# Measurement of Thermal Conductivity of ZnO and $SiO_2$ WaterBased Nanofluids

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**Abstract.** The preparation and definition of thermal characteristics of novel-type nanofluids are critical for understanding the fluidity mechanism of nanofluids and selecting appropriate nanofluids for application. This study seeks to give an alternative fluid for various applications and to fill a new type of nanofluid requirement in the literature that has been identified by many research groups. In this study, a water-based ZnO-SiO2 nanofluid is synthesized in two steps, and the thermal conductivity values are experimentally determined. It is found that thermal conductivity increases with the increase in the concentration of particles. The maximum deviation of thermal conductivity of SiO2 nanofluid is found to be 1.30% whereas in the case of ZnO nanofluid it is found to be 2.65%.

## 1. INTRODUCTION

Nanofluids have lately emerged as a key topic of promising technologies because nanofluids can have significantly superior properties than pure base fluids [1]. A nanofluid is a fluid containing nanoparticles inside a base fluid. Choi and Eastman [2] proposed the initial idea in 1995: to improve various thermophysical qualities by adding Nano-sized particles. Nanoparticles are typically less than 100 nm in size. Nanoparticles may easily move in the base fluid. Mixing nanoparticles into a base fluid can enhance several significant fluid characteristics. Furthermore, nanofluids offer various advantages such as improved thermal characteristics, the ability to be made from non-polluting materials, unique alternatives, ease of production, and so on. As a result of their distinct benefits, nanofluids have been exposed to a variety of applications [3]. Furthermore, nanofluids have recently emerged as a significant component of heat transfer fluids as a passive heat transfer improvement approach.

Nanofluids can also include one or more nanoparticles. A hybrid nanofluid is a nanofluid that contains two or more particles. Hybrid nanofluids should be regarded as a subset of nanofluids. Considering the results of open-source tests, hybrid nanofluids can outperform non-hybrid nanofluids in terms of discoveries [4]. They do, however, have several drawbacks, such as a tendency for sedimentation, unexpected behaviour, and high viscosity. Despite these drawbacks, they are quite popular due to their desirable features. Nanofluids have been used in a variety of applications in the literature. Lee et al. [5] discovered that the thermal conductivity and viscosity of water-based alumina (Al2O3) nanofluids increase linearly as the nanoparticle concentration increases. They changed the pH value of the nanofluids and the surfactant concentration and discovered that optimizing the pH value and using a suitable surfactant increased the thermal conductivity of water-based copper nanofluids. Masuda et al. [6] were the first to determine the viscosity of nanofluids using water as the base fluid and temperatures ranging from room temperature to 60℃. Later, Pak and Cho [7] demonstrated that the thermal conductivity and viscosity of Alumina water nanofluids are higher than those of base fluids and that both rise with an increase in particle volume concentration and decrease with an increase in temperature. He et al. [8] calculated the viscosity and thermal conductivity of water-based Titania (TiO2) nanofluids and found that as the volume percentage and particle size of the nanoparticles increased, so did the thermal conductivity and viscosity. The results also showed that the measured viscosity is substantially higher than the theoretical value calculated using Einstein's equation. Numerous research has been done to use nanofluids in various sectors (systems for heating and cooling, solar water heating, thermal storage, etc.) by increasing the thermal conductivity of traditional heat transfer fluids. Nanofluids are often created using metals and metal oxide nanoparticles. Nguyen et al. [9] emphasized the use of water-based Al2O3 nanofluids to cool electronic devices. They employed two distinct sizes of Al2O3 nanoparticles (36 nm and 47 nm). They also discovered that 36 nm nanoparticles had greater heat transfer coefficients than 47 nm nanoparticles. Wu et al. [6] used an Al2O3/water nanofluid to store thermal energy. They found that Al2O3 dispersed well in water and had a maximum thermal conductivity of 10.5%. Jiang et al. [7] investigated the thermal conductivity of CNT Nano refrigerant. As a host refrigerant, R113 was utilized. They also observed that CNT/Nano refrigerant with spherical nanoparticles had greater thermal conductivity than CNT/water. Tzeng et al. [8] used engine oil to distribute CuO and Al2O3 nanoparticles for rotary blade coupling. They improved the fluid by including CuO nanoparticles. Srikant et al. [10] investigated the performance of nanofluid as a cutting fluid in machinery. Their findings indicated that nanofluids, with their cooling and lubricating capabilities, may be an excellent answer. Kulkarni et al. [11] employed varying amounts of water-based Al2O3 nanofluid to cool diesel-electric generators. They discovered that employing nanofluid enhanced the waste heat recovery efficiency of heat exchangers. Khanjari et al. [12] hypothetically investigated the performance of photovoltaic thermal systems and compared water-based Al2O3 nanofluids with water. They improved efficiency by employing Al2O3 nanofluids instead of pure water. Pantzali et al. [13] investigated the experimental cooling of plate heat exchangers using 4% CuO nanofluid. According to their experimental results, they observed some undesirable effects while employing nanofluid. Zhang et al. [14] employed ZnO nanofluids as an antibacterial agent against Ecoli bacteria, and they produced satisfactory results. Hadad et al. [15] statistically examined nuclear reactor cooling with Al2O3/W nanofluids. They calculated the pressure drop, temperature change, and heat transfer coefficient of Al2O3/W nanofluids using single- and two-phase mixture models. As demonstrated by these researchers, nanofluids may be applied in a variety of fields, ranging from medicine to industry.

