Effect of Ceramic Nanoparticles on Nanofluids Electrical Conductivity

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Abstract. In this study, an extensive experimental evaluation is conducted on the electrical conductivity of water based nanofluids containing three types of ceramic nanoparticles of (Al₂O₃, CuO and ZrO₂) with different nanoparticles concentrations of (0.05, 0.1, 0.15 and 0.2 vol. %) and for various temperatures ranged by (20–80 °C) by using deionized water as a base fluid. The nanofluids volume (water/nanoparticles) is used at (200 ml). The nanofluid sample mixes slowly by stirring and ultrasonic vibration sonicator with power of (50 W) for a maximum time of (15-20 minutes) to break up any particle aggregates with no any surfactant that is added into the nanofluids to avoid reunion. The electrical conductivity of nanofluids is measured by electrical conductivity meter. Results indicate that the effect of solution temperature on the nanofluids electrical conductivity has little effect in the range of 20–40 °C, but the effect of temperature is increased in the temperature range of 40–80 °C. Also, the percent of electrical conductivity enhancement is 80%, 75% and 50 % when using the nanofluids of CuO, Al₂O₃ and ZrO₂ respectively. Finally, the theoretical model of Maxwell is used to compare with the present experimental results and it gives an agreements.

Keywords: Ceramic Nanofluids, Electrical Conductivity, Nanofluids, Nanoparticles.

1. Introduction
The attention of Nanotechnology material researchers is increasingly capturing as this technology pushes the limits and boundaries of the pure material itself. The base fluids physical properties such as thermal conductivity and electrical conductivity were enhanced by using the nanofluids. Also, the electrical conductivity and viscosity of the base fluid will be changed as addition the nanoparticles. The thermophysical properties have been studied by many previous literatures and it gives a sufficient enhancing to the base fluids. Also, there are some research studied focused on the electrical conductivity of various nanofluids, thus, the effect of addition of many types of nanoparticles on the electric conductivity have been investigated by various researchers that are summarized in Table 1 [4]. When an electric potential was applied on a sample of fluid, the fluid electrical conductivity comes from the ability of ions or charged particles that created in the fluids suspension to carry the charges (electrons) towards respective electrodes. In nanofluids, the electrical double layer (EDL) formation depends on the nanoparticles volume fraction, nanoparticles size, surface charge, and ionic concentration in the base fluid [1].

There are a few experimental studies have been reported of the effect of addition the ceramic nanoparticles water-based on the nanofluids electrical conductivity. The electrical conductivity of CuO nanofluid for different nanoparticles particles size, nanoparticles volume fraction, and nanofluids various temperatures were reported by [2]. Their results showed that the electrical conductivity increases with increasing both nanofluids volume fraction in range 0.12-0.18g/l and with increasing temperatures in the range 25–50°C. In addition, the electrical conductivity increases with linear
relationships with increasing the nanoparticles volume fraction. An aluminum oxide (Al$_2$O$_3$) nanofluid based on ethylene glycol (EG) to measure electrical properties in a wide range of temperatures (10 to 55°C) and frequencies (0.02-200 kHz) has been studied [3]. They observed that the increase in temperature and mass concentration causes a change in the electrical conductivity of these materials.

Table 1. Summary of previous studies in nanofluids electrical conductivity.

