DESIGN AND IMPLEMENTATION OF V – TROUGH TUBE SOLAR COLLECTOR TO IMPROVEMENT THE PERFORMANCE BY USING HYBRID NANOFLUIDS

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ABSTRACT :-

This article includes the design and improvement of the performance of V trough tube collector in solar heating systems by using hybrid nanofluids, when hybrid metal (Cu (20nm) +Al (20nm) +DW), hybrid metal oxide (CuO (50nm) +Al_2O_3 (50nm) +DW) and distilled water are taken as the working fluids. The effects of metal and metal oxides hybrid nanoparticles are taken into consideration on solar hybrid nanofluid heating system. In experiments two types of hybrid nanoparticles are used with volume flow rate (20 and 40 lit/hr) and four hybrid nanoparticles concentration ratios (i.e. 1, 2, 3 and 5 % vol). The distilled water used as base fluid. The working fluid with the higher thermal conductivity in V – trough tube solar collector could improve heat transfer compared with that of distilled water. The hybrid nanofluids (Cu (20nm) +Al (20nm) +DW) at 5 % vol and volume flow rate (20, and 40 lit/hr) indicated significant effects through the thermal solar characteristics values of $F_R(\tau\alpha)$, – F_RU_L were 0.524, – 7. 276 W/m^2. K, 0.551 and – 7.423 W/m^2.k, while the hybrid nanofluids (CuO (50nm) +Al_2O_3 (50nm) +DW) were 0.473, – 6.183 W/m^2. K, 0.492 and – 6.224 W/m^2. K. The synergistic between nanoparticles and type of hybrid nanofluid are a key factor for heat transfer improvement, and improve performance of (V) trough tube solar collector. Use of hybrid nanofluids (Cu (20nm) +Al (20nm) +DW) and (CuO (50nm) +Al_2O_3 (50nm) +DW) as a working fluid could improve thermal performance due to high thermal conductivity for copper and aluminum. At high inlet temperature, this kind (V trough tube) of solar furnace could improve the thermal performance by hybrid nanofluids compared with distilled water.

Keywords: V – Trough tube, hybrid nanofluid, hybrid metal, hybrid metal oxide

تصميم وتنفيذ مجمع شمسي ذو أنبوب داخل قناة على شكل حرف V لتحسين الأداء باستخدام موائع نانوية هجينة

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الخلاصة :-

يتضمن هذا البحث تصميم وتحسين مجمع انبوبي داخل قناة ذات مقطع على شكل حرف (V) في انظمة التسخين الشمسية . تم استعمال نوعين من المواد النانويه الهجينة وذات اقطار نانوية كما هو (النحاس و الالمنيوم (Cu (20nm) +Al (20nm) +DW) وأوكسيد الالمنيوم النحاس (CuO (50nm) +Al_2O_3 (50nm) +DW) كما تم استخدام الماء المقطر كمائع اساس. اخذ في الدراسة تأثير المواد الهجينة المعدنية وغير المعدنية على انظمة التسخين الشمية. في التجارب تم استخدام نوعين من المواد النانويه الهجينة وأربع نسب حجمية ذات تركيز (1,2, 5,3% vol) ومعدل تدفق جريان 20 ، 40 liter/ hr).

Received: 2016 - 8 - 7
Accepted :2016 - 11- 13

بينت الدراسة ان الموائع النانوية الهجينة تكون ذات موصلية حرارية أعلى من السوائل في انظمة الطاقة الشمية كما تعمل على تحسين أداء انظمة الطاقة الشمية مقارنة مع من الماء المقطر. وأشارت النتائج التجريبية أن التركيز 5 % vol يظهر تحسين افضل في الخواص الحرارية الشمسية باستخدام الموائع النانوية الهجينة مقارنة مع الماء المقطر. حيث كانت) للنوع الاول (0.524, – 7. 276, 0.551 , – 7.423,) W/m^2. K و للنوع الثاني 0.473, – 6.183, (0.492, 6.224) W/m^2. K . يعتبرالتناغم بين جزئيات المواد النانوية الهجينة ونوع المائع النانوي الهجينة عامل رئيسي لتعزيز انتقال الحرارة وتحسين أداء هذا النوع من المجمعات. كما ان استخدام المائع النانوي الهجين في المجمع الشمسي يحسن الأداء الحراري افضل من الماء المقطر بسبب حجم الحبيبات النانوية الهجينة والموصلية الحرارية العالية .

الكلمات المفتاحية : انبوب في قناة على شكل V، موائع نانوية هجينة ، معدن هجين ، اوكسيد المعدن الهجين

NOMENCLATURE :-

Ac	Surface area of solar collector(m^2)
Cp_{DW}	Heat capacity of distilled water (J/kg K)
Cp_{hpnf}	Heat capacity of hybrid nanofluid (J/kg K)
D	Tube outside diameter
Di	Tube inside diameter
F	Fin efficiency
F_R	Heat removal factor
I	solar radiation(W/m^2)
$K_{h\,b\,nf}$	Thermal conductivity of hybrid nanofluid (W/m K)
K_{DW}	Thermal conductivity of distilled water (W/m K)
Q	Volume flow rate of fluid flow (l/s)
Qu	Rate of useful energy gained (W)
Qcoll	Heat rate from solar collector (W)
R^2	Coefficient of determination
Tf	Working fluid temperature (^oC)
Tfi	Inlet temperature (^oC)
Ta	The ambient temperature (oC)
Tfo	Outlet temperature (^oC)
U_L	Overall heat loss ($W/m^2\ ^oC$)
Ui	Overall loss coefficient of solar collector ($W/m^2 K$)

