EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER IN AUTOMOBILE RADIATOR BY USING ALTERNATIVE WORKING FLUIDS AND NANOPARTICLES

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ABSTRACT :-

This article presents an experimental study on improvement of heat transfer in car radiator by using copper oxide, titanium oxide, Ethylene glycol and distilled water nanofluids. The concentrations of nanofluid used are ranging from (0.5 –5 vol %). Two types of nanoparticles used in this paper copper oxide (CuO (30nm)) and titanium oxide (TiO_2 (50nm)) as well as the base fluid (Ethylene glycol and distilled water). The effects of different parameters such as Reynolds number, nanofluid inlet temperature, concentration and type of nanoparticle on heat transfer coefficient of the flow are studied. The obtained results indicated that the improvement in heat transfer for the nanofluid (CuO(30nm) + EG + Dw) was greater than nanofluid (TiO_2 (50nm) + EG + Dw) due to nanoparticles size and thermal conductivity of the copper oxide. The results indicated that there is an increase in heat transfer when the volume concentration of nanoparticles are increased with range (0.5 vol % to 5 vol %). About 55% heat transfer improvement was achieved with addition of 5 vol % nanoparticles. Moreover overall heat transfer based on air side increased up 45 % with addition of 5vol % volume fraction nano particles of copper oxide and titanium oxide than the base fluid (EG +Dw). In addition the results indicated that using nanofluid as working fluid leads to higher heat transfer performance which is promoted the car engine performance and would reduce fuel consumption. Moreover, thermal conductivity for the nanofluids (CuO + EG +Dw) was greater than nanofluids (TiO_2+ EG + Dw) due to nanoparticles size and thermal conductivity for the copper oxide. The type and size nanoparticles play an important role in improvement of heat transfer rate. Results show that heat transfer coefficient increased with increasing of nanofluid inlet temperature, concentration of nanoparticles and Reynolds number. The results indicated that the improvement in heat transfer for the nanofluid (CuO (30nm) + Dw+EG) and (TiO_2 (50nm) + Dw+EG) of 12.4%, 9.52% at Φ = 5vol% and T=70 ^{o}C respectively compared with base fluid..

Keywords: Nanofluids, radiator, cooling system, heat transfer coefficient.

التحقق العملي في انتقال الحرارة لراديتر السيارة باستخدام موائع بديلة مع جزئيات نانوية

كريمة عاصي حمد

الخلاصة :-

تقدّمُ هذه المقالة دراسةَ تجريبيةَ على تحسين نقلِ الحرارةِ في مبرد السيارات باستخدام الموائع النانوية مثل اوكسيد النحاس واوكسيد التيتانيوم مع اثيلين الكلايكول والماء المقطر ويتراوح مدى التراكيز الوزنية المستخدمة مابين (0.5 –5 vol %) . تم في هذه الدراسة استخدام نوعين من الجزئيات النانوية ذات اقطار مختلفة هي (اوكسيد النحاس (30nm)) واوكسيد التيتانيوم ((50nm)). تم دراسة تأثير العوامل المختلفة مثل عدد رينولدز، درجة حرارة الدخول للمائع النانوي ،والتراكيز ونوع الجزئيات النانوية على معامل انتقال الحرارة لتدفق. بينت الدراسة أن معامل انتقال الحرارة يزداد مع زيادة درجة حرارة الدخول للمائع النانوي ، التركيز الحجمي، عدد رينولدز. أشارت النتائج أن التحسي في انتقال الحرارة لا وكسيد النحاس مع اثيلين الكلايكول والماء المقطر (CuO(30nm) + EG + DW) كان أكبر من اوكسيد التيتانيوم مع اثيلين الكلايكول والماء المقطر (TiO_2 (50nm) + EG +Dw) بسبب حجم الجزئيات النانوية والتوصيل الحراري لاوكسيد للنحاس. وبالإضافة إلى ذلك أشارت النتائج إلى أن استخدام المائع النانوي كمائع اشتغال يودي الى ان يكون الأداء في نقل الحرارة عالي والذي يؤدي الى تعزيز أداء محرك السيارة، وبالتالي سوف يقلل من استهلاك الوقود. علاوة على ذلك، ان الموصلية الحرارية للمائع النانوي الذي يتألف من (اوكسيد النحاس+ اثيلين الكلايكول + الماء المقطر) أكبر من المائع النانوي الذي يتألف من (اوكسيد التيتانيوم+ اثيلين الكلايكول + الماء المقطر) نظرا لحجم الجزئيات النانوية والتوصيل الحراري لاوكسيد النحاس. ان نوع وحجم الجزئيات النانوية تلعب دورا هاما في تحسين معدل انتقال الحرارة. أشارت النتائج أن التحسين في انتقال الحرارة للنحاس والماء المقطر و اثيلين الكلايكول (CuO(30nm) + DW+EG) كان أكبر من اوكسيد التيتانيوم واثيلين الكلايكول والماء المقطر (TiO_2(50nm)+Dw+EG) بسبب حجم الجزئيات النانوية والتوصيل الحراري لاوكسيد النحاس.

