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# Experimental Study of Heat Transfer Enhancement in Car Radiator by Using copper and aluminum Nanofluids

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## Abstract

The cooling system of a car plays an important role in vehicle's performance, consists of two main parts, known as radiator and fan. Improving thermal efficiency of engine leads to increase the engine's performance, decline the fuel consumption and decrease the pollution emissions. This study presents an experimental study on enhancement of heat transfer in car radiator by using aluminum, copper and distilled water nanofluids. The range of nanoparticles concentrations used were in the range of (15 – 35 wt %). Two nanoparticles aluminum (Al (50nm)) and cupper (Cu (30nm)) used in this study and distilled water was used as base fluid (distilled water). The coefficient of heat transfer was studied with the effect of many parameters such as inlet temperature of nanofluid, Reynolds number, nanofluid concentration and types of nanoparticle.. Results show that Nusselt number increased with increasing of nanofluid inlet temperature, nanoparticle volume fraction and Reynolds number.The obtained results indicated that the enhancement in heat transfer for the nanofluid (Cu(30nm) + Dw) was greater than nanofluid (Al(50nm) + Dw) due to nanoparticles size and thermal conductivity of the cupper. 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. Furthermore, Thermal conductivity for the nanofluids (Cu + Dw) was greater than nanofluids (Al + Dw) due to nanoparticles size and thermal conductivity for the cupper. It was indicated that the type and size of nanoparticle play an important role in enhancement of heat transfer rate.

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

# دراسة عملية لتحسين انتقال الحرارة في راديتر السيارة باستخدام النحاس والالمنيوم كموائع نانوية

**الخلاصة**

نظام التبريد في السيارة يلعب دورا هاما في أداء السيارة، ويتألف من جزئين رئيسيين، معروفة باسم المبرد والمروحة. أن تحسين الكفاءة الحرارية للمحرك يؤدي إلى زيادة أداء المحرك، وانخفاض



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استهلاك الوقود وتقليل انبعاثات التلوث . يقدّمُ هذ البحث دراسةً تجريبيةً على تحسين نقلِ الحرارةِ في مبرد السيارات باستخدام الموائع النانوية مثل النحاس والألومنيوم مع الماء المقطر ويتراوح مدى التراكيز الوزنية المستخدمة مابين (15 – 35 wt %) . تم في هذه الدراسة استخدام نوعين من الجزئيات النانوية ذات اقطار مختلفة هي (النحاس (30nm)) والألومنيوم ((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 عدد نسلت يزداد مع زيادة درجة حرارة الدخول للمائع النانوي , التركيز الحجمي, عدد رينولدز. أشارت النتائج أن التحسين في انتقال الحرارة للنحاس والماء المقطر (Cu(30nm) + DW) كان أكبر من الالمنيوم والماء المقطر (Al(50nm)+Dw) بسبب حجم الجزئيات النانوية والتوصيل الحراري 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 (النحاس + الماء المقطر) أكبر من المائع النانوي الذي يتألف من (الالمنيوم + الماء المقطر) نظرا لحجم الجزئيات النانوية والتوصيل الحراري للنحاس . ان نوع وحجم الجزئيات النانوية تلعب دورا هاما في تحسين معدل انتقال الحرارة.

## .INTRODUCTION

One he improvement of heat exchange systems performance will be reduced the energy Consumption and introduced enhancement techniques for heat transfer [1 – 7]. Studiedthe enhancement of heat transfer with the variation the geometry of the heat exchanger by using different types of the fins or various inserted tube and the kind of the surface roughness. [8 – 11] have been investigated the application of magnetic field, electric and vibration techniques for the heat transfer enhancement of the heat exchanger [12]. Experimental investigated convection heat transfer for the nanofluids with nanoparticles smaller than 100nm and laminar flow. He obtained a higher thermal conductivity than the liquid without a nanoparticle. [13] Enhancement the thermal conductivity by using ananofluids with particles of CuO to obtained a good thermal property. [14] Investigated experimentally the characteristics of oxide nanoparticles $Al_2O_3$ with water base on the turbulence convection heat transfer. [15 – 21] Investigated experimental the enhancement the heat transfer by using nanofluid of nanoparticles of $Al_2O_3$ with water base and different conditions. The results showed that the coefficient of the heat transfer of nanofluid increased when the particle of nanofluid particle concentration increase and also when reynolods number increase. [22– 24] investigated the enhancement of convection heat transfer of a nanofluid with a nanoparticle of $TiO_2$ – distilled water. They obtained with higher coefficient of heat transfer of nanofluid than the base fluid. In this work the coefficient of heat transfer for forced convection for two types of nanofluid (Cu, Al + Dw) are study experimentally. Also the the effect of the inlet temperature of nanofluid and volume fraction of nanoparticle on the enhancement the heat transfer are investigated.