Greek symbols

$\alpha\tau$	The transmittance - absorptance product
η	Collector efficiency (%)
η_o	Initial efficiency
ηi	Instantaneous efficiency
μ_{DW}	The Viscosity of distilled water (m^2/s)
μ_{nf}	The Viscosity of nanofluid (m^2/s)
Φ	volume fraction of nanoparticles in nanofluid
ρ_{nf}	The density of nanofluid (kg/m^3)
ρ_{DW}	The density of distilled water (kg/m^3)

INTRODUCTION: -

The hybrid nanofluid is new type of nanofluid and many researches have been carried out on nanofluid and hybrid nanofluid such as preparation, characterization, modeling, convective and boiling heat transfer and applications. The different methods used for preparation of this type of nanofluids consist of two or more than two type of nanoparticles in fluid and composite nanoparticles in fluid. The hybrid nanofluid properties for different materials include physical and chemical properties which give a homogeneous phase from (physicochemical). The aggregations of hybrid nanofluids are to get good thermal properties or rheological properties and all the appropriate characteristics required to a special purpose. The advantages of hybrid nanofluids are good thermal conductivity than individual nanofluids due to the impact of synergistic Charles [1995] & Duffie et al. [1991]. The characteristics of heat transfer and pressure drop has been conducted in many of the investigations. Experimental investigation was carried out through circular tube for laminar flow with uniform heated by using hybrid nanofluids (Cu+ Al_2O_3 –water). The results showed that the average increase in Nu for this type of hybrid nanofluids was 10.9% while the enhancement of heat transfer in turbulent of 8% compared with pure water Faghri [1995] & Dunn et al. [1982]. The average increase in coefficient of convective heat transfer for hybrid nanofluid was 24.35% at 0.1% of concentration (Cu+ Al_2O_3) Riffat, et al. [2005]. Experiment was performed for the performance of heat transfer in grooved heat pipe by using hybrid nanofluids hybrid nanofluids. The results indicated that strong increase in the dynamic viscosity, the friction factors for hybrid nanofluids Riffat, et al. [2004]. Also Experimental was performed for laminar forced convective tube flow by using two types of hybrid nanofluids the first type consist of silver, multiwall nanotube, graphene and distilled water (Ag + MWNT+ HEG) – Dw while the second type consist of silver, multiwall nanotube, graphene and ethylene glycol (Ag + MWNT+ HEG) – EG . The results showed that tremendous enhancement in coefficient of heat transfer Azad et al. [1987a, 1986b] & Facao et al. [2004]. An enhancement in heat transfer was obtained more for ethylene glycol based hybrid nanofluids. Two types of hybrid nanofluids (CuO + HEG – water) and (CuO+ HEG – EG) Azad [2008] are used to investigate in the laminar forced convective tube flow. Also the two types of hybrid nanofluids are used the first type consist of carbon nanotube, graphene and distilled water (CNT + HEG) – Dw while the second type consist of carbon nanotube, graphene and ethylene glycol (CNT + HEG) – EG. The results indicated that the enhancement in coefficient of heat transfer at concentration of 0.01% and that is more for EG based Hull [1986] & Hussein [2003]. The coefficients of heat transfer and pressure drop for fully developed turbulent flow are measured experimentally in circular tube with uniform heat flux. The type of hybrid nanofluid used in this study was multiwall nanotube, Iron oxide and water (MWCNT + Fe_3O_4) + water. The maximum enhancement was 31.1% in Nu while a penalty pumping power of 1.18 times Chun, et al. [1999]. Experiment was performed in heat exchanger (counter flow tube in the tube type) and the type of hybrid nanofluid used in this investigated was cupper, Titanium Oxide and water (Cu+TiO_2 – water). This study indicated that the Nu and coefficient of overall heat transfer were increased by 82%, 49% and 68% respectively Jahar et al. [2015].

The aims of the present study to design and implement of a V– trough tube solar collector to study the effect of hybrid nanoparticles concentration, size, type and synergistic of hybrid nanoparticles, inlet temperature of hybrid nanofluid in V – trough tube solar collector .

DESIGN OF THE V – TROUGH TYPE COLLECTOR :-

In solar water collectors, incident solar radiation is converted to heat when absorbed by working fluid such as distilled water and hybrid nanofluids such as (Cu (20nm) +Al (20nm) +DW) and (CuO (50nm) +Al_2O_3 (50nm) +DW). Therefor effective heat transfer is important with the aim to assist energy conversion process. Basically the collector is designed in a (V) trough covered with thermal isolation tape and attached with mirrors. These stages are fitted together to form the collector and, it's placed in glass box with no ventilation to create a (Global warming). Each stage have two tubes is attached below the top of the box by (2 cm), and these pipes are connected together in a parallel manner. As shown in Fig.(1) and Fig .(2). The specifications of the V – trough collector are indicated in the table.1. The design dimensions of the collector and specifications have been deduced by the researcher through literature review .

The side mirrors are inclined at (Θ=60°). This angel reveals the vertical rays from the reflector to the middle mirror to get the optimum reflection. As shown in Fig. (3).

The angle (60°) indicated that the vertical rays from the reflector to the middle mirror so as to create (Thermal Convection Currents) which rises up and transfer the heat to the pipes. As shown in Fig. (4).

The cold water enters the collector from one of the pipes and flowing in all the pipes in the parallel manner to acquires the heat transfer from the pipes and come out from the last pipe.

PREPARATION OF THE HYBRID NANOFLUID:-

This article used two types of the hybrid nanofluid in the experiments (Cu(20nm)+ Al(20nm) + Dw) and (CuO(50nm)+Al_2O_3(50nm)+Dw). The preparation of the hybrid nanofluid by used two step methods. Figure.(6). shows hybrid nanofluid used in this study.