الكلمات المفتاحية: المائع النانوي ، المبرد ، منظومة التبريد، معامل انتقال الحرارة

Nomenclature

Symbol	Quantity	units	Symbol	Quantity	units
A	peripheral area	m^2	T	Temperature	°C
DW	Distilled water	__	E	Effectiveness	__
EG	Ethylene glycol	__		**Greek Symbol**	
Q	thermal energy	J	μ	Dynamic viscosity	$N.s/m^2$
Cp	Specific heat	J/kg k	ρ	density	Kg/m^3
d_{hy}	hydraulic diameter $=\frac{4A}{P}$	m	Φ	Volume concentration	__
h	heat transfer coefficient	W/m^2 K		**Subscripts**	
$\dot{m}$	Mass flow rate	kg/s	bf	Base fluid	__
Nu	Nusselt number	__	nf	Nanofluid	__
U	Overall heat transfer coefficient	W/m^2 K	in	input	__

1. INTRODUCTION :-

The radiator is one of the most important components of vehicle engine. Its function is to reject the heat from a cylinder wall to the water which acts as heat transfer medium. Pumps is used to circulate the water within the system. **Vlassov et al. [2006]** investigated the optimal mass characteristics for a radiator of heat pipe type. The assembly with acetone Hp can be more weight effective than the one with ammonia. As a result of high thermal conductivity for most material which are up to three times higher than the distilled water. **Pantzali et al. [2009]** developed heat transfer and turbulent flow within heat exchangers, by using nanofluid as a coolant medium. In other hand, thermal performance of an outomotive car radiator is developed numerically by **Kakac et al. [2009]**. **Leong et al. [2010]** by using ethylene glycol based copper nanofluids as a coolants meduim. For laminar flow the overall heat transfer coefficient for a car radiater is decreased with increasing inlet temperature by **Naraki et al. [2013]. Vajjha et al. [2010]** studied three dimensional laminar flow and heat transfer for two different nanofluids, Al_2O_3 and CuO, numerically. These nanofluids are circulating through the flat tubes of automobile radiator as a mixture with ethylene glycol water. The convective heat transfer coefficient is improved over that for base fluid. The flow behavior of nanofluid (Al_2O_3 – water; 20 nm) circulating through millimeter – sized stainless steel test tube is studied by, Lai **et al. [2006].** The wall of tube is subjected to a constant heat flux and the Reynolds number range was (Re< 270). The Nusselt number enhancement was 66% at 1 vol.% concentration. **Peyghambarzadeh et al. [2011]** enhanced the Forced convection heat transfer in radiator by using water/ethylene glycol based nanofluids. The enhancement was 40% compared to the base fluids, while **Jung et al. [2009]** presented an

experimental study for laminar flow convective heat transfer with a rectangular micro channel under. From this study,
The coefficient of convective heat transfer is increased more than 32% by using 1.8 vol% nanoparticle in the base fluid . In the other hand, the Nusselt number increased with increasing in Reynolds number with a range (5<Re<300). **Peyghambarzadeh et al. [2012]**. Enhanced the overall heat transfer coefficient for automobile radiator by using nanofluid. **Kim et al. [2009]** studied a laminar and turbulent flow within circular straight tube. They concluded that the convective heat transfer coefficient was improved when compared with the base fluid by 15% and 20% for laminar and turbulent flows, respectively. **Sheikholeslami et al. [2013]**.Concluded that the (Nu) increases with increasing the nanoparticle volume fraction and Eckert number in case of two plates are moving. The forced convective heat transfer coefficient was enhanced experimentally by using Al_2O_3/EG and CuO/EG nanofluids in a double pipe and plate heat exchangers under turbulent flow by **Zamzamian et al. [2011].**

Now, experimental investigation of forced convection heat transfer coefficients for ethylene glycol and distilled water based and nanoparticles (CuO, TiO_2) is presented experimentally. The effects of the inlet temperature and nanoparticle volume fraction on heat transfer enhancement are examined.

2. NANOFLUID PREPARATION :

The studied nanofluid is formed by copper oxide (CuO (30 nm)), titanium oxide (TiO_2) (50 nm)) nanoparticles, distilled water and ethylene glycol. The method used to prepare nanofluids know two – step. Nanofluid samples were prepared by dispersing pre – weighed quantities of nanoparticles in ethylene glycol and distilled water. The mixtures were then subjected to ultrasonic mixing [150 kHz, 400 W at 25 – 30 C^0, for two hour to break up any nanoparticle aggregates. The nanofluid of this article was included distilled water and nanoparticles. Their properties nanoparticle of are shown in Table 1, and 2 respectively.

Picture nanofluids include copper oxide (CuO (30 nm)) and titanium oxide (TiO_2) (50 nm) is show in Fig .1. Nanofluids with different concentrations (Φ= 0.5, 2, 3 and 5 vol %).

3. EXPERIMENTAL SETUP

The experimental rig consists of:

1. Flow pipes
2. reservoir
3. electrical heater
4. water pump
5. rotameter
6. Fan
7. Automobile radiator

Fig 2. Shows the experimental rig for this study which of louvered aluminum finned tube, with 34 stadium shaped cross – section vertical tube. The fan of 1600 r. p. m is placed face to face to the radiator to ensure cross flow heat exchanger between air and water flowing inside the tubes.

Fig 3. Shows rotameter, fan and radiator. The type of the pump [Bosch 1046 – AE], German industry .The pump developed a flow rate within a range of (70 – 120) l/min, where the globe valve is used to regulate the flow. Flow meter (Dwyer series MMA mini – Master) with a precision of 0.4 l/min is used to measure the flow rate. The inlet and outlet temperatures are measured by two thermocouples (T – type). While ten thermocouples of the same type are soldered along the test section at the center of radiator surfaces (both sides). The inside and outside temperature of the tube are considered equal as result of very high thermal conductivity and low thickness of tubes. The control of temperatures by used thermostat. The temperature of working fluid is maintained between (40 – 80^0C) for heating by using electrical heater. In the outside walls of the radiator, twelve thermocouples are attached by silicon paste for a various positions. Fig. 4, illustrates Schematic of experimental setup.

