Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943


# Viscosity Of CuO Nanofluid Due to Nanoparticles Size and Concentration

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**ABSTRACT**

Past studies showed that varying nanoparticles size could affect several properties of nanofluids. This could lead to significant change of hydro-thermal performance in various applications. In the present study, the effect of copper oxide (CuO) nanoparticle size on the viscosity of nanofluid was investigated under different working temperature and concentration. Base fluid consists of equal amount of distilled water and ethylene glycol. It was found that the addition of 0.05 vol.% CuO into base fluid caused increment of viscosity by 11.8% and 7.27%. On the other side, particle size effect was found to be insignificant on the viscosity of nanofluids at low concentration of CuO nanoparticles (0.025 vol.%). Lastly, the viscosity measured in the present study was predictable by two correlations proposed in past studies and only slight deviation was observed.

***Keywords:***
Nanofluid; viscosity; particle size

**Received: 22 July 2022** **Revised: 11 September 2022** **Accepted: 12 Sept. 2022** **Published: 30 Sept. 2022**

## 1. Introduction

Nanofluid has been widely researched in different fields due to its promising enhancement. Wide range of studies has been performed to further explore the potential of nanofluid. It is known that even using the same type of nanoparticles in a base fluid, altering the concentration [1], degree of stability [2], particles size studies [3], shape [4] and temperature of suspension would cause significant difference in term of thermophysical properties and performance. The following reviews focus on the effect of particles size as it is the main focus in present study.

In many past studies, smaller size of nanoparticles is found to exhibit higher viscosity. Pastoriza-Gallego *et al.* [5] prepared water-based nanofluids using CuO with diameter of 23 – 37 nm and 8 – 14 nm. By increasing nanoparticles concentration from 0.0016 to 0.017 vol.%, nanofluid with larger CuO nanoparticles showed gradual increment at all points. Interestingly, similar viscosity was observed

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https://doi.org/10.37934/araset.28.1.161167

for both different-sized CuO nanofluids until the nanoparticles concentration reached 0.006 vol.%. From this concentration onwards, a sharp increase in gradient was observed for the nanofluid with smaller CuO nanoparticles. They proposed that small particle size may lead to non-Newtonian behavior in the suspension.

Jia-Fei *et al.* [6] concluded that the viscosity of nanofluid would become more dependent on the concentration of nanoparticles as the particle size decreases. In addition, they found that pH value affects smaller sized particles (12, 16 and 20 nm) but insignificant effect on larger size (40 nm) for their $SiO_2$-water nanofluid. For small size particles, both aggregate size and electrical double layer affect the viscosity of nanofluid as well. Another research on $SiO_2$ nanofluid with different sizes showed that smaller sized particles could provide higher heat transfer enhancement due to the Brownian motion [7].

Lin and Weng [8] suggested that the larger specific surface area from smaller sized nanoparticles increases the number of collision and friction between the nanoparticles, in which results in higher viscosity. Another researchers [9] found that at low nanoparticles concentration, nanoparticle size shows insignificant effect on the viscosity of suspension.

There are many studies focus on the effect of particle size on thermal conductivity and heat transfer performance of nanofluids. Teng *et al.* [10] measured the thermal conductivity of alumina/water nanofluids with different diameters (20, 50 and 100 nm) and concentrations (0.5, 1.0, 1.5, and 2.0 wt.%). At their highest measurement temperature (50 $^{o}$C), 14.7%, 7.3% and 5.6% of enhancement was observed when compared to base fluid. They proposed that larger particles move slower and hence reducing the number of collisions then followed by the rate of heat transfer. Mahian *et al.* [11] tested different $Al_2O_3$-water nanofluids in a solar collector. Nanoparticles used were 25, 50, 75 and 100 nm and concentration was up to 4 vol.%. At the same concentration, total number of nanoparticles decreases with larger nanoparticles because of reduced total contact area, followed by lower local shear stress and then effective viscosity. When coolant with larger nanoparticles was used, Nusselt number increases due to the increased turbulent flow. However, varying the nanoparticle size affects the outlet temperature of solar collector minimally.