| References                  | Nanoparticle(s)                  | Concentration | Base Fluid(s) | Observations                                      |
|-----------------------------|----------------------------------|---------------|---------------|---------------------------------------------------|
| Mahboobeh et al., [5]       | Graphene oxide                   | 0.06 % wt.    | Distilled water | 25.678 % ^aEC enhancement                        |
| White et al., [6]           | Zinc Oxide (ZnO)                 | 7 % vol.      | Propylene-Glycol | Level off at high nanoparticle concentrations     |
| Zawrah et al., [7]          | Al$_2$O$_3$                      | 0.2 vol.%     | Distilled water | EC is dependent on nanoparticles concentration and EDL |
| Madhusree and Dey, [8]      | Functionalized graphene          | 0 – 0.395 vol.% | Deionized Water | EC is dependent on loadings of particle, sizes, and charges. The results indicate the nonlinear relation between the EC and both temperature and nanoparticle concentration. Using Al$_2$O$_3$-water nanofluid gives an enhancement in the EC. The enhanced EC for the composites of 5% and 20% |
| Dong et al., [9]             | Aluminum-nitride-(AlN)           | 0.5% vol.%    | Transformer Oil |                                                  |
| Chang et al., [10]          | K$_4$Fe/K$_3$F-based alumina nanofluids | 0.068 vol.% | Deionized Water |                                                  |
| Subhash, et al., [11]       | Cadmium Oxide (CdO)              | (5%,10%, 20%)% wt. | Starch and Distilled Water |                                                  |
| SaktIyaramana, et al., [12] | Graphene Oxide (GO)              | 0.03% vol.    | deionized water | GO nanofluids with volume concentration of 0.03% and temperature of 50°C is shown to have the highest conductivity value. The ZnO NPs coating on the surface of bacterial nanowires improve the electrical conductivity of the bacterial nanowires. Increase in both mass concentration and temperature give rise to increase in EC |
| Maruthupandy, et al., [13]  | Zinc Oxide Nanoparticles (ZnO NPs) | 0.01% vol.    | coating on the surface of bacterial nanowires |                                                  |
| Fal and Zyla, [14]          | Silicon Dioxide (SiO$_2$)        | 0.5 wt.%      | Ethylene glycol (EG) |                                                  |

^aEC denotes electrical conductivity

The electrical conductivity of nanofluids containing metallic and ceramic particles (Cu, Al$_2$O$_3$, and CuO) in both water and ethylene glycol as a base fluid was measured [4]. Their results showed that the electrical conductivity increases with increasing nanoparticle volume fraction and with reducing nanoparticle size. In addition, they showed that the enhancement of the ceramic nanofluids electrical conductivity is more than that of metal nanofluids at the same conditions. Based on the above literature survey, it is found that, there are a few previous studies are reported for the effect of addition
the ceramic nanoparticles water-based on the nanofluids electrical conductivity. Thus, the aim of this study is to investigate the effect of using ceramic nanoparticles on the electrical conductivity of the nanofluids. In the present work, the effects of using three types of ceramic nanoparticles, namely (Al₂O₃, CuO and ZrO₂) with different concentrations of (0.05, 0.1, 0.15 and 0.2 vol. %) and nanofluid temperature ranged by (20–80 °C) on the electrical conductivity of nanofluids are carried out in this work.

2. Experimental Work
2.1. Nanofluid Preparation
Nanofluids are suspensions of nanometrical size particles in a liquid base, which is usually water, oil or ethylene glycol. Three types of nanoparticles of (Al₂O₃, CuO and ZrO₂) are used in this experimental study. The electrical and physical properties for the three types of the nanoparticle and the base fluid are listed in Table 2. In this study, the two-steps method is used for nanofluid preparation. First, to get the desired weight of nanopowder by using the dispersant weighed powder of (Al₂O₃, CuO or ZrO₂) nanoparticles are dissolved in the deionized water. This nanofluid mixture with volume of (water/nanoparticles) of (200 ml) is mixed slowly stirring and ultrasonic vibration sonicator type of (Yo Xun 3560) with power of (50W) for (15-20 minutes) time period to break up any aggregates of nanoparticles. In this work, four concentrations volume of (0.05, 0.1, 0.15 and 0.2 % vol.) are used for each type of the ceramic nanoparticles of (Al₂O₃ and CuO and ZrO₂). Figure 1 shows the prepared samples of the prepared nanofluids of (ZrO₂, CuO, and Al₂O₃). To specify the nanoparticles volume concentration, the amount of nanoparticles is given by [15]:

\[ \phi = \frac{m_p/\rho_p}{m_p/\rho_p + m_f/\rho_f} \]  