3.1 Experimental procedure

After the preparation of the two types of nanofluids, the experimental producer starts with nanofluid (Cu+ EG+ DW). Place the nanofluid (volume) in heater. Open the needle valve that is located down the supplying heater for entry the nanofluid to the loop .Operate the pump to circulate the nanofluid in the testing pipe. The flow rate is controlled by means of the control device on the pump speed to get the desired flow rate. After the steady state was secured, the following readings were recorded: The wall temperature at the specified points and the temperature of the nanofluid at inlet and outlet of the testing tube. The same steps were repeated with nanofluid (TiO_2+ EG+ DW).

4. ERROR AND ACCURACY ANALYSIS :

By introducing the error of measurement, the error analysis is carried out. The error in measuring the volume flow rate and hydraulic diameter of tubes reflected to the uncertainty range of Reynolds number and Nusselt number. According to **Moffat [1988],** the error in measuring Reynolds and Nusselt number was less than 4 % and 15 % respectively. The experiments repeatability was within 5%. A constant water both is used to calibrate all thermocouples and there accuracy are ± 0.2 ^{0}C.

5. MEASUREMENT OF THERMAL PROPERTIES NANOFLUID :-

The thermal properties of the two types of the nanofluids (CuO, + EG + Dw) and (TiO_2 + EG + Dw) needed to calculate the pressure drop and the coefficient of heat transfer are measured. The dynamic viscosity (μ) is measured using brook field digital viscometer model DV – E. Hot Disk Thermal Constants Analyzer (6.1) used to measure the thermal conductivity, specific heat and specific heat apparatus (ESD – 201). The measurement of density was carried out by weighing a sample and volume. The thermo physical properties of nanofluids density, specific heat, thermal conductivity, and dynamic viscosity (μ) are measured with different concentrations at (Φ= 0.5, 2, 3 and 5 vol %). The empirical correlations used to comparison with the practical measurements for nanofluid properties. The average bulk temperature of the nanofluid used to calculate the thermo physical properties of nanofluid by the following equations.

Density , **Trisaksri et al**.[**[2007]**.

$$\rho_{nf} = \Phi\, \rho_s + (1 - \Phi)\, \rho_{Dw+EG} \quad (1)$$

Viscosity , **X. Wang et al.[1999]**

$$\mu = (1 + 7.3\Phi + 123\Phi^2)\mu_{Dw+EG} \quad (2)$$

Specific heat, **Kulkarni et al.[[2007].**

$$Cp_{nf} = \frac{\Phi(\rho_s Cp_s) + (1-\Phi)(\rho_{Dw+EG}\, Cp_{Dw+EG})}{\rho_{nf}} \quad (3)$$

Recently **Chandrasekar et al.[2007]** presented an effective thermal conductivity model (Eq.4)

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

To obtain heat transfer coefficient and corresponding Nusselt number, the following procedure has been performed. According to Newton's cooling law:

$$Q = h\, A\, \Delta T = hA(T_b - Tw) \quad (5)$$

Heat transfer rate can be calculated as follows:

$$Q = \dot{m}\, Cp_{nf}\, \Delta T = m\, Cp_{nf}(Tin - Tout) \quad (6)$$

Regarding the equality of Q in the above equations:

$$Nu = \frac{h_{ex}\, D_h}{k_{nf}} = \frac{\dot{m}\, Cp\, (Tin - Tout)\, D_h}{k_{nf}} \quad (7)$$

$$D_h = \frac{4 \text{ x Flow Area}}{\text{wetted perimeter}}$$

(8)

The Effectiveness of the radiator is given below, **Periyasamy et al.[[2015]**

$$\text{Effectiveness of the fin} = \frac{\text{actual heat transfer}}{\text{maximum heat transfer}} \quad (9)$$

$$E = \frac{m_{nf} c_{nf} (T_{nfo} - T_{nfi})}{m_a c_{p\,a} (T_{nfo} - T_{ai})} \quad (10)$$

$$C_{min} = m_a\, C_{pa} \quad (11)$$

Total heat transfer in the radiator is given below

$$Q_t = E\, C_{min}(T_{nf} - T_{ai}) \quad (12)$$

Overall Heat Transfer coefficient based on the air side can be express below

$$U = \frac{Q_t}{A_{fr}(T_{nfi} - T_{ai})} \quad (13)$$

The enhancement of heat transfer between the case of nanofluid and the pure fluid (base fluid) case is defined as:

$$\text{Enhancement} = \frac{h\,(nf) - h\,(bf)}{h\,(bf)} \text{ x } 100 \quad (14)$$

6. RESULTS AND DISCUSSION :

The heat transfer coefficients are experimentally measured using distilled water as the working fluid before obtaining those of (CuO+ Dw + EG) and (TiO_2 + Dw + EG) nano fluids to verify the accuracy and the reliability of the experimental system. The three empirical relations: one of them suggested by **Dittuse Boelter** correlation **[2002], Gnielinsky** correlation **[1970]** and the other developed by **Petukhov et al. [2015]** used to comparison with the results of the experimental (see Figure 5). These three relations are shown in Equations (15 – 17), respectively. In Equations (16) and (17), f is friction factor.