ZnO nanoparticles have been used alone in previous studies. Pastoriza-Gallego et al. [16] investigated the thermal conductivity, density, and dynamic viscosity of ZnO nanofluid based on ethylene glycol. They determined that particle size, temperature, and volume fraction might all have a 6.2% effect on thermophysical characteristics. Suganthi et al. [17] combined ethylene glycol and an ethylene glycol-water combination with ZnO particles. At 27 °C, their analysis found that the thermal conductivity of nanofluid increased by 33.4% and viscosity decreased by 39.2%. The dynamic viscosity of water-based $SiO_2$-graphite hybrid nanofluids was investigated by Dalklç et al. [18]. They measured dynamic viscosity at temperatures ranging from 15 to 60 °C and volume concentrations up to 2%. The maximum dynamic viscosity rise was 36.12% at 15 °C a for 2% vol. concentration. Akilu et al. [19] investigated the thermal properties of a hybrid $SiO_2$-CuO/C nanofluid. They determined their hybrid nanofluid thermal conductivity, viscosity, and specific heat. Using a hybrid nanofluid, they were able to boost heat conductivity by 26%. Finally, they provided three equations for obtaining experimental data. In terms of oilfield applications, Kumar and Sharma [20] investigated the stability, electrical conductivity, and rheology of $SiO_2$, TiO2, $SiO_2$-TiO2, mono, and hybrid nanofluid samples. According to their findings, hybrid nanofluid samples were more stable than mono nanofluids. Esfe et al. [21] used a DWCNTs-ZnO/water-ethylene glycol (60:40) nanofluid to evaluate the effects of solid volume fraction on thermal conductivity. They picked a solid concentration of up to 1% and a temperature range of 25 to 50 °C. In the study, they presented a nonlinear regression. The dynamic viscosity of a MWCNTs/ZnO-engine oil hybrid nanofluid was measured by Asadi and Asadi [22]. They investigated the issue between 5°C and 55°C, with doses ranging from 0.125 to 1%. Giwa et al. [23] evaluated the pH, thermal conductivity, electrical conductivity, and viscosity values of a water-based MgO-ZnO hybrid nanofluid with different nanoparticle mixing ratios (20%-80%, 40%-60%, 60%-40%, and 80%- 20%). They found that 40% MgO—60% ZnO has the best heat transmission capacity. Wole-Osho et al. [24] investigated the specific heat and viscosity of an Al2O3-ZnO hybrid nanofluid based on water. They created hybrid nanofluid samples using 1:1, 1:2, and 2:1 nanoparticle mixtures. Among their samples, they discovered that 1:1 nanofluid had the highest specific heat capacity and the lowest viscosity. Finally, they presented new correlations with R2 values of 99.2% and 93.34% for determining specific heat capacity and viscosity, respectively. Ruhani et al. [25] investigated the rheological properties of a hybrid ZnO-Ag (50%-50%)/water nanofluid. They discovered that raising the concentration and reducing the temperature increased the viscosity of a ZnO-Ag (50%-50%) hybrid nanofluid. They provided an equation with a 1.8% margin of error.