EXPERIMENTAL SETUP : -

The experimental rig consists of the six tubes solar collector, helically coiled tube heat exchanger, pump, and flow meter. This study concentrated on design and implementation of V trough tube solar collector in solar energy system. Fig (7) reveal diagram of this rig. The tests of V trough tube solar collector are required measure of the three temperatures i.e. temperature of ambient air and the inlet and outlet temperature of the hybrid nanofluid in the V trough tube solar collector. The surrounding air temperature is measured by temperature sensor. The specifications of the V – trough solar collector indicated in Table 1. The V – trough solar collector has one cover of glazed and the tilt angle 48° oriented to south. The inlet and outlet temperatures of the hybrid nanofluid in V – trough solar collector are measured by two mercury thermometers respectively with accuracy of 0.12 °C. Pump [Bosch 2046 – AE], German is used to pump distilled water and hybrid nanofluid through the V – trough solar collector; two control valves after pump and solar storage. The flow meter type Dwyer series MMA mini – Master flow meter used to measure flow rate. The TES 1333 solar power meter (Houston Texas) used to measure solar radiation (I) with accuracy during ±10 W/m^2 and resolution 0.1 W/m^2. The wind velocity was measured by the Prova AVM – 03 anemometer with ± 3.0% accuracy

ESTIMATION OF HYBRID NANOFLUID THERMO PHYSICAL PROPERTIES:-

The thermal physical properties of hybrid nanofluid are calculated by using nanoparticles properties indicated in the table .2. and equations (1 to 4).

Density. Jahar et al. [2015]. .

$$\rho_{hb,nf} = \Phi_{np1}\rho_{np1} + \Phi_{np2}\rho_{np2} + \left(1-\Phi_{np1}-\Phi_{np2}\right)\rho_{Dw} \quad (1)$$

Viscosity. Jahar et al. [2015]. .

$$\mu_{hb,nf} = \left(1 + 2.5\left(\Phi_{np1} + \Phi_{np2}\right)\right)\mu_{Dw} \quad (2)$$

Specific heat. Jahar et al. [2015]. .

$$\rho_{hb,nf} Cp_{hb,nf} = \Phi_{np1}\rho_{np1} Cp_{np1} + \Phi_{np2}\rho_{np2} Cp_{np2} \left(1-\Phi_{np1}-\Phi_{np2}\right)\rho_{Dw} Cp_{Dw} \quad (3)$$

Recently Huang et al.[2010] presented an effective thermal conductivity model (Eq.4)

$$\frac{k_{hb,\,nf}}{k_{Dw}} = \left[\frac{Cp_{hb,\,nf}}{Cp_{Dw}}\right]^{-0.023}\left[\frac{\rho_{hb,\,nf}}{\rho_{Dw}}\right]^{1.358}\left[\frac{\mu_{Dw}}{\mu_{hb,\,nf}}\right]^{0.126} \quad (4)$$

Figures (8 to 11) indicated that thermal conductivity, density, viscosity and specific heat for the two types of hybrid nanofluid (Cu, Al+ Dw) and (CuO, Al_2O_3 +Dw).

DATA PROCESSING :-

The collector efficiency, useful heat energy and temperatures difference, were calculated by using the equations (5 to 12). These equations are taken from refs Koffi, et al. [2008] & Jaisankar et al. [2008a, 2009b].
The equation for useful heat energy (Qu), as:

$$Q_u = A_c F_R\left[I\alpha\tau - U_L\left(T_f - T_a\right)\right] \quad (5)$$

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

$$Q = \dot{m}\ Cp\left(T_{f\,o} - T_{f\,i}\right) \quad (6)$$

Then

$$\dot{m}\,Cp\left(T_{f\,o}-T_{f\,i}\right)=A_c F_R\left[I\alpha\tau-U_L\left(T_f-T_a\right)\right] \quad (7)$$

Therefore,

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

F_R may be obtained from, Koffi, et al. [2008] & Jaisankar et al. [2008a, 2009b].

$$F_R=\frac{\dot{m}\,Cp}{A_c U_L}\left[1-\exp\left(\frac{U_L F' A_c}{\dot{m}\,Cp}\right)\right] \quad (9)$$

Then the collector efficiency is obtained by using the relation,

$$\eta=\frac{Q_u}{A_c\,I} \quad (10)$$

Substitution of Eqs. (6) and (8) in Eq. (9) yields,

$$\eta=F_R\left[\alpha\tau-\frac{U_L\left(T_f-T_a\right)}{I}\right] \quad (11)$$

Since F_R, α τ & U_L are constant,

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

Nevertheless the plots of instantaneous efficiency against temperature parameters, $\frac{\left(T_i-T_a\right)}{I}$, would be straight lines with intercept $F_R(\tau\alpha)$ and slope – $F_R U_L$. Although of these difficulties, long – time to performance estimate of the various solar heating systems, collectors are often characterized by the intercept and slope (i. e., by $F_R(\tau\alpha)$, and – $F_R U_L$) Jaisankar et al. [2009b]. Using Mat lab program and curve fitting tool box, a line was fitted to experimental results of thermal efficiency against the reduced temperature parameters, for every case. Goodness of fitting was resolute by R^2. Finally the area under curves as index of collector total efficiency was used for comparison the cases.