Heidarshenas *et al.* [12] compared water-based nanofluids containing alumina nanoparticles of 20 nm, 50 nm, 80 nm and 135 nm in a microchannel heat sink. They found that larger particle size would decrease the convective heat transfer coefficient. At Reynolds number of 1,100, Nusselt number enhancement of 21.9%, 21.1%, 18.7% and -8.5% was observed by increasing alumina particles size from 20 nm to 135 nm. This could be the instability of nanofluids due to large particle size. Moreover, the highest pressure drop obtained in their study was caused by the largest alumina particles.

Heat transfer enhancement in a diesel engine cylinder using γ-$Al_2O_3$ nanoparticles with different sizes was investigated by Rahwan *et al.* [13]. All nanoparticle sizes studied (30, 100 and 150 nm) showed improvement when compared to water. Using the smallest size, the maximum enhancement was up to 88.74% at working temperature of 80 $^{o}$C and flow velocity of 2 m/s.

From literature review, rheological behavior of nanofluids due to particle size is less focused as compared to heat transfer behavior. From year 2011 to now, there was only a research [14] reported on the viscosity of CuO nanofluid due to particle size. However, they considered only two different diameters at very low concentration. As reported by Nguyen *et al.* [9], there is no significant effect from varying particle size at low concentration. Thus, authors are desired to determine the viscosity of nanofluids due to different CuO particle size at different temperature (20 – 70 $^{o}$C) and unstudied concentration (0.025 - 0.2 vol.%).

## 2. Methodology

Base fluid used consists of 50:50 volumetric percentage of distilled water and ethylene glycol. CuO nanoparticles (99%, US Nanomaterial) with 10 nm and 40 nm of diameter were dispersed separately into the base fluid, as two different samples. All samples were then prepared from 0.025 vol.% to 0.2 vol.% and found to be stable up to 14 days after 2 hours of ultrasonication (20 kHz, 1200W probe).

The viscosity of all samples was measured using a rheometer (Anton Paar MCR92). 60 ml from each sample was used for verification and measurement in the concentric cylinder (CC39). Constant shear rate (100 $s^{-1}$) was applied for all samples. Working temperature ranged from 20 to 70 °C was applied to all samples.

## 3. Results and Discussions

For each sample, 50 data points are used for obtaining the viscosity curve. Figure 1 illustrates the relationship between viscosity and temperature for both base fluid and nanofluids. It is obvious that nanofluids exhibit higher viscosity due to the addition of solid nanoparticles which increases the shear stress. The gradual decrement of viscosity along temperature rise is due to the weakened intermolecular and interparticle interactions [15]. 10 nm of CuO with 0.025 vol.% and 0.05 vol.% of concentration increased the viscosity of base fluid by 7.75% and 11.8% in average, respectively. On the other side, 0.025, 0.05, 0.1, 0.15 and 0.2 vol.% of 40 nm CuO nanofluids showed 6.19%, 7.27%, 8.19%, 10.4% and 13.6% higher viscosity than base fluid.

Figure 2 shows the comparison of viscosity between CuO nanofluids with different particle size. When CuO size was increased from 10 nm to 40 nm, the viscosity of nanofluids decreased by 4.08%, 3.16%, 3.15%, 4.18%, 4.79% and 4.77% at 20, 30, 40, 50, 60 and 70 °C, respectively. The phenomenon observed is the same as past studies [16, 17] where relatively small particles exhibit higher viscosity at the same concentration, in which increased number of particles increases the resistance of fluid to flow [18]. Small sized particles with larger total surface area have higher surface energy and surface properties such as shape [19] or aggregates aspect ratio [20] could be significant on varying the viscosity of base fluid. However, the particle size effect is insignificant at lower concentration (0.025 vol.%). It can be presumed that a minimum total surface area is required before the effect of particle size becomes significant.