Numerous studies have recently been conducted to investigate the thermal characteristics of nanofluids; nevertheless, open sources lack substantial experimental research for hybrid nanofluids. Many research studies strongly advised that novel types of nanofluids, particularly those created experimentally, be prepared and measured. Taking these guidelines into account, water-based ZnO and $SiO_2$ nanofluid are created with 0.1%, 0.2%, and 0.3% volume fractions.

## 2. EXPERIMENTAL SETUP AND METHODOLOGY

### 2.1 Apparatus

Ultrasonicator, surfactant, and magnetic stirrer are some physical and chemical methods for improving the stability of nanofluids by making them more homogeneous and stable than before. To prepare the nanofluid samples in this study, an ultrasonicator probe (Labman) is used to prepare and homogenize nanofluids. A magnetic stirrer is used to stir nanoparticles in a base fluid.

Thermal conductivity is an important feature of nanofluids. Using nanofluid interferometer tools,it is possible to experimentally determine the thermal conductivity of nanofluids from sound velocity. The fundamental idea behind a nanofluid interferometer is to accurately determine wave length (λ) in themedium at hand to calculate the fluid's sound velocity (m/s). A quartz plate placed at the bottom of the interferometer's cell produces ultrasonic waves with known frequencies (f) [26]. To keep nanofluids at the correct temperature between 25 and 90 C, a temperature control unit is helpful. The sound velocity in nanofluids is $v=\lambda f$.

### 2.2 Preparation of nanofluids

There are two popular approaches for creating nanofluid in the literature: one-step and two-step procedures. The two-step strategy is more widely used than the one-step method [27], and it was chosen for this investigation. This is because the one-step procedure is more involved and costly than the two-step method. Samples made in one stage, on the other hand, are more stable than those prepared in two steps [28]. Nanoparticles are immediately introduced to the base fluid in the two-step approach. The nanoparticles and base fluid are then conditioned using technologies such as ultrasonic agitation and intense magnetic force to homogenize the nanofluid. The two-step procedure is an excellent strategy for creating a hybrid.

In the current examination, ZnO and $SiO_2$ nanoparticles have been chosen to create nanofluids. Two nanoparticles, $SiO_2$ and ZnO, with particle sizes of approximately 15 and 240 nm, respectively, were employed in this study. Since the two-step approach works better for creating nanofluids containing oxide nanoparticles, nanofluids containing $SiO_2$ and ZnO, respectively, were created using the two-step method. Equation (1) determines how many nanoparticles should disperse into the base fluid about their concentration. Nanofluid samples are prepared as 25 ml. 0.1%, 0.2%, and 0.3% are chosen as volume concentrations for both ZnO and $SiO_2$ in 25 ml base fluid respectively. Fig 1 Shows the sample of $SiO_2$ nanofluid with 3 different volume concentrations. We added surfactant (Sodium Lauryl Sulphate) to the ZnO nanofluid to preserve stability because it lacked much of it. Fig. 2 showsthe sample images of ZnO nanofluid before and after surfactant at different volume concentrations respectively. $SiO_2$ and ZnO were chosen as the materials for the nanoparticles because they are easier to get, more affordable, and chemically more stable than their metallic counterparts. The SEARL lab of ZHCET Aligarh Muslim University purchased the $SiO_2$ and ZnO nanoparticles from Sisco Research Laboratory for this experiment.