## Experimental work

**Material:** cupper (Cu (30 nm)) and Aluminum (Al (50 nm))**.**

**Nano fluid preparation**

The preparation of nanofluid samples are prepared by dispersing pre – weighed quantities of dry particles of cupper (Cu (30 nm)) and Aluminum (Al (50 nm)) in base fluid (distilled water). In a typical procedure, the acidity (pH) of each concentration of nanofluid a mixture was measured (pH = 4.5 –5). The mixtures were then subjected to ultrasonic mixing [100 kHz, 300 W at 25 – 30 $C^0$, and Toshiba, England] for two hour to break up any particle aggregates. The nanofluid of this study was included distilled water and nanoparticles from (US Research Nano materials, Inc). Their properties are shown in table 1, and 2 respectively. The picture of preparation of nanofluids containing cupper (Cu (30 nm)) and Aluminum (Al (50 nm)) is display in Fig .1. Nanofluids prepared with different weight percent (Φ = 15, 20, 25, and 35 wt %).

**Table (1) the properties of Nanoparticles Cu [25]**

| **Cupper Nano powder Cu, 99%, 30 nm** | |
|---|---|
| Purity | >99% |
| crystal phases | Monoclinic |
| APS | 30 nm |
| SSA | 20– 40 $m^2/g$ |
| Color | read |
| Morphology | Nearly spherical |
| True density | 8.933 $g/cm^3$ |

**Table (2): The properties of Nanoparticles Al [25]**

| **Aluminum Nano powder Al 99%, 50 nm** | |
|---|---|
| Purity | >99% |
| crystal phases | Monoclinic |
| APS | 50 nm |
| SSA | 20 – 40 $m^2/g$ |
| Color | Lead |
| Morphology | spherical |
| True density | 2.707 g $/cm^3$ |

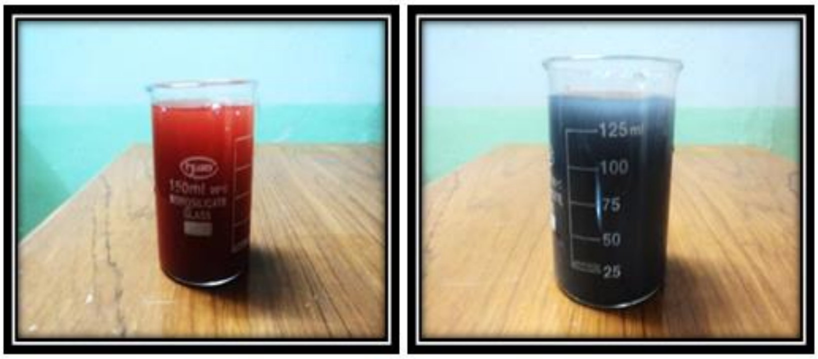


**Figure (1) show nanofluids for based on Cu, Al nanoparticles.**

## Experimental setup

The experimental set up consists of, flow lines, a storage tank, a heater, a centrifugal pump, a flow meter, a forced draft fan and a cross flow heat exchanger (an automobile radiator) as shown in Fig. 2,. The pump gives a variable flow rate of **70 – 120** l/min; the flow rate to the test section is regulated by appropriate adjusting of a globe valve. Mass flow rate was measured directly by flow meter type Dwyer series MMA mini – Master flow meter with the precision of 0.4 l/min. Two thermo couple (T – types) were implemented on the flow line to record radiator fluid inlet and outlet temperatures. as seen in table (3). Also ten thermocouples (T – types) are soldered at place along the test section. These thermocouples were installed at the center of the radiator surfaces (both sides). Due to very small thickness and very large thermal conductivity of the tubes, it is reasonable to equate the inside temperature of the tube with the outside one. For heating the working fluid, an electrical heater and a controller were used to maintain the temperature between 40 and 80 $^0$C. Twelve thermocouples were attached by silicon paste to various positions of the external walls on each side of the radiator. All used thermocouples were thoroughly calibrated by using a constant temperature water bath, and their accuracy has been estimated to be ± 0.2 $^0$C. Error analysis was carried out by calculating the error of measurements. The uncertainty range of Re No comes from the errors in the measurement of volume flow rate and hydraulic diameter of the tubes and the uncertainty of Nu refers to the errors in the measurements of volume flow rate, hydraulic diameter, and all the temperatures. According to uncertainty analysis described by Moffat [26], the measurement error of Re No was less than 4 % and for Nu was less than 15 %. The repeatability of the experiments was always within 5%. Fig. 3, depicted the Schematic of experimental setup automobile radiator used in this experiment which is of the louvered fin-and tube type, with 34 vertical tubes and stadium – shaped cross section. The fins and the tubes are made with aluminum. For cooling the liquid, a forced fan (Techno pars 1600 rpm) was installed close and face to face to the radiator and consequently air and water have in direct cross flow contact and there is heat exchange between hot water flowing in the tube – side and air across the tube bundle. Constant velocity and temperature of the air are considered throughout the experiments in order to clearly investigate the internal heat transfer.