$$\mathrm{Nu} = 0.0235\ \mathrm{Re}^{0.8}\ \mathrm{Pr}^{0.3} \tag{15}$$

$$\mathrm{Nu} = \frac{\left(\frac{f}{2}\right)(\mathrm{Re}-1000)\ \mathrm{Pr}}{1+12.7\left(\frac{f}{2}\right)^{0.5}\left(\mathrm{Pr}^{\frac{2}{3}}-1\right)} \tag{16}$$

$$f = (1.82\log(\mathrm{Re}) - 1.64)^{-2} \tag{17}$$

Figs (6 – 9) depicted the thermal properties of the two nanofluids (CuO + EG+ Dw) and (TiO_2 + EG + Dw) in comparison with those of ethylene glycol and distilled water. These figures showed that thermal conductivity density and viscosity increased with increasing concentration of nanoparticles while the specific heat decreased with increasing concentration of the nanoparticles due to the nanoparticle concentration shape and size play a major role in specific heat of nanofluid. Thermal conductivity for the nanofluids (TiO_2 + EG+ Dw) was lower than nanofluids (CuO + EG+ Dw) due to nanoparticles size and thermal conductivity for the titanium oxide.

Figs (10 – 15) reveal the effects of the concentration of nanoparticles copper oxide and titanium oxide, Reynolds number, and fluid inlet temperature on coefficient of heat transfer for the two types of the nanofluids (CuO + EG+ Dw) and (TiO_2 + EG + Dw). The nanofluid velocity components increase as a result of an increase in the energy transport in the fluid with the increasing the concentration of nanoparticles. The sensitivity of thermal boundary layer thickness to concentration of nanoparticles is related to the increased the nanofluid thermal conductivity. Addition of nanoparticles copper oxide and titanium oxide to the coolant has the potential to improve automotive and heavy – duty engine cooling rates, or equally causes to remove the engine heat with a reduced – size cooling system. So as to consider the effect of temperature on thermal performance of the radiator, different inlet temperatures of fluid have been applied for each concentration. The nanofluid inlet temperatures of 40°C, 50°C ,60°C, and 70°C for the two type's nanofluids (CuO + EG+ Dw) and (TiO_2 + EG+Dw). These figures showed that an increase in the nanofluid inlet temperature slightly improves the coefficient of heat transfer due to increment in the effect of test liquid radiation to the tube internal wall. Also, these figures indicated that coefficient of heat transfer increases with increase of Reynolds number.

Figs (16 – 17) reveal coefficient of overall heat transfer based on the air side increase in the volume concentration of copper oxide and titanium oxide nanoparticles in ethylene glycol and distilled water. The coefficient of overall heat transfer 1100 W/m^2K can be achieved for nanofluid (CuO + EG+ Dw) at concentration 5 vol % compared 500 W/m^2 K for ethylene glycol and distilled water while coefficient of overall heat transfer 850 W/m^2 K for nanofluid (TiO_2 + EG+Dw) at concentration 5 vol % compared 450 W/m^2 K for ethylene glycol and distilled water (EG+Dw). This article also found that the rate of heat transfer is increased linear as the concentration of copper oxide and titanium oxide nanoparticles are increased as shown in Figs (18– 19). This improvement is calculated using Eq. (11). The effectiveness of the radiator is increased by using nanofluids. Nevertheless the effectiveness percentage does not increase basically, although the improvement of coefficient of overall heat transfer is significant. With increased concentration of copper oxide and titanium oxide nanoparticles in distilled water and ethylene glycol and. It increased the radiator effectiveness. It indicated in Figs (20 – 21). Figs (22 – 28) depicted the improvement in heat transfer has increased by increment in the nanoparticle concentrations, Reynolds number and inlet temperature of nanofluid. Improvement in the rate of heat transfer for different concentrations of the two types of nanofluid can be seen in Table 4. The improvement in heat transfer for the nanofluid (TiO_2 (50nm) + Dw+EG) was smaller than nanofluid (CuO (30nm) + Dw+EG) due to size of nanoparticles and thermal conductivity of the titanuim oxide.

7. CONCLUSION :-

The two types of nanoparticles are used in investigation with four concentration at (Φ= 0.5, 2, 3 and 5 vol %) and the based working fluid was ethylene glycol and distilled water (EG+Dw). The conclusions are as follows:

1. The increasing in the concentration of nanoparticles within arrange (0.5 vol % to 5 vol %) led to increase the heat transfer rate with addition of 5 vol % nanoparticles, the heat transfer enhances about 55%.
2. Overall heat transfer coefficient based on air side increased up 45 % with addition of 5vol % volume fraction nanoparticles of copper oxide and titanium oxide than the ethylene glycol and distilled water (EG+Dw).
3. Effectiveness of the radiator increased up to 47% with addition of 5 vol % volume fraction nano particles of copper oxide and titanium oxide than the ethylene glycol and distilled water (EG+Dw).
4. The improvement in heat transfer for the nanofluid (CuO(30nm) + Dw+EG) was greater than nanofluid (TiO_2(50nm)+ Dw+EG) due to size of nanoparticles and thermal conductivity of the copper oxide. The high value of thermal diffusivity causes a drop in the temperature gradients and accordingly increases the boundary layer thickness .