$$\phi = \frac{V_p}{V_p + V} \qquad (1)$$

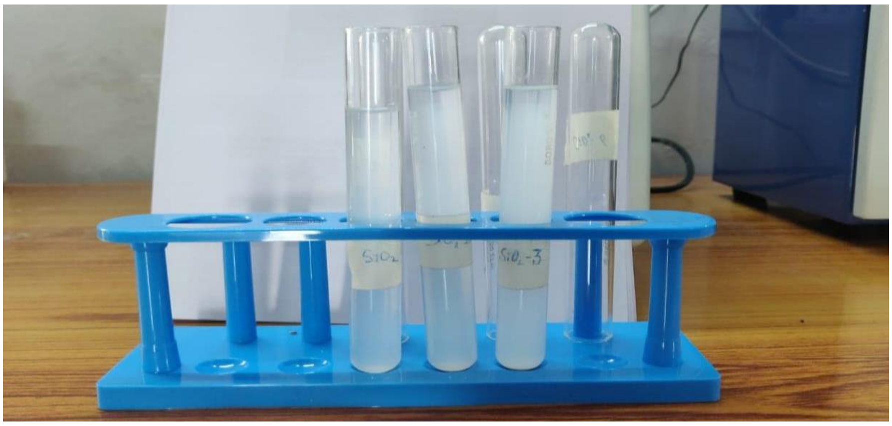
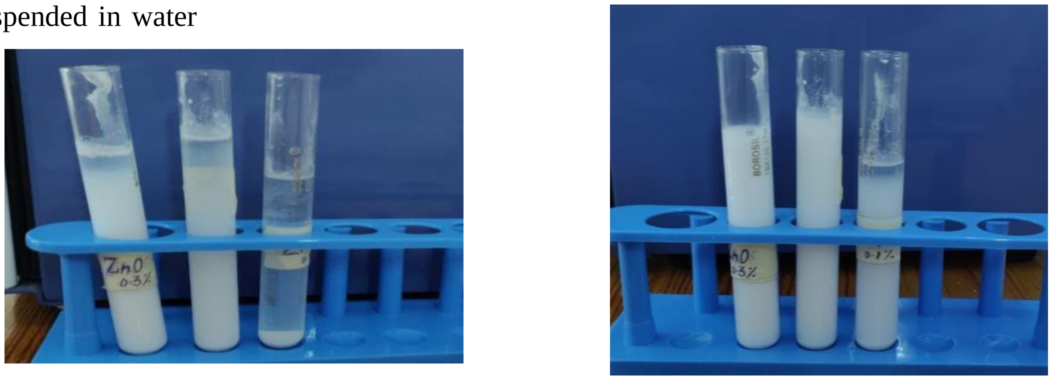


**FIGURE 1**. SiO2 Nanofluid after 2 days of preparation with 0.1, 0.2, and 0.3 wt.% concentration suspended in water



a) (b)

**FIGURE 2.** ZnO Nanofluid after 2 days of preparation with 0.1, 0.2 , and 0.3 wt.% concentration suspended in water. Sample (a) is without surfactant and sample (b) is with surfactant

### 2.3 Characterization

SEM analysis was used to determine the morphological characteristics of samples of ZnO and $SiO_2$ Nano powder. The SEM has a wide depth of field, allowing for more of a specimen to be in focus at once. The SEM also offers a significantly greater resolution, allowing for much higher magnification of closely spaced specimens. The images of ZnO Nano powder with different magnifications are displayed in fig. 3 and the same for $SiO_2$ are displayed in fig.4.