RESULTS AND DISCUSSION :-

The design and implementation V – trough tube solar collector is considered very important in application of renewable energy. Also required stimulate a demand for cheaper and cleaner energy from households, public building and small businesses that requires constant supplies of hot water. This would then be matched with an increasing supply of renewable energy products by encouraging businesses and entrepreneurs to set up production facilities. At firstly the V – trough tube solar collector was tested for distilled water as a show in figure (8). The two types of hybrid nanofluid used in the experiments first type (Cu (20nm) + Al (20nm) +Dw) and second type (CuO(50nm)+Al_2O_3(50nm) +Dw). Figs (13 to 16) indicated the curves of performance for V – trough tube solar collector under the Draft ASHRAE [2009], Standard by using the two types of hybrid nanofluids. The two volume flow rate 20 and 40 lit/hr and volume fraction percentage (0, 1, 3 and 5%vol) used in the experiments. These figures reveal efficiency of V – trough tube solar collector for two types of hybrid nanofluids at 5 % vol were higher than base fluid (distilled water) because many factors such as high thermal conductivity to the hybrid nanofluids and synergistic between types of nanoparticles. At 5 % vol and volume flow rate 20 and 40 lit/hr, the thermal solar characteristics values of $F_R(\tau\alpha)$, – F_RU_L were –7.276 W/m^2.K, 0.524 and –7.423 W/m^2.K, 0.551,while for the hybrid nanofluid (CuO+Al_2O_3+Dw) –6.183 W/m^2.K, 0.473 and –6.224 W/m^2.K, 0.492 respectively. The thermal solar characteristics values of distilled water for 20 and 40 lit/hr were –5.023 W/m^2.K, 0.426 –5.075 W/ m^2. K, and 0.445 respectively. This indicates that hybrid nanofluids (Cu (20nm)+ Al (20nm)+Dw) and (CuO(50nm)+Al_2O_3 (50nm)+Dw) was able to improvement of V – trough tube solar collector performance. The V – trough solar collector could work at higher temperature compared with base fluid (distilled water). Furthermore this figures indicated that the slopes of efficiency models are negative when increases ((Ti – Ta) / I) due to the efficiency to approach zero. The fast heat transfer from wall to hybrid nanofluid,due to diffusion and relative movement of hybrid nanoparticles near wall of tube. Kahani, et al. [2013] The steeper of slope of hybrid nanofluids compared with distilled water shows the effect of using hybrid nanofluids in improvement of the V – trough tube solar collector heat removal factor (F_R). 'A' (Area under the curve×100) is a factor used to compare the collector efficiency as shows in Table 3. The quantities of 'A' for two volume flow rate of distilled water are 1.25 and 1.28 indicated that the 1.50 % increase of second volume flow rate related to the first volume flow rate. The increase of factor 'A' for the two volume flow rate 20 and 40 lit/hr were 15.62 of hybrid nanofluids (Cu (20nm)+ Al (20nm)+Dw) while hybrid nanofluids (CuO(50nm) +Al_2O_3 (50nm)+Dw) were 13.6% at 5 % vol. The increases in collector efficiency factor (F ') was through heat transfer coefficient inside the tube (hfi), Duffie et al. [1991] include the use of hybrid nanofluids and increasing mass flow rate . Figs. (17 to 20) show the inlet and outlet temperature of V – trough tube solar collector for two types of hybrid nanofluids at different volume fractions and volume flow rate. When increases the volume fraction and thermal conductivity for hybrid nanofluids lead to get good heat rate from V – trough tube solar collector. It is observed that there is increase in temperature difference between inlet and outlet with thermal conductivity and concentration of the hybrid nanofluids compared with distilled water. The results indicated that no significant effects at 1%vol of hybrid nanofluids (Cu (20nm) + Al (20nm) +Dw) and (CuO(50nm)+Al_2O_3(50nm)+Dw). It is also observed that the high inlet temperature, the deviation in temperature difference of hybrid nanofluid was great than distilled water at hybrid nanoparticles concentration (3%vol, 5%vol) and 20 lit/hr. This indicates that the hybrid nanofluid give good heat rate and less heat loss compared with distilled water. It was indisputable that the increase of volume flow rate and the inlet temperature decreased of temperature difference. Figs (21 – 24) reveal the useful heat gains of V – trough tube solar collector at difference inlet temperature, volume flow rate and volume fraction. This variation was similar to an indicated in Figs. (17 to 20). The hybrid nanofluids (Cu (20nm) + Al (20nm) +Dw) and (CuO (50nm) + Al_2O_3 (50nm) + Dw) at 5% vol gave better improvement compared with distilled water while the hybrid nanofluid at 1%vol gave similar results with distilled water. The V – trough solar collector efficiency for hybrid nanofluid (Cu (20nm)+ Al (20nm)+Dw) was greater than hybrid nanofluid (CuO (50nm)+Al_2O_3(50nm)+Dw) due to small hybrid nanoparticles size for the copper and aluminum compared with copper oxide and aluminum oxide as well as high thermal conductivity for copper and aluminum. The type and synergistic of hybrid nanofluid is a key factor for heat transfer enhancement, and improve performance of V – trough tube solar collector.

CONCLUSIONS :-

The conclusions that can be drawn from the results of experimental study were as follows:

1. The synergistic between hybrid nanoparticles and type of hybrid nanofluid are playing important role in enhancement of heat transfer, and improvement performance of V – trough tube solar collector.
2. The hybrid nanofluids used as a working fluid could improve thermal performance of V – trough tube solar collector compared with distilled water, especially at high inlet temperature.
3. Hybrid nanofluids that contain metal nanoparticles such as Cupper, aluminum produce more enhancements in the thermal solar characteristics compared to oxide hybrid nanofluids which contains of CuO +Al_2O_3 compared with base fluid flow.
4. The solar collector efficiency for hybrid nanofluid (Cu (20nm) +Al (20nm) +DW) was greater than hybrid nanofluid (CuO (50nm) +Al_2O_3 (50nm) + DW) due to small hybrid nanoparticles size, high thermal conductivity and synergistic nanoparticles.
5. The difference between inlet and outlet temperatures of the hybrid nanofluid will increase due to heat rate in V – trough tube solar collector and heat loss less when increased concentration of hybrid nanoparticles .