(1)

Where

\[ m_p = \frac{\rho_p \phi}{\rho_f (1-\phi)} m_f \]  

(2)

| Particle | ρₚ (kg/ m³) | Dielectric constant, ε | dₚ (nm) | K(μs/cm) | Color |
|----------|-------------|------------------------|---------|-----------|-------|
| Al₂O₃    | 3970        | 9.2                    | 20      |           | white |
| CuO      | 6500        | 18.1                   | 40      |           | black |
| ZrO₂     | 5680        | 6.3                    | 80      |           | white |
| DIW      | 997.1       | 80                     | -       | 5.5       | -     |

Table 2. Ceramic nanoparticles and base fluid properties.
2.2 Measurements of Electrical Conductivity
The experimental setup that used in this study is presented in Figure 2. It shows all the instruments that used in this work, it includes electric heater, sonicator, nanofluids sample beaker, EC meter and heat distribution screen.

The principles of nanofluid mixture electrical conductivity of an electrolyte is measured by determining the resistance of the solution between two cylindrical or flat electrodes as shown in Figure 3 which is separated by a fixed distance [16].
In the experimental measurements, 200 mL of deionized water nanofluid sample is filled between the two electrodes. If the voltage \( V \) applies on the two electrodes to produce \( I \sim V \) curve, the current \( I \) will flow through the nanofluid sample. Thus, the nanofluid EC can be determined as [4]:

\[
K = \frac{I}{L} \frac{S}{V} \tag{3}
\]

The water and nanofluids EC are measured as a function of nanoparticles concentration and nanofluids temperatures by using the JENWAY 4520 conductivity meter that has two coaxial electrodes are named as the inner electrode and the outer electrode. In addition, a DMA-35N portable density meter device is used to measure the water and nanofluids density. In addition, the measurement experimental data error analysis is used to get the deviation from the actual results (from repeatability). Thus, the error is found to be \( \pm 1.5\% \) and the instrumental uncertainty for temperature is \( 0.15 \) K and for electrical conductivity measurements is \( \pm 1\% \).

3. Results and Discussion
In this study, firstly, the de-ionized water electrical conductivity is measured, and it was about 5.5 \( \mu \)S/cm. Therefore, the results of the (Al\(_2\)O\(_3\), CuO and ZrO\(_2\)) nanofluids with different volume fractions electrical conductivity is measured and compared with this value of electrical conductivity of water. The measurement experimental data error is attributed to the deviation from the actual results (from repeatability) due to experimental conditions. In this study, the error is found to be \( \pm 1.5\% \). Nevertheless, the instrumental uncertainty for temperature at 0.15 K and for electrical conductivity measurements is \( \pm 1\% \) in the conductivity range of 0–199 \( \mu \)S/cm. Figure 4 presents the effect of temperature on the nanofluids electrical conductivity, the experimental changes of electrical conductivity as a function of temperature for the three nanofluids are compared with de-ionized water. All the results curves follow a nonlinear relationship. As revealed in Figure 4, it shows that the electrical conductivity increases with increasing the solution temperature for the base fluid and nanofluids that employed in this study. The CuO nanofluid electrical conductivity values show the highest values as compared with the others, but the ZrO\(_2\) nanofluid shows a lowest value as compared with the Al\(_2\)O\(_3\) and CuO nanofluids. However, it can be observed that the ZrO\(_2\) nanofluid has a high electrical conductivity if it compared with the de-ionized water at the same temperatures. Moreover, the results show that there is little effect of nanofluid temperatures on the EC in the range of 20–40 °C, but the nanofluid EC will increase with increasing the nanofluids temperature in the range 40–80 °C.