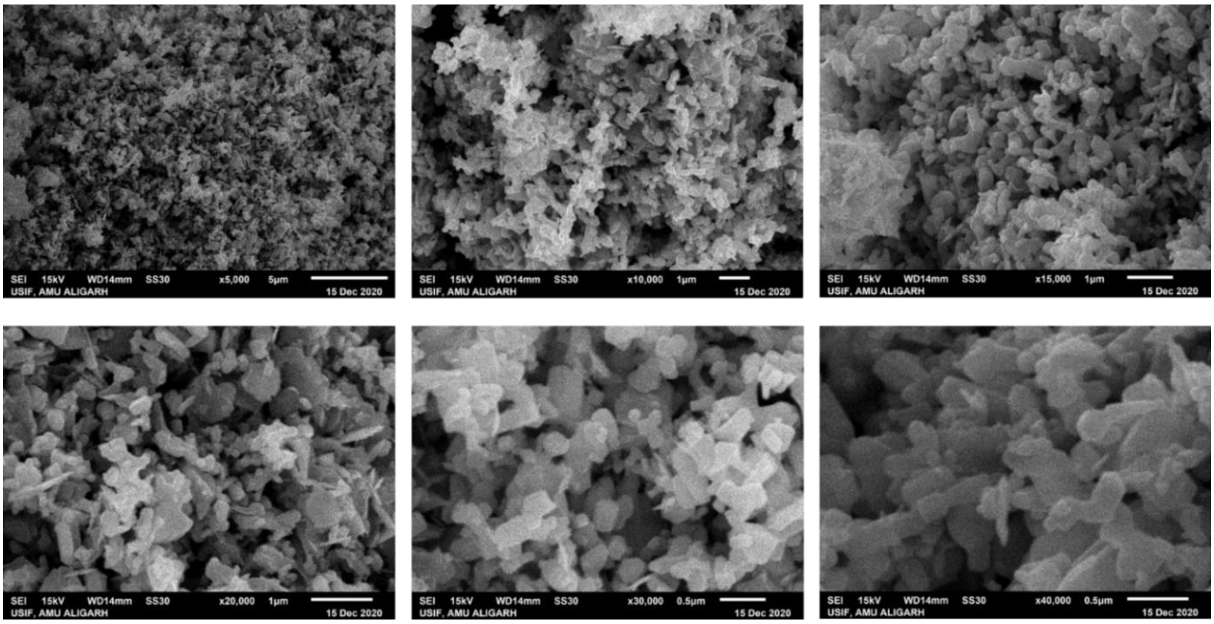



**FIGURE 3.** Observed SEM images of ZnO nanoparticles with different magnification

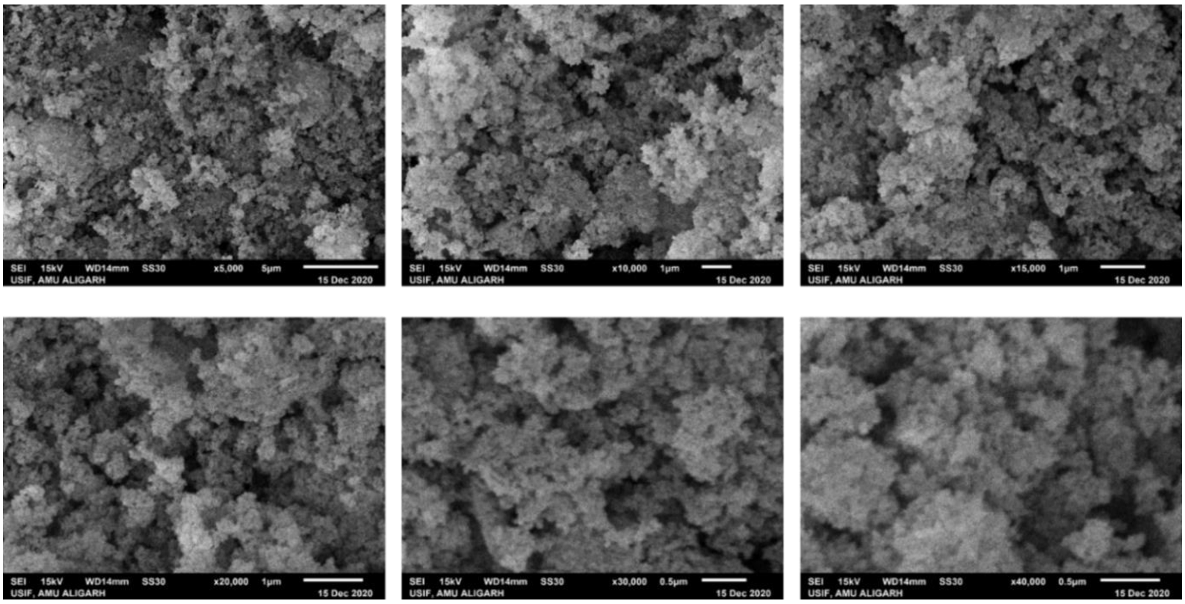



**FIGURE 4.** Observed SEM images of SiO2 nanoparticles with different magnification

XRD analysis was used to examine the ZnO and $SiO_2$ powder sample's crystallinity and phase. The X- ray diffraction pattern is a basic way of explaining the crystal structure of the produced nanoparticles, which have monochromatic