect of MWCNT – H2O nanofluid on the efficiency of flat – plate solar collectors". Experimental Thermal and Fluid Science, *39*, 207 – 212, 2012b.