**Table (3) the characteristics of radiator are illustrated**

| Type of fin and tubes | Aluminum |
|---|---|
| Dimensions of the radiator | 320x20x382.4 mm |
| Fin shape | Corrugated |
| Heat transfer area | 1.25m$^2$ |
| Side area | 4.7m$^2$ |
| Volume of the fin | 1.14 liter |

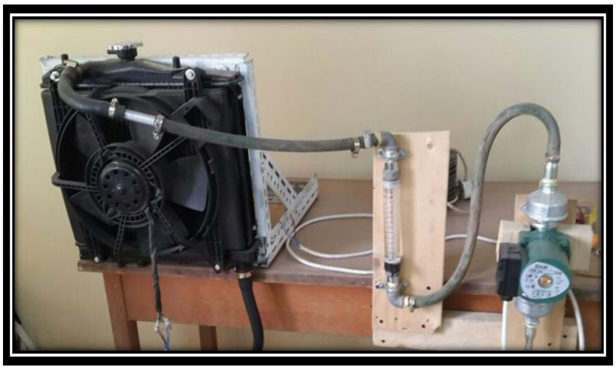

**Figure (2) Experimental setup.**

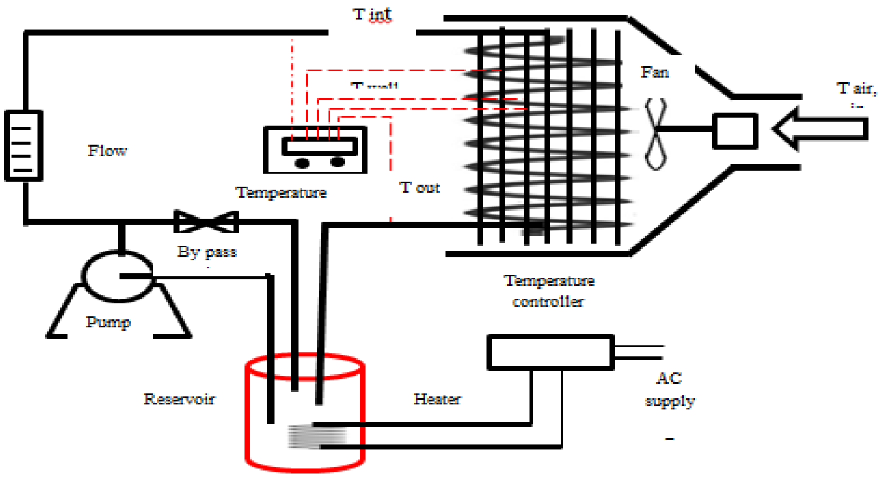


**Figure ( 3) Schematic of experimental setup.**

**Measurement of Thermal Properties Nanofluid**

All physical properties of the nanofluids (Cu, Al + Dw) and distilled water needed to calculate the pressure drop and the convective heat transfer, are measured. The dynamic viscosity (μ) is measured using brook field digital viscometer model DV – E. The thermal conductivity, specific heat and density are measured by Hot Disk Thermal Constants Analyzer (6.1), specific heat apparatus (ESD – 201) as well as the measurement of density was carried out by weighing a sample and volume. The thermal properties of nanofluids dynamic viscosity (μ) , thermal conductivity, specific heat and density are measured at different weight concentrations at (Φ= 15, 20, 25 and 35 wt %). The empirical relation used in this study to comparison with the practical measurements for nanofluid properties. The thermo physical properties of nanofluid were calculated at the average bulk temperature of the nanofluid by the following equations.

Density [28].

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

Viscosity [28].

$$\mu_{nf} = (1 + 2.5\Phi)\, \mu_{Dw} \qquad \ldots(2)$$

Specific heat [28].

$$Cp_{nf}\, \rho_{nf} = \Phi(\rho_s\, Cp_s) + (1-\Phi)(\rho_{Dw} Cp_{Dw}) \qquad \ldots(3)$$

Recently Chandrasekar et al.[28] presented an effective thermal conductivity model (Eq.4)

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

Figures (6 – 7) reveal density, viscosity, specific heat, and thermal conductivity for the two types of nanofluid (Cu+ Dw) and (Al +Dw).

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

$$Q = hADT = hA(T_b - Tw) \qquad (5)$$

Heat transfer rate can be calculated as follows:

$$Q = m\, cp\, DT = m\, cp(Tin - Tout) \qquad \ldots(6)$$

Regarding the equality of Q in the above equations:

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

In Equation (7), Nu is average Nusselt number for the whole radiator, $\dot{m}$ mass flow rate which is the product of density and volume flow rate of nanofluid, cp fluid specific heat capacity, and Tin and Tout inlet and outlet, Tb bulk temperature which was assumed to be the average values of inlet and outlet temperature of the nanofluid moving through the radiator, and Tw tube wall temperature.In this equation, $k_{nf}$ is thermal conductivity of the nanofluid and Dh is hydraulic diameter of the tube. It should also be mentioned that all the thermo physical properties were calculated at nanofluid bulk temperature. The temperature measured by thermocouples with the accuracy of inlet and outlet temperature was estimated to be ± 0.5°C.