Table1: The properties of Nano powder CuO [14]

Copper oxide Nanopowder CuO, 99%, 30 nm	
Purity	>99%
crystal phases	Monoclinic
APS	30 nm
SSA	20– 40 m^2/g
Color	read
Morphology	Nearly spherical
True density	6.500 g/cm^3

Table2: The properties of Nano powder TiO_2 [14]

Titanium oxide Nano powder TiO_2, 99%, 50 nm	
Purity	>99%
crystal phases	Monoclinic
APS	50 nm
SSA	20 – 40 m^2/g
Color	white
Morphology	spherical
True density	4.250 g /cm^3

Table.3. The specifications of radiator are illustrated

Type of fin and tubes	Aluminum
Dimensions of the radiator	340× 30×385.5 mm
Fin shape	Corrugated
Heat transfer area	2.25m^2
Side area	6.5m^2
Volume of the fin	1.75 liter

Table 4. The improvement of the two types of the nanofluids

T (°C)	Φ (vol%)	Enhancement (%) Nanofluid (CuO+ Dw)	Enhancement (%) Nanofluid (TiO_2+ Dw)
40	0.5	3.94	2.10
	3	6	3.2
	5	6.8	4.10
60	0.5	5.28	4.08
	3	7.17	4.86
	5	9.89	5.1
70	0.5	6.22	4.65
	3	9.2	6.15
	5	12.4	9.52

Fig.1 Depicted nanofluids for CuO +(EG+ Dw) , TiO_2 +(EG + Dw)

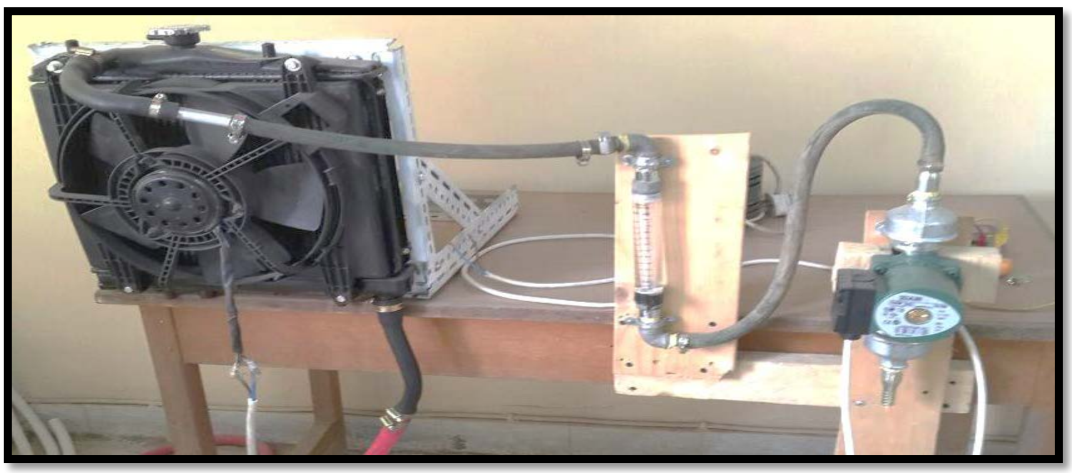

Fig 2. Experimental setup

Fig 3. The radiator, flow meter and pump used in the experiments.

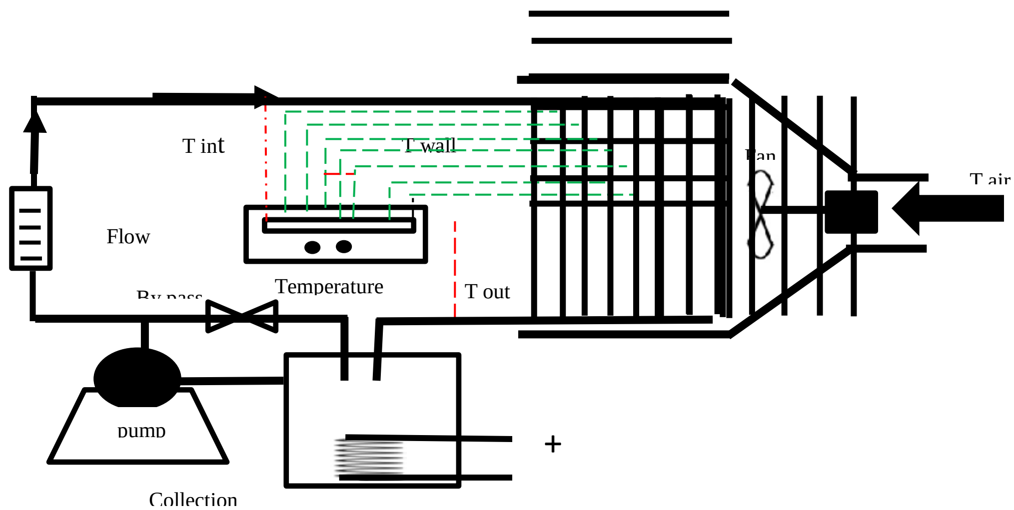

Fig. 4. Schematic of experimental setup

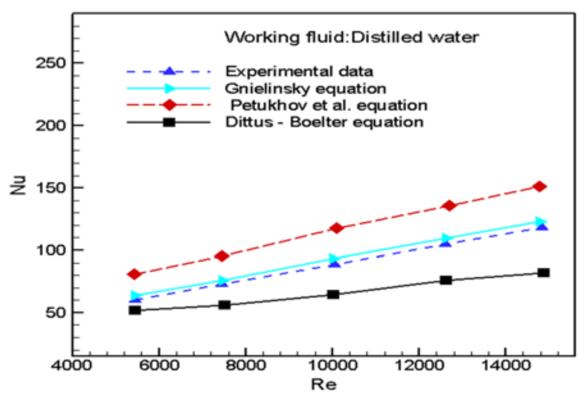

Fig 5. Comparison between present and previous results for distilled water.