CuKα radiations (k = 0.15418 nm) and are used as a 40 kV/35 mA energy source and the graph is captured between the range of 5º–80º 2θ.

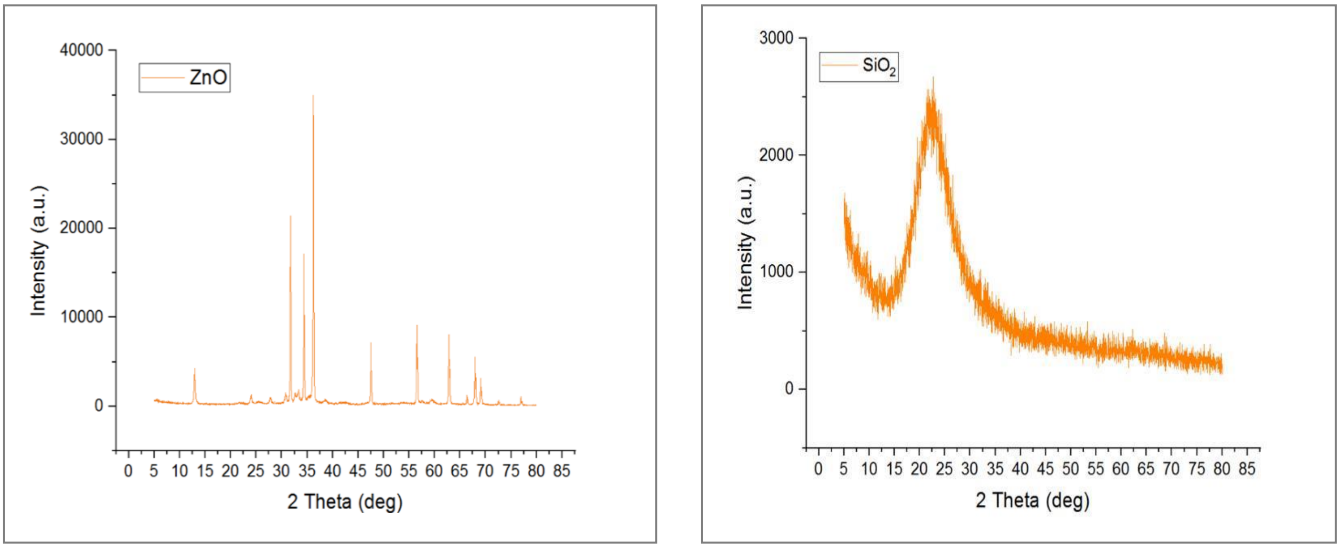



**FIGURE 5.** XRD pattern of ZnO and SiO2 nanoparticles.

## 3. RESULTS AND DISCUSSION

### 3.1 Measurement of thermal conductivity

Bridgman derived a formula in 1923 that predicts the direct relationship between thermal conductivity and sound velocity in pure liquid based on the heat transfer mechanism [29].