## Results and discussion

In order to verify the accuracy and the reliability of the experimental system, the heat transfer coefficients are experimentally measured using base distilled water as the working fluid before obtaining those of distilled water Cu and Al nanofluids**.** Comparison was made between the results of the experimental and three well – known empirical correlations: one of them suggested **by** Dittuse Boelter correlation [29], Gnielinsky correlation [30] and the other developed by Petukhov et al. [31] (see

Figure 5). These three relations are shown in equations (9 – 13), respectively. In equations (11) and (13), $f$ is friction factor.

$$\mathrm{Nu} = 0.0235\ \mathrm{Re}^{0.8}\ \mathrm{Pr}^{0.3} \qquad \text{… (9)}$$

$$\mathrm{Nu} = \frac{\left(\frac{f}{2}\right)(\mathrm{Re}-1000)\ \mathrm{Pr}}{1+12.7\left(\frac{f}{2}\right)^{0.5}\left(\mathrm{Pr}^{\frac{2}{3}}-1\right)} \qquad \text{… (10)}$$

$$f = (1.58\ln(\mathrm{Re}) - 3.82)^{-2} \qquad \text{… (11)}$$

$$\mathrm{Nu} = \frac{\left(\frac{f}{8}\right)\ \mathrm{Re}\ \mathrm{Pr}}{1.07+12.7\left(\frac{f}{8}\right)^{0.5}\left(\mathrm{Pr}^{\frac{2}{3}}-1\right)} \qquad \text{…(12)}$$

$$f = (1.82\log(\mathrm{Re}) - 1.64)^{-2} \qquad \text{…(13)}$$

In Fig. (5) Reasonably good agreement can be seen between Gnielinsky equation and the measurements over the Reynolds number range used in this study. Figs (6 – 7) shows the dimensionless thermal properties of the two nanofluids (Cu + Dw) and (Al + Dw) in comparison with those of distilled water. These figures indicated that density, thermal conductivity and viscosity increased with increasing concentration of nanoparticles while the specific heat decreased with increasing concentration of the nanoparticles. Thermal conductivity for the nanofluids (Cu + Dw) was greater than nanofluids (Al + Dw) due to nanoparticles size and thermal conductivity for the cupper. Figs (8 – 13 ) show the effect of the Reynolds number, nanoparticle volume fraction and fluid inlet temperature on Nusselt number for the two types of the nanofluids (Cu + Dw) and (Al + Dw). The velocity components of nanofluid increase as a result of an increase of energy transport in the fluid with the increasing the volume fraction. The sensitivity of thermal boundary layer thickness to volume fraction of nanoparticles is related to the increased thermal conductivity of the nanofluid. In fact, higher values of thermal conductivity are accompanied by higher values of thermal diffusivity. The high value of thermal diffusivity causes a drop in the temperature gradients and accordingly increases the boundary layer thickness [32]. This increase in thermal boundary layer thickness reduces the Nusselt number, however, the Nusselt number is a multiplication of temperature gradient and the thermal conductivity ratio (conductivity of the of the nanofluid to the conductivity of the base fluid).

Since the reduction in temperature gradient due to the presence of nanoparticles is much smaller than thermal conductivity ratio, therefore, an enhancement in Nusselt number is taken place by increasing the volume fraction of nanoparticles. Therefore, addition of nanoparticles 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. In order to consider the effect of temperature on thermal performance of the radiator, different fluid inlet temperatures have been applied for each concentration. The nanofluid inlet temperatures include 44°C, 60°C, and 70°C for the two types nanofluids (Cu + Dw) and (Al + Dw). These figures indicated that an increase in the nanofluid inlet temperature slightly enhances Nusselt number because of augmentation in the effect of test liquid radiation to the internal wall of the tubes. Also, these figures show that Nusselt number increases with the increase of Reynolds number. The enhancement of heat transfer between the case of nanofluid and the pure fluid ( base fluid) case is defined as:

$$\text{Enhancement}\,\% = \frac{\text{Nu (nf)} - \text{Nu (bf)}}{\text{Nu (bf)}} \times 100 \qquad \ldots(14)$$

The effect of the Reynolds number, nanoparticle volume fraction and nanofluid inlet temperature on enhancement in heat transfer are shows in Figures (14 – 19 ). The enhancement in heat transfer has increased by augmentation in the concentrations of nanoparticle, Reynolds number and nanofluid inlet temperature. For the distilled water based nanofluid it is obvious that the enhancement increases with Reynolds number and at higher concentrations of nanoparticle the effect of Reynolds number becomes pronounced. Improvement in the heat transfer rate for different concentrations of the two types of nanofluid can be seen in (table 4). The enhancement in heat transfer for the nanofluid (Cu (30nm) + Dw) was greater than nanofluid (Al(50nm) + Dw) due to nanoparticles size and thermal conductivity of the cupper.