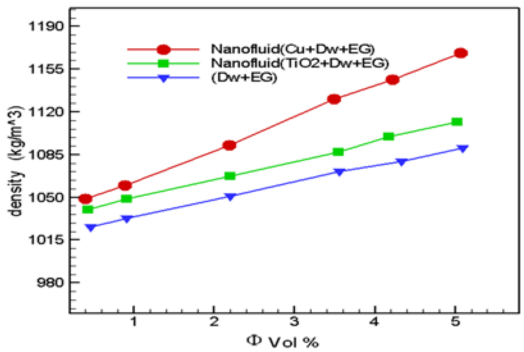

Fig 6. Density of nanofluids for (CuO+EG+ Dw) and (TiO_2+ +EG+ Dw)

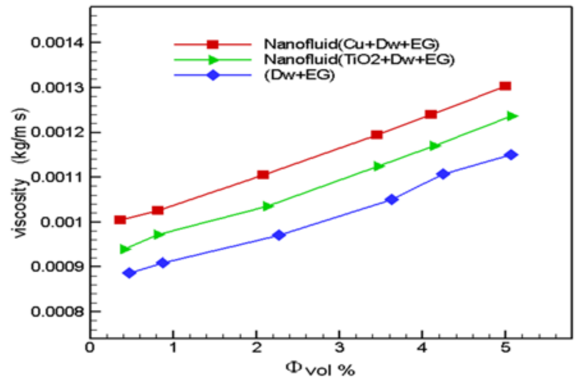

Fig 7. Vicosity of nanofluids for (CuO +EG+ + Dw) and (TiO_2+EG+ Dw)

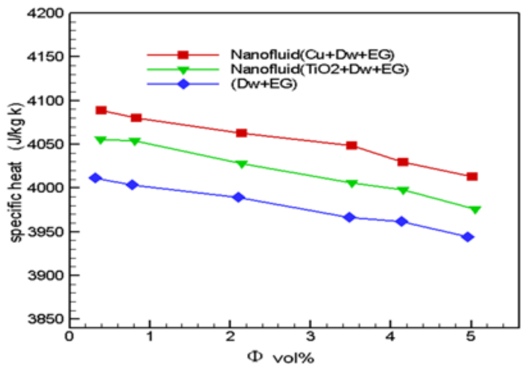

Fig 8. Specific heat of nanofluids for (CuO +EG+ Dw) and (TiO_2+EG+ Dw)

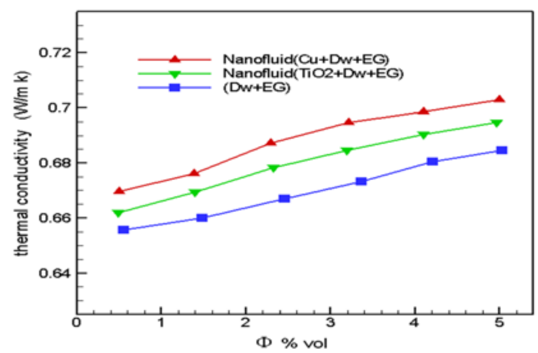

Fig 9. Thermal conductivity of nanofluids for (CuO +EG+ Dw)and (TiO_2+EG+ Dw)

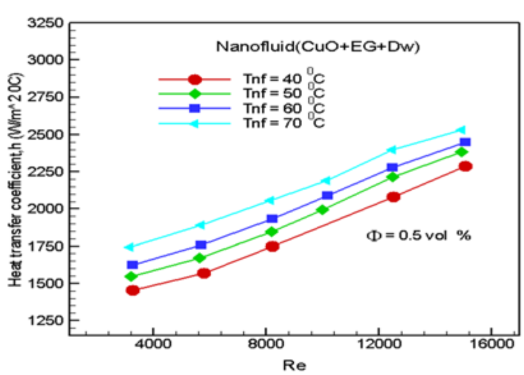

Fig 10. Variation of h with Re number inlet temperature for (CuO + EG +DW)

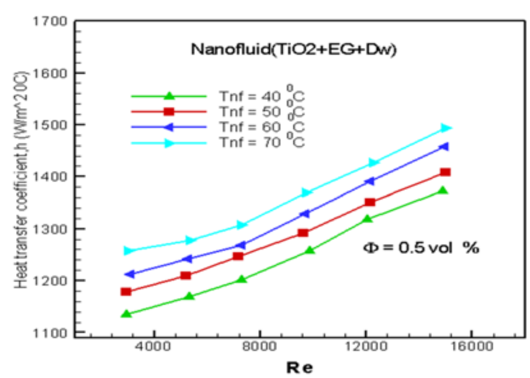

Fig 11. Variation of h with Re number inlet temperature for (TiO_2 + EG+DW)

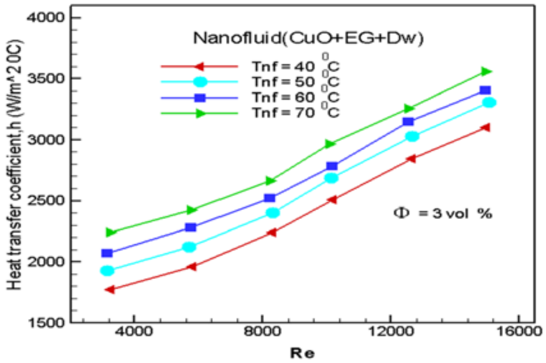

Fig 12. Variation of h with Re number, inlet temperature for (CuO + EG+ DW)