Table 1. Specification of the V – trough collector (all the dimensions are in Cm).

<table>
<tr><th colspan="2">Description</th><th>specification</th><th>Note</th></tr>
<tr><td colspan="2">Collector dimensions
(length × width × height)</td><td>180 × 180 × 12</td><td>Nothing mentioned</td></tr>
<tr><td colspan="2">Collector type</td><td>V Trough</td><td>Nothing mentioned</td></tr>
<tr><td colspan="2">Number of glass covers</td><td>1</td><td>Attached to the frame by silicon</td></tr>
<tr><td colspan="2">Iron plates
(length × Width × thickness)</td><td>150 × 13.5 × 0.4</td><td>Nothing mentioned</td></tr>
<tr><td colspan="2">Insulation material</td><td>Thermal isolation tape</td><td>Covered the iron plate (under the mirror)</td></tr>
<tr><td colspan="2">Pipes material</td><td>Copper pipes</td><td>High thermal conductivity</td></tr>
<tr><td colspan="2">Pipes dimension
(length × diameters)</td><td>150 × 1.5</td><td>Nothing mentioned</td></tr>
<tr><td colspan="2">Crock</td><td>Equilateral triangle (13.5 cm)</td><td>To close the open triangle between the stages</td></tr>
<tr><td>Storage tank capacity</td><td>40 litters capacity</td><td colspan="2">(crock material)</td></tr>
</table>

Table. 2 . Thermo physical properties of the hybrid nanoparticles employed J. P Holman[2005]

Nano sized Particles	ρ (kg/m^3)	Cp (J/kg K)	k (W/m K)	Mean diameter (nm)
Copper (Cu)	8933	385	401	20
Aluminum (Al)	2707	896	236	20
copper oxide (CuO)	6500	535.6	76.5	50
Aluminum oxide (Al_2O_3)	3970	765	40	50

Table 3. The experimental results

	Volume fraction (% vol)	$\dot{Q}$ l/hr	Model	Area under curve X100 (A)	R^2
Distilled Water (DW)	0	20	$\eta = -5.023\,X + 0.426$	1.25	0.963
	0	40	$\eta = -5.075\,X + 0.445$	1.28	0.965
Hybrid nanofluid ($CuO+Al_2O_3+DW$)	1%vol	20	$\eta = -6.183\,X + 0.473$	1.33	0.976
	5%vol	20	$\eta = -6.224\,X + 0.492$	1.35	0.978
	1%vol	40	$\eta = -6.324\,X + 0.506$	1.37	0.981
	5%vol	40	$\eta = -6.183\,X + 0.473$	1.39	0.985
Hybrid nanofluid (Cu+Al+DW)	1%vol	20	$\eta = -7.214\,X + 0.519$	1.41	0.99
	5%vol	20	$\eta = -7.276\,X + 0.524$	1.42	0.992
	1%vol	40	$\eta = -7.332\,X + 0.543$	1.44	0.993
	5%vol	40	$\eta = -7.423\,X + 0.551$	1.48	0.991

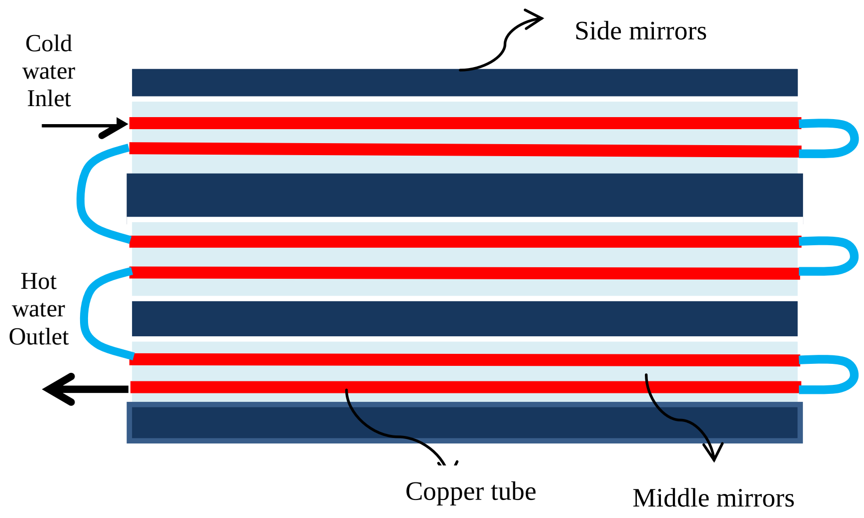


Fig. 1. The design of the collector (Top view)