**Table (4) The enhancement of the two types of the nanofluids**

| T (°C) | Φ (wt%) | Enhancement (%) Nano fluid (Cu+ Dw) | Enhancement (%) Nano fluid (Al+ Dw) |
|---|---|---|---|
| 44 | 15 | 4.6 | 2.2 |
| | 20 | 6 | 2.8 |
| | 25 | 6.8 | 3.2 |
| | 35 | 7.4 | 4.8 |
| 60 | 15 | 6.4 | 4 |
| | 20 | 6.8 | 4.4 |
| | 25 | 8.6 | 5 |
| | 35 | 10.6 | 5.8 |
| 70 | 15 | 6.8 | 5 |
| | 20 | 9.2 | 6 |
| | 25 | 11.2 | 7.5 |
| | 35 | 14.4 | 12 |

## Conclusion

Thermal enhancement of car radiators performance was investigated with nanofluids (Cu (30nm) + DW) and (Al (50nm) + DW), as working fluid. The two types of nanoparticles are used in investigation with four particle concentration ratios (i.e. 15, 20, 25 and 35 wt %) and the based working fluid was distilled water. The summary results are as follows:

1. Type of nanofluid play very important role in enhancement of heat transfer and coolant of car radiators

2.Effects of the nanofluid inlet temperature, Reynolds number and nanoparticle volume fraction on heat transfer are considered.
3. The enhancement in heat transfer for the nanofluid (Cu(30nm) + Dw) was greater than nanofluid (Al(50nm) + Dw) due to nanoparticles size and thermal conductivity of the cupper. The high value of thermal diffusivity causes a drop in the temperature gradients and accordingly increases the boundary layer thickness.
4. Using nanofluid as working fluid leads to higher heat transfer performance which is promoted the car engine performance and would reduce fuel consumption.
5. Nusselt number increased with the increasing of nanofluid inlet temperature, nanoparticle volume fraction and Reynolds number.
6. Thermal conductivity for the nanofluids (Cu + Dw) was greater than nanofluids (Al + Dw) due to nanoparticles size and thermal conductivity for the cupper.

## Nomenclature

| Symbol | Quantity | units |
|---|---|---|
| A | peripheral area | $m^2$ |
| Q | thermal energy | J |
| Cp | Specific heat | J/kg k |
| $d_{hy}$ | hydraulic diameter $=\frac{4A}{P}$ | m |
| h | heat transfer coefficient | $W/m^2\ K$ |
| $\dot{m}$ | Mass flow rate | kg/s |
| Nu | Nusselt number | __ |
| P | Tube cross section perimeter | m |
| Pr | Prandtl number $=\frac{\mu}{\rho\ \alpha}$ | — |
| Re | Reynolds number $=\frac{4\dot{m}}{\pi\ dhy\ \mu}$ | — |
| T | Temperature | °C |
| f | Friction factor | m |
| | **Greek Symbol** | |
| μ | Dynamic viscosity | $N.s/m^2$ |
| ρ | density | $Kg/m^3$ |
| Φ | Volume concentration | __ |
| | **Subscripts** | |
| bf | Base fluid | __ |
| nf | Nanofluid | __ |
| in | input | __ |
| out | output | __ |
| w | wall | __ |