Bridgeman's thermal conductivity formula yields more accurate findings when compared to traditional values derived from the transient hot wire method, parallel plate heat transfer method, and other methods. Bridgman hypothesized that liquid molecules were organized in a cubic lattice and that energy was transported from one lattice plane to the next at the speed of sound. Bridgman's equation isas follows:

$$k = 3\left(\frac{\bar{N}}{V}\right)^{\frac{2}{3}} K v \qquad 2)$$

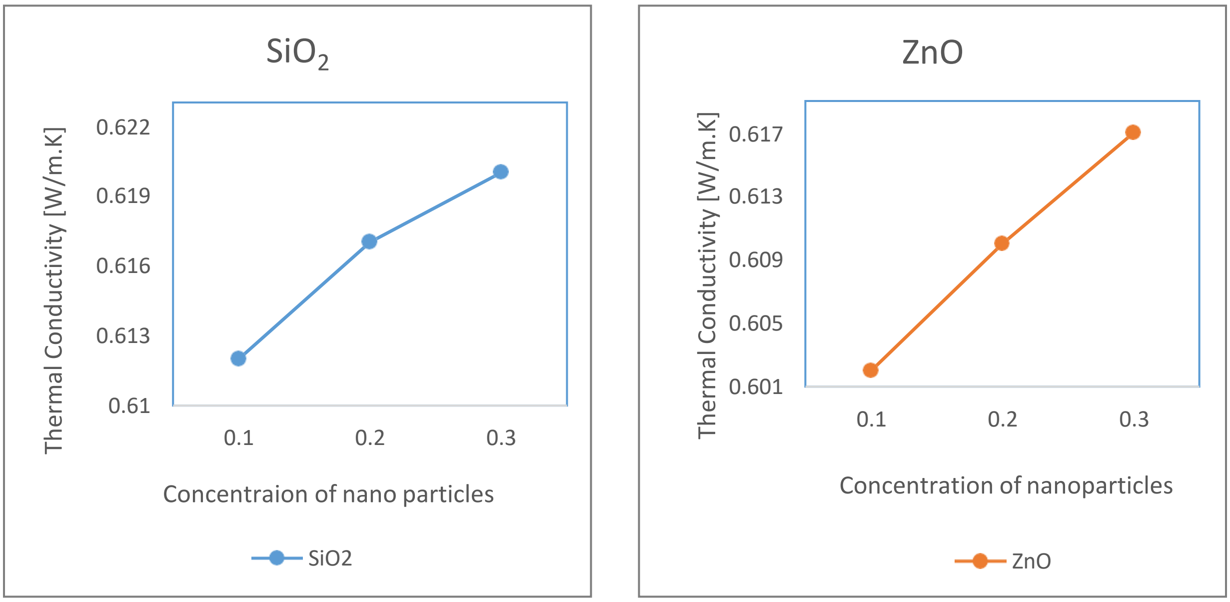
$$V = \frac{M_{nf}}{\rho_{nf}} \qquad 3)$$

$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_f \qquad 4)$$

Where k is the thermal conductivity obtained by the modified Bridgman equation, v is the ultrasound velocity, N is Avogadro's number = $6.023\times10^{23}$, V is the molar volume, K is the Boltzmann's constant = $1.3807\times10^{-23}$ J/K. $\rho_{nf}$ defines the density of nanofluid, and $M_{nf}$ is the molar mass of nanofluid. We produce sound velocity by pouring nanofluid with 0.1, 0.2, and 0.3 wt% concentrations of ZnO and $SiO_2$

into the base fluid of water. Using the equations above, we determine the thermal conductivity of a nanofluid at three distinct concentrations.

Fig. 6 shows thermal conductivity with respect to nanoparticle volume fractions (φ%) by using curve fitting for $SiO_2$ and ZnO water-based nanofluids. Fig. 7 shows the thermal conductivity of both $SiO_2$ and ZnO with respect to water at 0.1, 0.2, and 0.3 wt% concentrations.