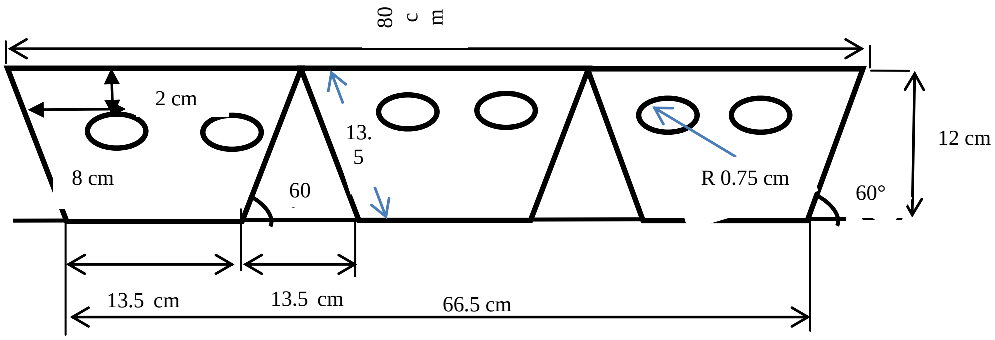


Fig. 2. Dimensions sheet and side view of the construction

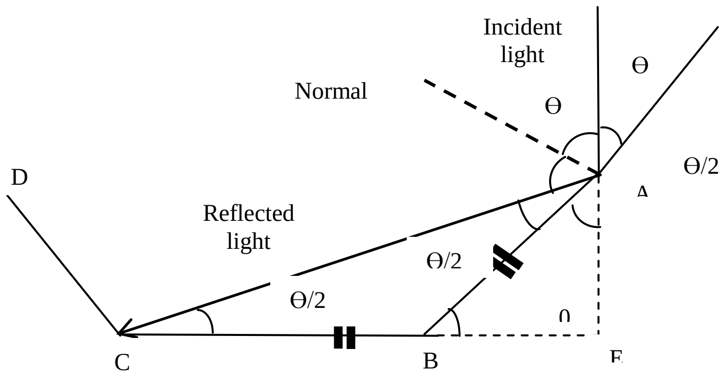


Fig . 3. A flat reflector at angle (Θ=60°)

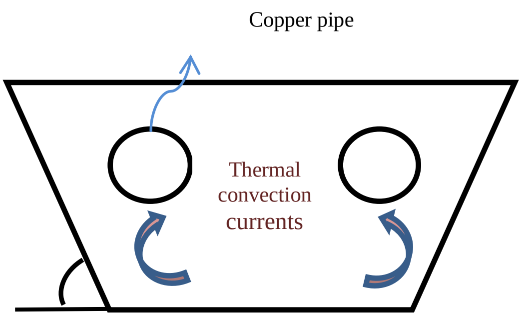


Fig.4. Thermal convection current flows up to the pipes

Fig. 5. Set up of the V – trough solar collector

Fig .6. Hybrid nanofluid (Cu+ Al + Dw) and ($CuO+Al_2O_3$+Dw)

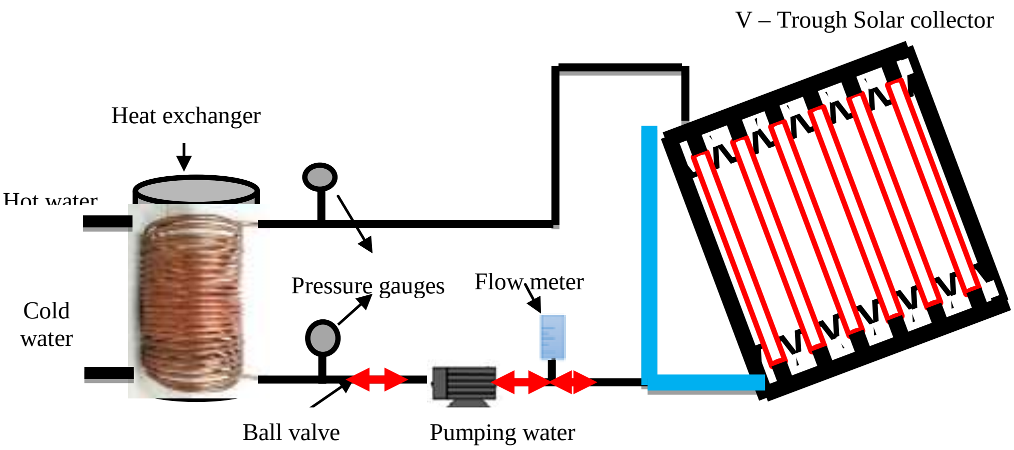


Fig .7. Schematic of the experimental setup

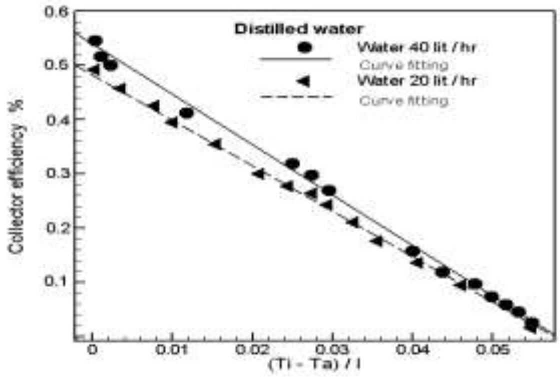


Fig.8 Efficiency of collector versus the reduced temperature parameters to distilled water At different volume flow rate

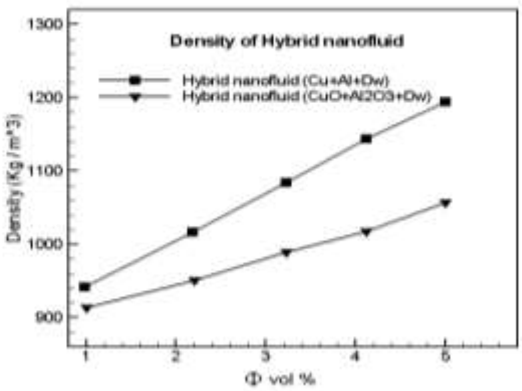


Fig 9. Density of hybrid nanofluids for (Cu +Al+ Dw) and (CuO+ Al_2O_3+Dw) at different volume fraction