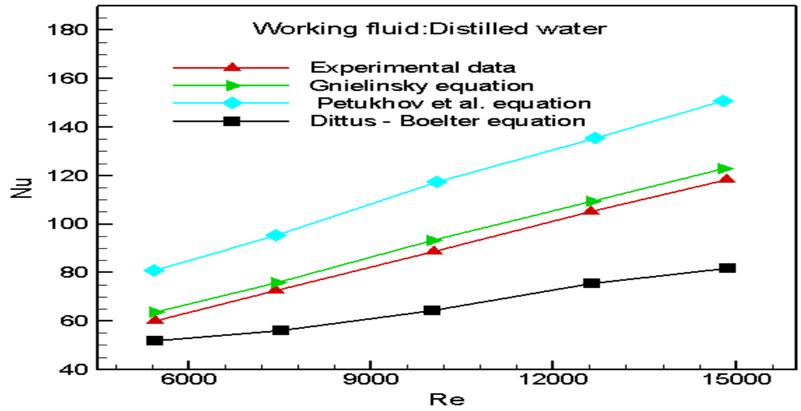


**Figure ( 4) Experimental results for distilled water in comparison with The results obtained in previous studied.**

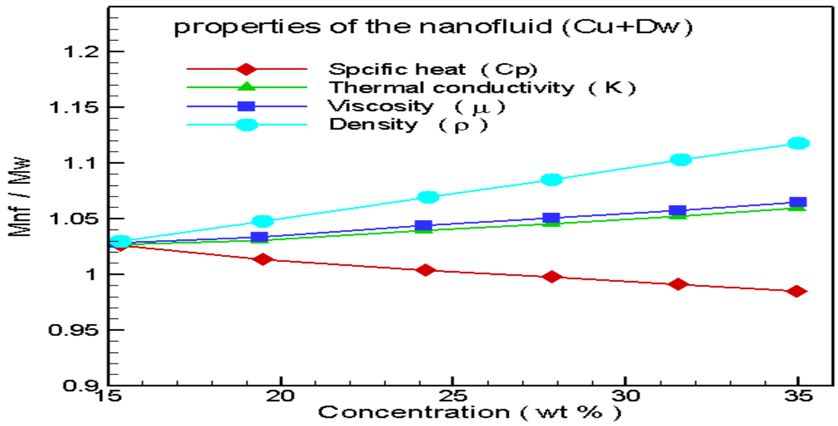


**Figure (5) Dimensionless thermal properties of nanofluid(Cu+Dw) in comparison with those of distilled water**

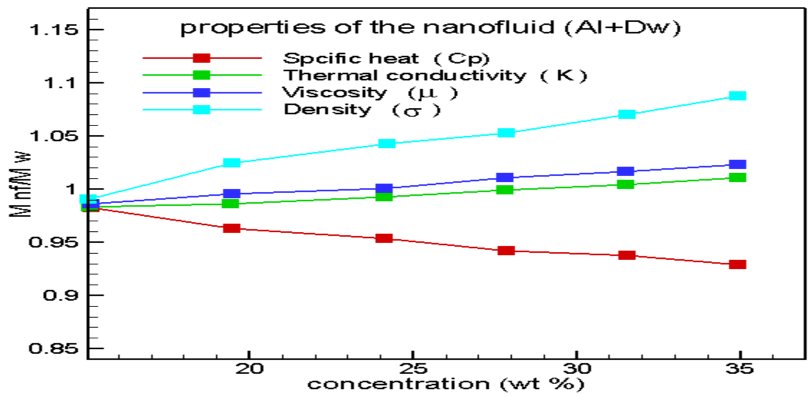


**Figure (6) Dimensionless thermal properties of nanofluid (Al+Dw) in comparison with those of distilled water**

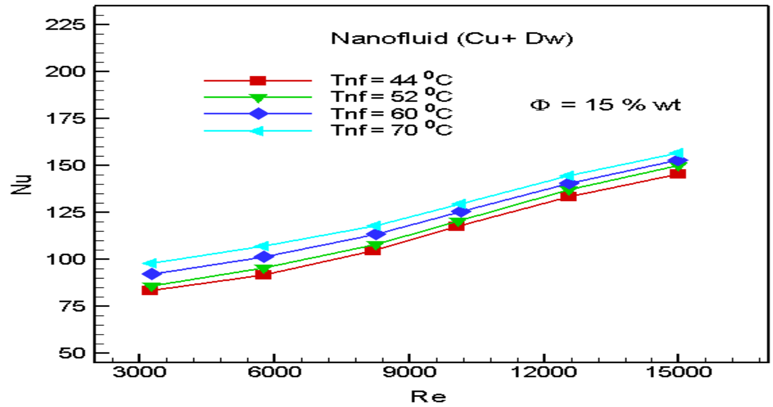


**Figure (7) Variation of Nusselt number with Reynolds number , inlet temperature at Φ=15 wt% for (Cu + DW)**

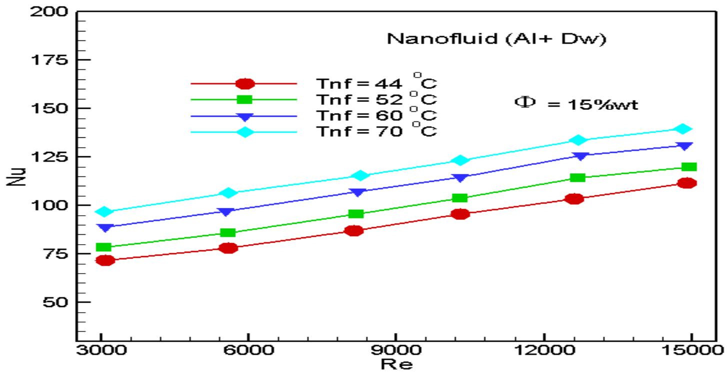