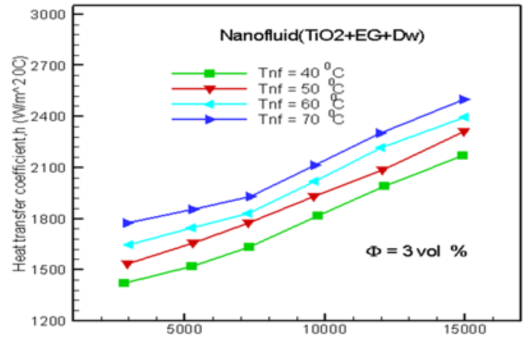

Fig 13. Variation of h with Re number, inlet temperature for (TiO_2 + EG+ DW)

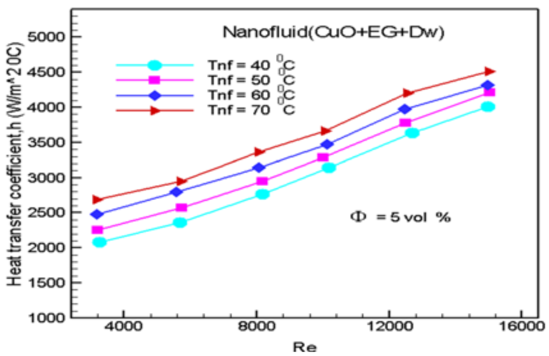

Fig 14. Variation of h with Re number inlet temperature for (CuO + EG+DW)

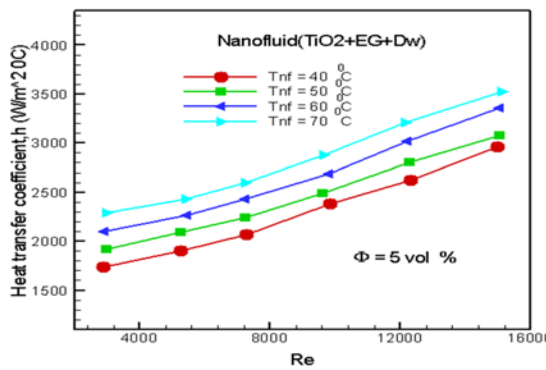

Fig 15. Variation of h with Re number inlet temperature for (TiO_2 + EG+DW)

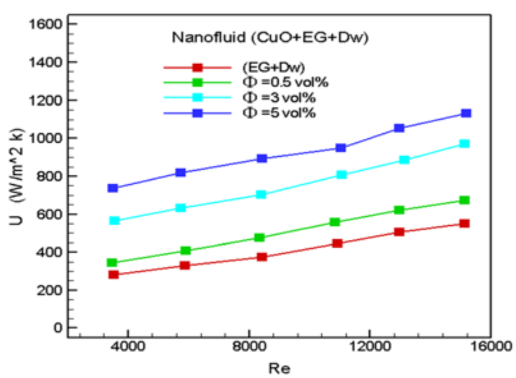

Fig 16. Variation of U with Reynolds number for (CuO + EG +DW)

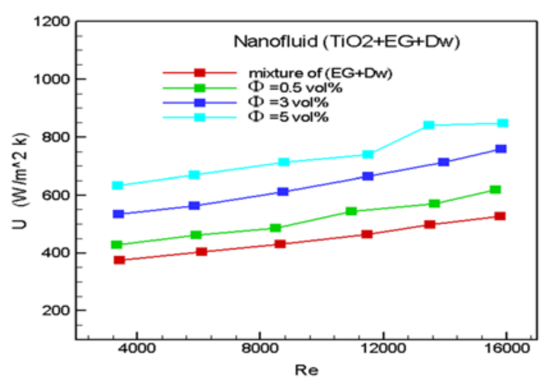

Fig 17. Variation of U with Reynolds number for (TiO_2 + EG+DW)

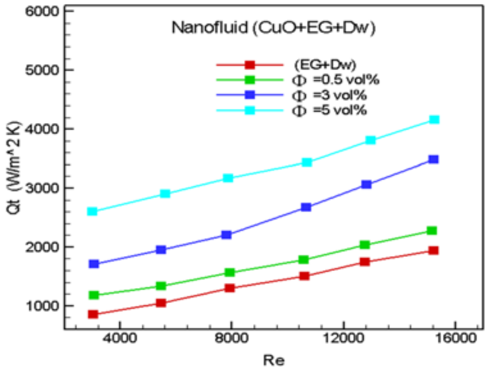

Fig 18. Variation of U with Reynolds number for (CuO + EG +DW)

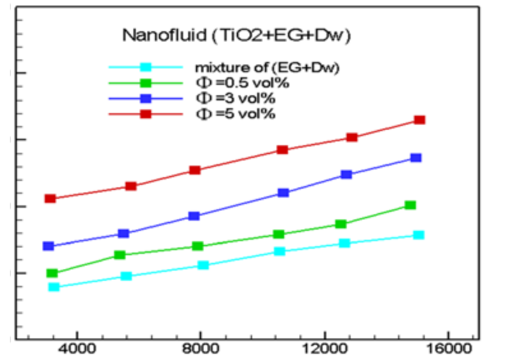

Fig 19. Variation of U with Reynolds number for (TiO_2 + EG+DW)

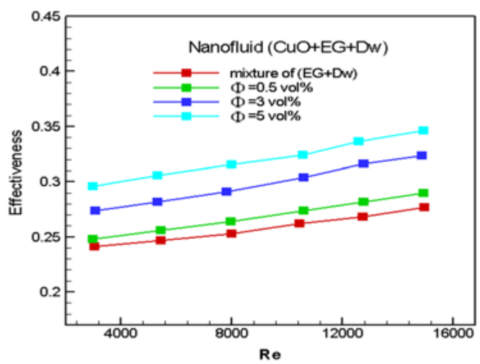

Fig 20. Variation of E with Reynolds number for (CuO + EG +DW)