![Figure 4](image-url)  
**Figure 4.** Experimental nanofluids electrical conductivity as a function of nanofluid temperatures.
In order to study the effect of using different nanoparticles concentrations it can review in Figure 5. It plots the de-ionized water nanofluid electrical conductivity versus nanoparticles volumetric fraction. It can be observed that there is a nonlinear relation between the electrical conductivity and nanoparticles volumetric fraction, which is different from the reported linear relation of electrical conductivities on volume fraction of nanoparticles in other literatures [2]. However, it can be seen that the electrical conductivity increases with increasing the nanoparticles volumetric fraction for all three nanofluids. However, this effect appears strongly in the case when using Al$_2$O$_3$ and CuO nanofluids. However, the maximum electrical conductivity is (51.22 μS/cm) at nanoparticles volumetric fraction of (ϕ=0.2 vol. %) in the case of using CuO nanofluid, but it can be observed that the minimum value showed about (9.45 μS/cm) at nanoparticles volumetric fraction of (ϕ=0.05% vol.) in the case of using ZrO$_2$ nanofluid according to the present experimental work.

**Figure 5.** Experimental nanofluids electrical conductivity as a function of volumetric fraction

To correlate the effects of temperatures and nanoparticles concentrations on the experimental electrical conductivity as illustrated in Figures 6 respectively for the case of using CuO nanofluid at volume fraction of (ϕ=0.1 vol. %) and T=30 °C.

**Figure 6.** The experimental data Correlation of CuO nanofluid electrical conductivity.

The electrical conductivity percentage of the base fluid with different nanoparticle concentrations is formed as in Eq.(4), where $K_o$ represents the base fluid or the water electrical conductivity which set as (5.5 μS/cm) and $K$ represents to the nanofluids electrical conductivity, the electrical conductivity percentage values is listed in Table 3:

\[ K = \frac{K_o + (K - K_o) \Phi}{(1 + (K - K_o) \Phi)} \]

where $K_o = 5.5 \, \mu S/cm$, $K$ are the electrical conductivity values of the nanofluids, and $\Phi$ are the nanoparticles volume fraction.
Enhancement, % = \frac{K-K_0}{K} \times 100\% \quad (4)

Table 3. Enhancement percentage for all tested fluids.

| Volume fraction (%) | DIW | Al₂O₃ | CuO | ZrO₂ |
|---------------------|-----|-------|-----|------|
| Enhancement (%)     | -   | 71    | 123 | 158  |
|                     |     | 184   | 380 | 414  |
|                     |     | 432   | 449 | 282  |
|                     |     | 360   | 396 | 407  |

The enhancement in the electrical conductivity that lists in Table 3, it obtains from the formation of surface charges by nanoparticles polarisation when dispersed in the water that is considered as polar fluid. The densities of both the particles and the base fluid and the effective dielectric constants are quantified the polarization process.

The enhancement rate in the electrical conductivity by using the ceramic nanofluids is plotted in Figure 7. The present results show a slightly increasing in electrical conductivity with respect to increase in the temperature of nanofluid at (20-40°C). In addition, the enhancement is similar value to those of lower temperature mainly, because the samples are low concentrated of CuO and Al₂O₃ nanofluids. The enhancement is increasing in the range of temperatures of (40 – 80°C). The enhancement of electrical conductivity are about 80%, 75% and 50 % when using the nanofluids of CuO, Al₂O₃ and ZrO₂ respectively at fluid temperature of (T=50°C) and (\(\phi=0.1\) vol. %). In the other hand, for low volume fractions (less than 0.1%), there is a little enhancement of the electrical conductivity with increasing the nanofluids temperature. Generally, the nanoparticles aggregation time decreases with decreasing the nanoparticles size and with increasing the nanofluids temperature, due to the nanoparticles aggregation in the nanofluids is a time-dependent phenomena. In this study, the nanoparticle size is same, due to the contact of the aggregated particle and forms (percolation).