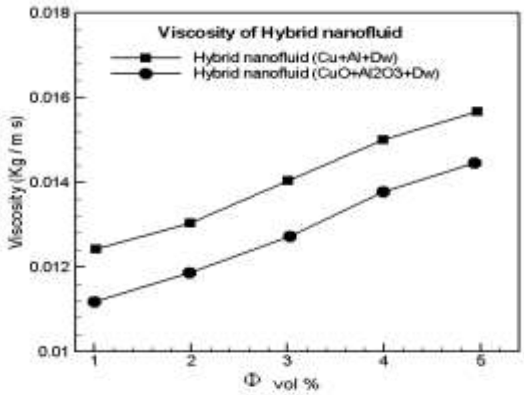


Fig 10. Viscosity of hybrid nanofluids for (Cu +Al+ Dw) and (CuO+ Al_2O_3+Dw) at different volume fraction

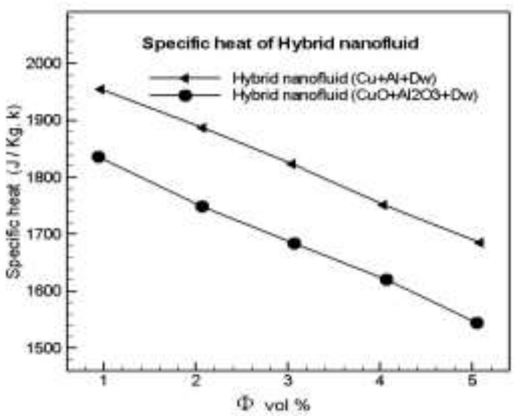
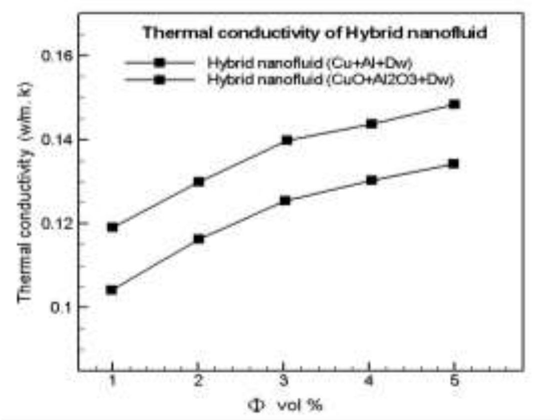


Fig 11. Specific heat of hybrid nanofluids for (Cu + Al+Dw) and (CuO+ Al_2O_3+Dw) at different volume fraction



F ig 12. Thermal conductivity of hybrid nanofluids for (Cu + Al+ Dw) and (CuO+ Al_2O_3+Dw) at different volume fraction

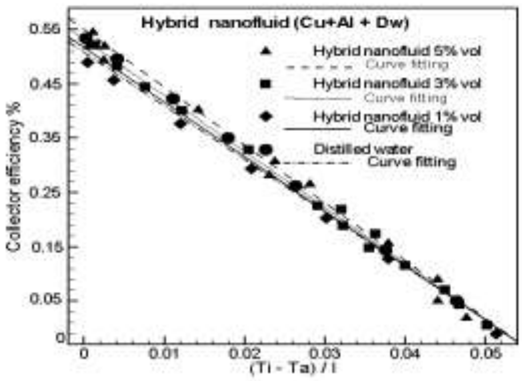


Fig 13. Efficiency of collector at different Φ and volume flow rate 20 lit/ hr for Hybrid nanofluid (Cu+Al + DW)

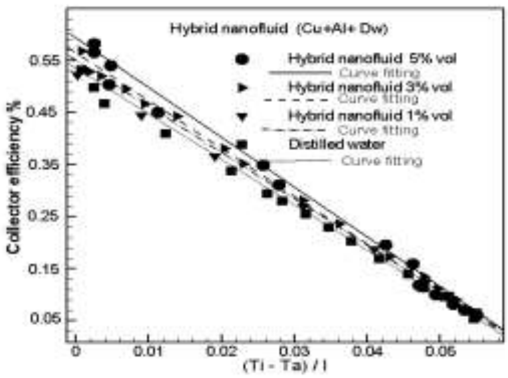


Fig 14. Efficiency of collector at different Φ and volume flow rate 40 lit/ hr for Hybrid nanofluid (Cu+Al + DW)

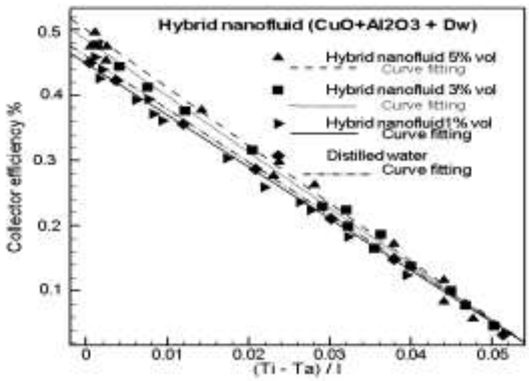


Fig 15. Efficiency of collector at different Φ and volume flow rate 20 lit/ hr for Hybrid nanofluid (Cu+Al + DW)

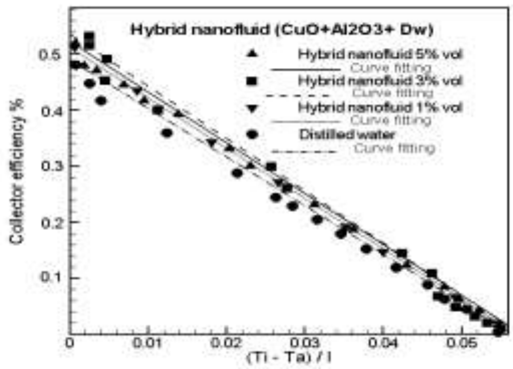


Fig 16. Efficiency of collector at different Φ and volume flow rate 40 lit/ hr for Hybrid nanofluid (Cu+Al + DW)