(a) (b)

**FIGURE 6.** Measured Thermal conductivity w.r.t. three different concentrations (a) SiO2 at 0.1, 0.2 and 0.3 concentrations
(b) ZnO at 0.1, 0.2, and 0.3 concentrations

In figure. 6 (a) it is found that the thermal conductivity of $SiO_2$ increases with the increase of the concentration of the particles, the thermal conductivity increases about 0.81% when we increase concentration from 0.1% to 0.2% and about 0.48% when we increase from 0.2% to 0.3%. The maximum deviation of $SiO_2$ is about 1.30%.

In figure. 6 (b) the graph shows the increase in thermal conductivity of ZnO with respect to the concentration of the particles, in the experiment we have found that when we increase the concentration of ZnO from 0.1% to 0.2% the thermal conductivity increases about 1.32% and it increases about 1.31% when we increase from 0.2% to 0.3%. The maximum deviation of ZnO is about 2.65%.

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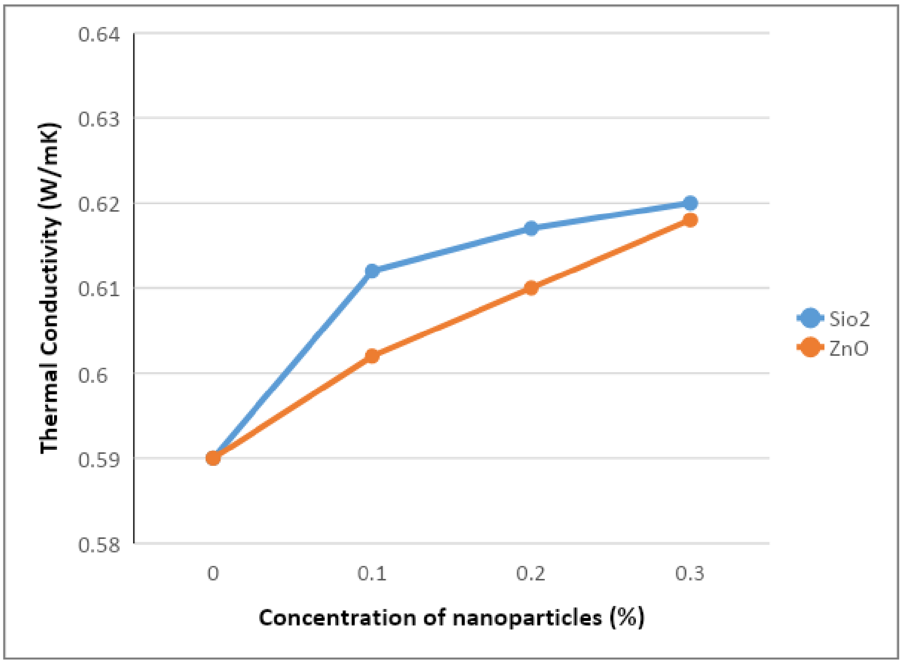


**FIGURE 7.** Thermal conductivity of both SiO2 and ZnO with respect to water at 0.1, 0.2, and 0.3 wt% concentrations.

## 4. CONCLUSION

This research synthesized water-based nanofluids based on ZnO and $SiO_2$. Thermal conductivity has been experimentally examined. Thermal conductivity increases as particle surface area increase with particle volume concentration. Thermodynamical factors are achieved using an ultrasonic interferometer. For all of the samples at various concentrations, ultrasonic velocity and other acoustical characteristics were computed. The findings indicated that the behaviours and consequences of nanofluid samples are outstanding and may surprise.

- The thermal conductivity increases about 0.81% when we increase concentration from 0.1% to 0.2% and about 0.48% when we increase from 0.2% to 0.3%. The maximum deviation of $SiO_2$ is about 1.30%.
- When we increase the concentration of ZnO from 0.1% to 0.2% the thermal conductivity increases by about 1.32% and 1.31% when we increase from 0.2% to 0.3%. The maximum deviation of ZnO is about 2.65%.

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