**Figure (8) Variation of Nusselt number with Reynolds number, inlet temperature at Φ=15 wt% for (Al + DW)**

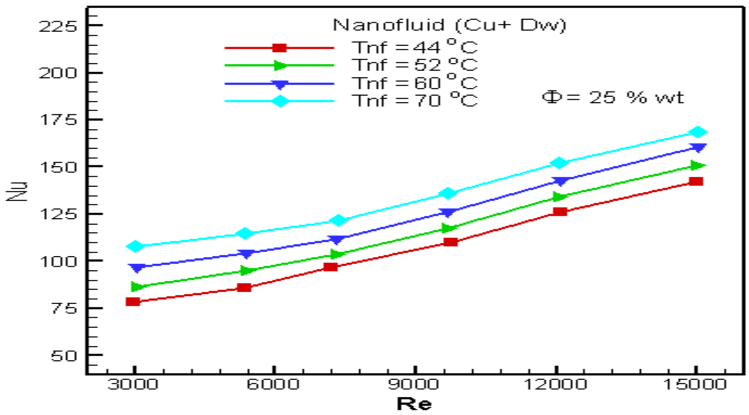


**Figure ( 9) Variation of Nusselt number with Reynolds number, inlet temperature at Φ=25 wt% for (Cu +DW)**

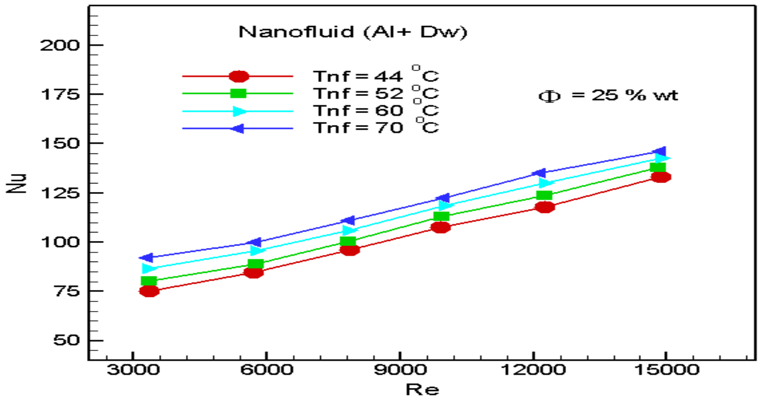


**Figure (10) Variation of Nusselt number with Reynolds number, inlet temperature at Φ=25 wt% for (Al +DW)**

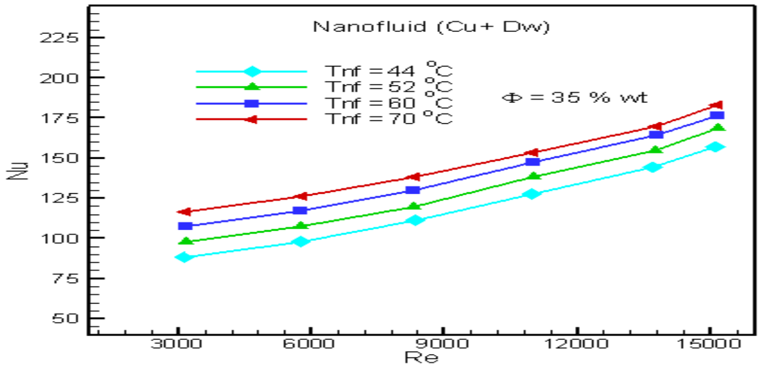


**Figure (11) Variation of Nusselt number with Reynolds number, inlet temperature at Φ=35 wt% for (Cu +DW)**

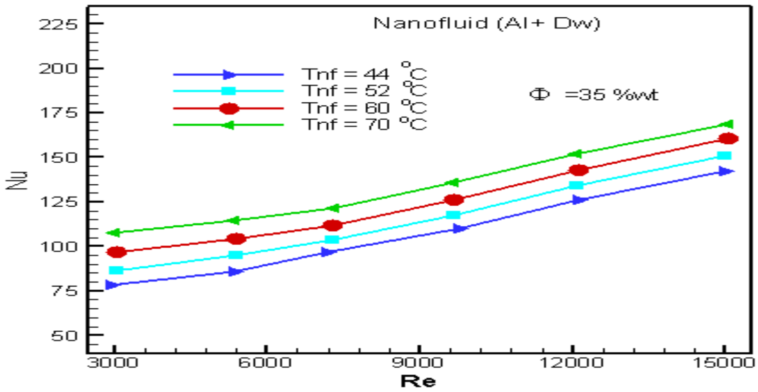


**Figure (12) Variation of Nusselt number with Reynolds number, inlet temperature at Φ=35 wt% for (Al +DW).**

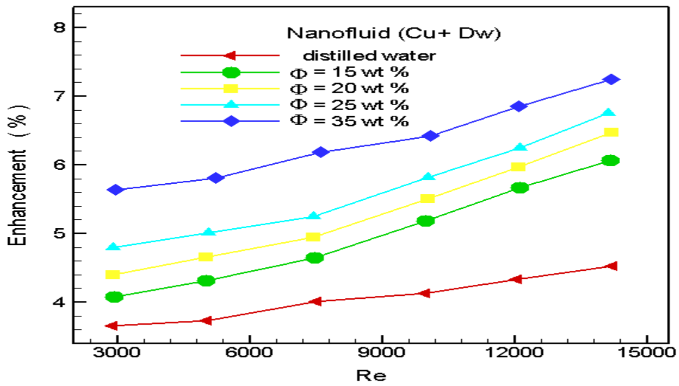