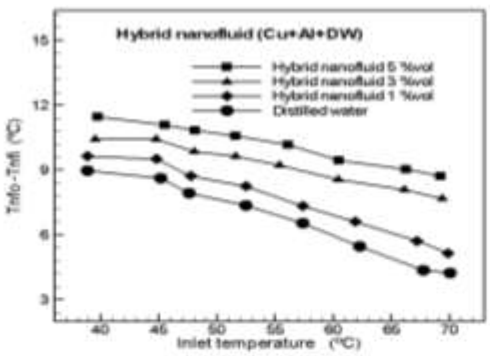


Fig 17. Temperatures difference between inlet and outlet collector solar for (Cu +Al + Dw)at different Φ, 20 lit/ hr

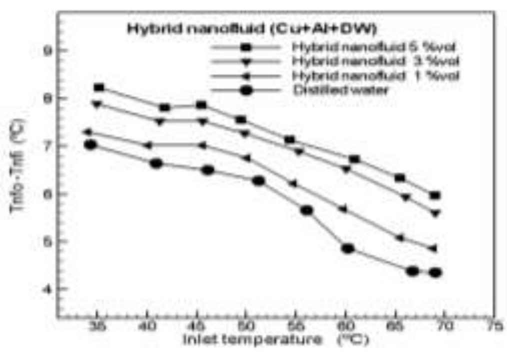


Fig 18. Temperatures difference between inlet and outlet collector for (Cu +Al + Dw)at different Φ, 40 lit/ hr

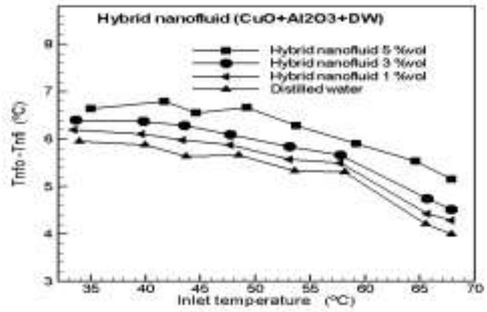


Fig 19. Temperatures difference between inlet and outlet collector solar for (CuO +Al_2 O3+ Dw)at different Φ, 20 lit/ hr

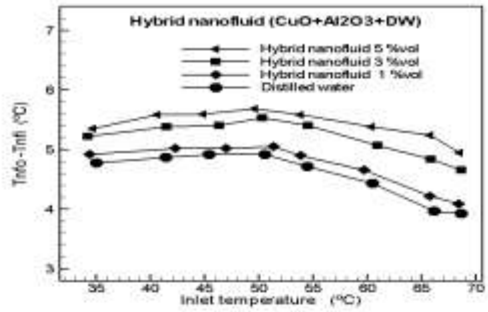


Fig 20. Temperatures difference between inlet and outlet collector for (CuO +Al_2 O3+ Dw)at different Φ, 40 lit/ hr

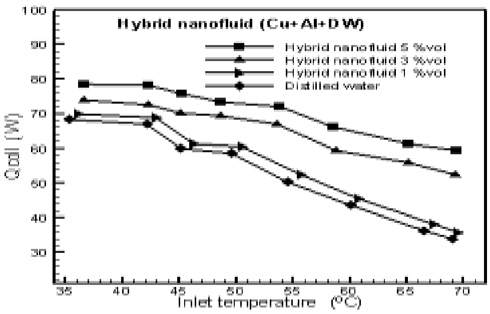


Fig 21. Useful heat gain from collector solar at different Φ, 20 lit/ hr for Hybrid nanofluid (Cu +Al+ Dw)

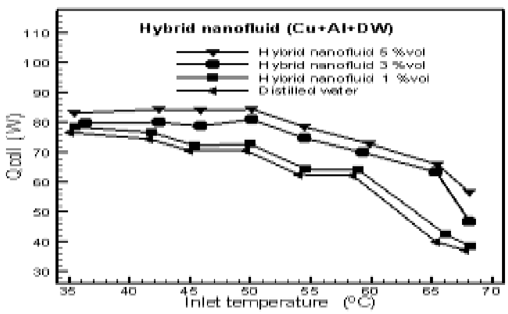


Fig 22. Useful heat gain from collector solar at different Φ, 40 lit/ hr for Hybrid nanofluid (Cu +Al+ Dw)

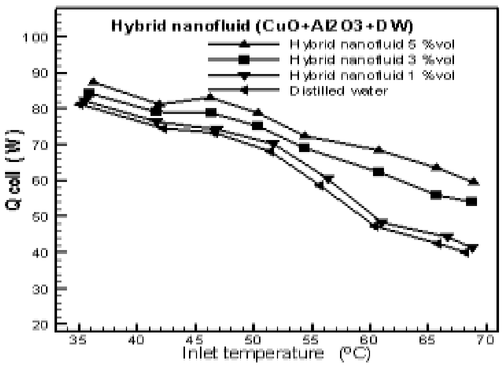


Fig 23. Useful heat gain from collector solar at different Φ, 20 lit/ hr for hybrid nanofluid (CuO +Al_2O_3+ Dw)

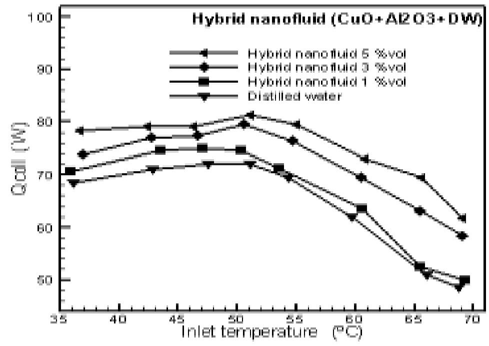


Fig 24. Useful heat gain from collector solar at different Φ, 40 lit/ hr for hybrid nanofluid (CuO +Al_2O_3+ Dw)

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