![Figure 7](image_url)

Figure 7. Enhancement of electrical conductivity as a function of nanofluids temperature.
The enhancement rate increases with increasing the nanoparticles concentration as shown in Figure 8. The results show that the electrical conductivity has a clear relation with the nanoparticles concentration, but this relation not clear with nanofluids temperatures. The electrical conductivity enhancement is about 72% for nanoparticles concentration of (ϕ=0.05 % vol.) of CuO Nanofluids at temperature of 25°C. Moreover, by rising the nanoparticles concentration to (ϕ=0.2 % vol.), the enhancement in the electrical conductivity becomes 94%.

![Figure 8. Enhancement of electrical conductivity as a function of volume fractions.](image)

To validate the experimental results by using the Maxwell conductivity model, it can be obtain by [4]:

$$K_M = \frac{K_p + 2K_f - 2\phi(K_f - K_p)}{K_p + 2K_f + \phi(K_f - K_p)}$$  \hspace{1cm} (4)

And dynamic electrical conductivity [4]:

$$K_E = \frac{2\phi\varepsilon_0^2\mu_0^2}{\rho\nu(1 + 25\phi + 625\phi^2)\tau^2} e^{\lambda(T - T_0)}$$  \hspace{1cm} (5)

Finally, the sum of dynamic and Maxwell conductivity electrical conductivity can be obtained as the total electric conductivity, it is given by [4]:

$$K_{theoretical} = K_E + K_M$$  \hspace{1cm} (6)

The comparison between the nanofluid electrical conductivity with the Maxwell model is plotted in Figure 9. Due to the model is depending on the nanoparticle volume fractions alone, it does not agree for non-conducting (non-metallic) nanoparticles of Al₂O₃, CuO and ZrO₂ nanofluids which employed in this study. The results show that the electrical conductivity has nonlinear relation with volume fractions for ZrO₂ nanofluid, but it has a linear relation with Maxwell model as formed in Eq. (4).
The peculiar variation of electrical conductivity does not follow the traditional Maxwell model. Thus, the present experimental results of the nanofluids electrical conductivity are calculated by new model is given by [9] as shown in Figure 10 and given a good agreement with the experimental data.

4. Conclusions
As a result, the electrical conductivity of (Al₂O₃, ZrO₂ and CuO) nanofluids are systematically studied for different nanoparticles volumetric fraction and different fluid temperature. The results show that the addition of nanoparticles to the di-ionized water will lead to increase the electrical conductivity of the base fluid. However, it can be noted that the electrical conductivity strongly increases with increasing the volumetric fraction but slightly with increasing the temperature. The using of CuO nanofluid recorded the highest enhancement values as compared with other nanofluids. The enhancement rate in the electrical conductivity is found by about 80%, 75% and 50 % when using the nanofluids of CuO, Al₂O₃ and ZrO₂ respectively at fluid temperature of (T=50°C) and nanoparticles concentrations of (ϕ=0.1 % vol.). finally, the experemntal results is compared with previous data and given a good agreement.
Nomenclatures

\( m_p \) mass in (g) of the nanoparticle.
\( m_f \) mass in (g) of the base fluid.
\( L \) electrodes spacing.
\( S \) electrodes effective area.
\( K \) nanofluid experimental EC, \( \mu \text{S/cm} \)
\( K_o \) base fluid experimental EC, \( \mu \text{S/cm} \)
\( K_M \) base fluid Maxwell EC, \( \mu \text{S/cm} \)
\( K_E \) base fluid dynamic EC, \( \mu \text{S/cm} \)
\( T \) temperature, °C
\( U_0 \) Zeta potential of the nanoparticle
\( \nu \) kinematic viscosity
\( V \) applied voltage
\( I \) current.

Greek Symbols

\( \rho_p \) density of the nanoparticle, (kg/m\(^3\)).
\( \rho_f \) density of the base fluid, (kg/m\(^3\)).
\( \phi \) volume fraction, (%).
\( \lambda \) decreasing rate of the viscosity.
\( \varepsilon_0 \) dielectric constant of the vacuum,
\( \varepsilon_r \) relatively dielectric constant of the nanoparticles.

Subscripts

\( p \) particle
\( f \) base fluid

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