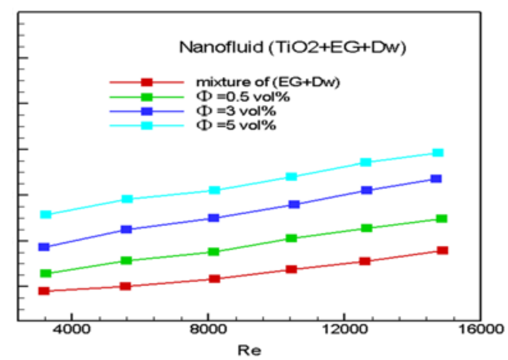

Fig 21. Variation of E with Reynolds number for (TiO_2 + EG+DW)

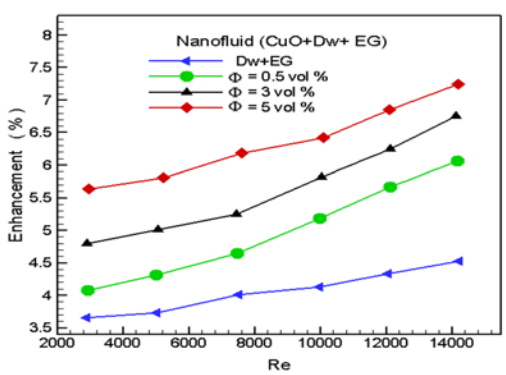

Fig 22. Variation of improvement with Re ,Φ and Tnf = 40 ^{O}C for (CuO + DW+Dw)

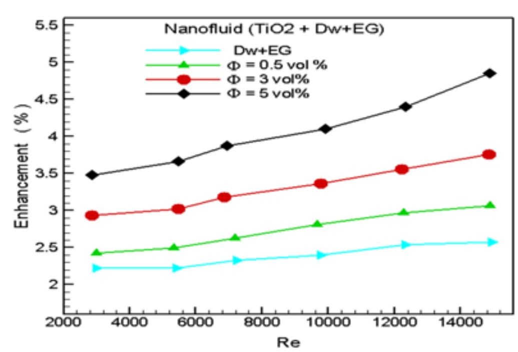

Fig 23. Variation of improvement with Re ,Φ and Tnf = 40 ^{O}C for (TiO_2 + DW+Dw)

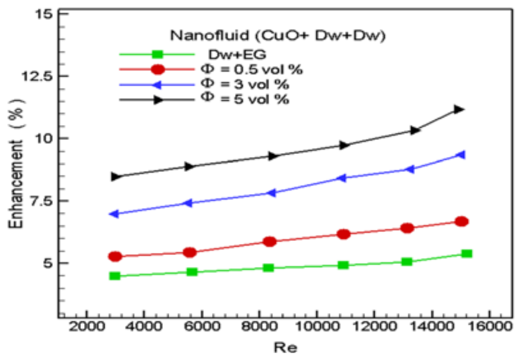

Fig 24. Variation of improvement with Re ,Φ and Tnf = 60 ^{O}C for (CuO + DW+Dw)

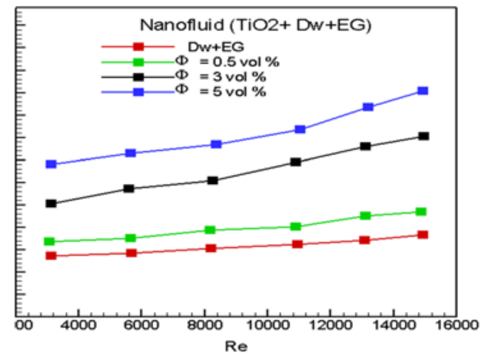

Fig 25. Variation of improvement with Re ,Φ and Tnf = 60 ^{O}C for (TiO_2 + DW+Dw)

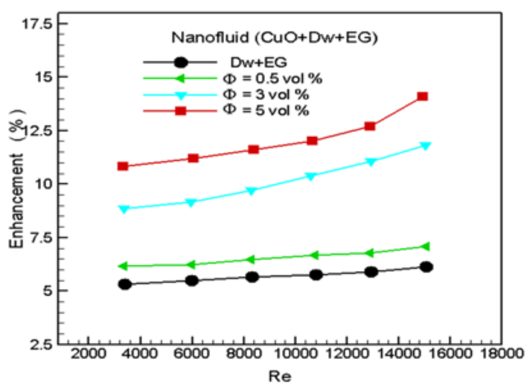

Fig 27. Variation of improvement with Re ,Φ and Tnf = 70 ^{O}C for (CuO + DW+Dw)

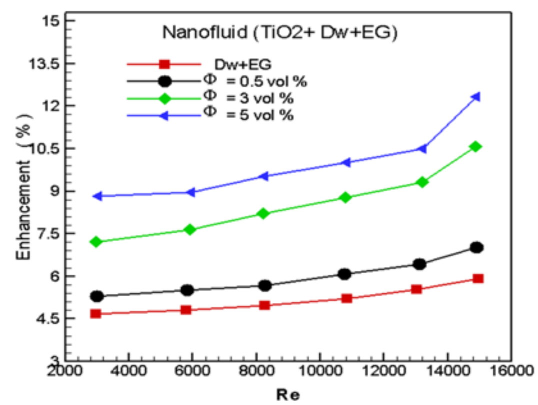

Fig 28. Variation of improvement with Re ,Φ and Tnf = 70 ^{O}C for (TiO_2 + DW+Dw)

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