**Figure ( 13) Variation of Enhancement with Re, Φ and Tnf = 44 $^{O}$C for (Cu + DW).**

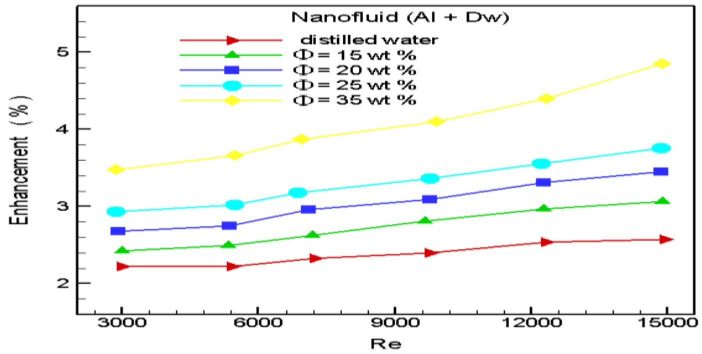


**Figure (14) Variation of Enhancement with Re ,Φ and Tnf = 44 $^{O}$C for (Al + DW)**

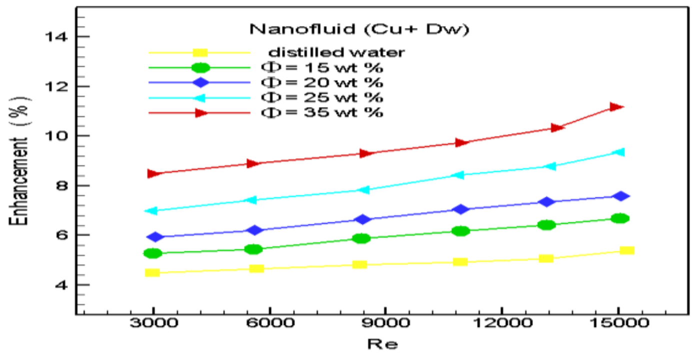


**Figure (15) Variation of Enhancement with Re, Φ and Tnf = 60 $^{O}$C for (Cu + DW)**

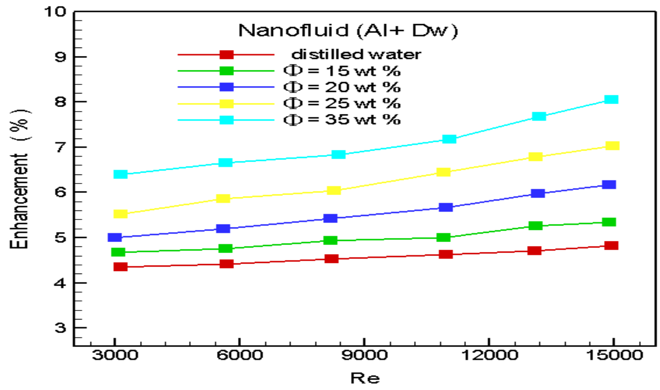


**Figure (16) Variation of Enhancement with Re, Φ and Tnf = 60 $^{O}$C for (Al + DW).**

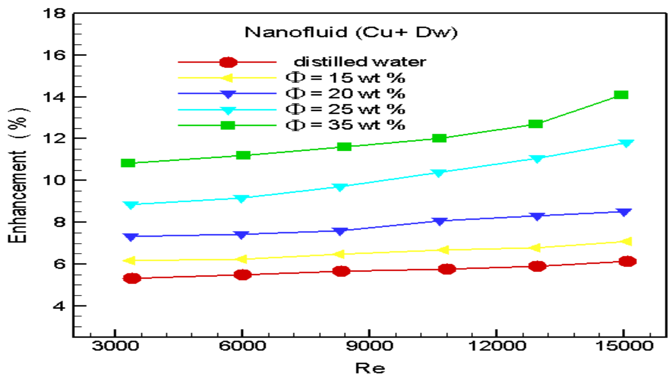


**Figure (17) Variation of Enhancement with Re, Φ and Tnf = 70 $^{O}$C for (Cu + DW).**

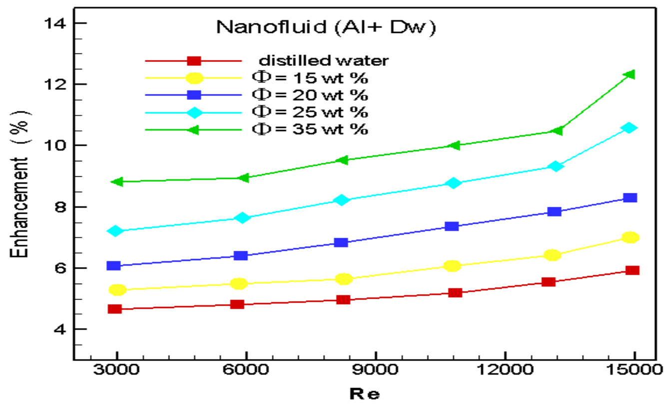


**Figure (18) Variation of Enhancement with Re ,Φ and Tnf = 70 $^{O}$C for (Al + DW)**

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