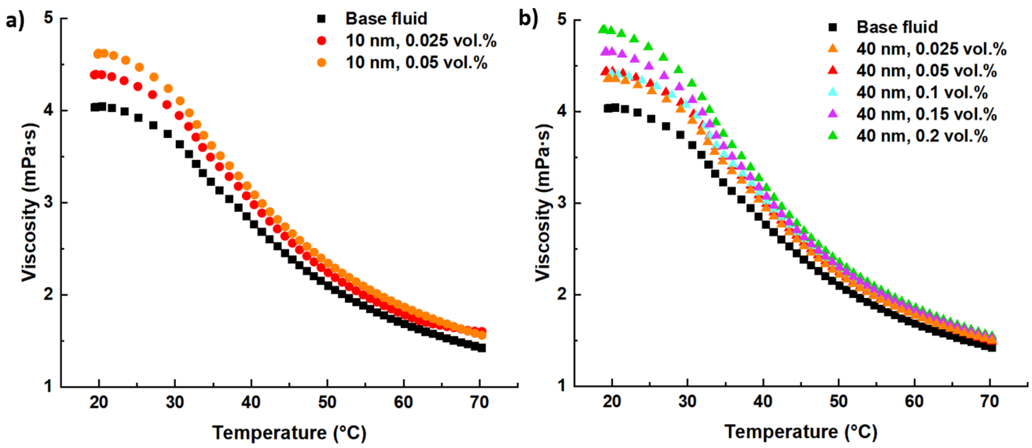


**Fig. 1.** Viscosity of base fluid and CuO nanofluids with different sizes against temperature. (a) 10 nm (b) 40 nm

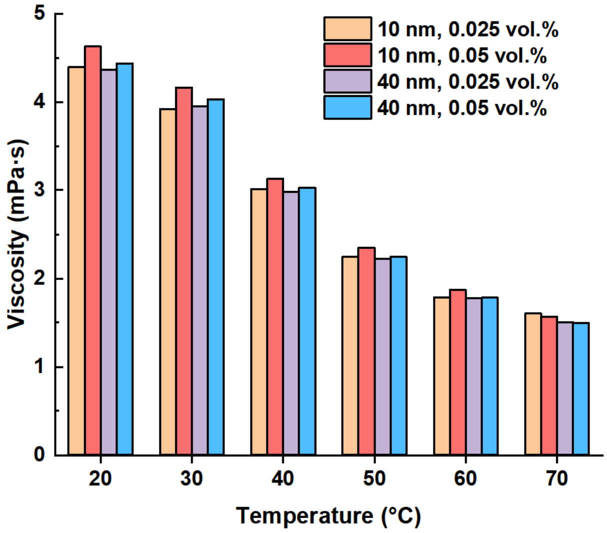


**Fig. 2.** Viscosity of base fluid and nanofluids against temperature

Due to varying viscosity from different particle size, many general models have been modified as most of it focused on nanoparticles concentration and working temperature only. Hence, different correlations were proposed by past researchers for different types of nanoparticles and particle size. For verifying the statement, few models were selected to estimate the viscosity of present CuO nanofluids. Viscosity model proposed by Azmi *et al.* [21] was generated using experimental data from $Al_2O_3$, $SiO_2$, CuO, ZnO and $TiO_2$ nanofluids with particles size ranged from 20 to 170 nm and volume concentration of less than 4%, as Eq. (1). General viscosity models from Brinkman [22] and Batchelor [23] were chosen for comparison purpose also, as Eq. (2) and Eq. (3), respectively.

$$\frac{\mu_{nf}}{\mu_{bf}} = (1+\frac{\phi_{np}}{100})^{11.3}(1+\frac{T_{nf}}{100})^{-0.038}(1+\frac{d_{np}}{170})^{-0.061} \quad (1)$$

$$\frac{\mu_{nf}}{\mu_{bf}} = \frac{1}{\left(1-\phi_{np}\right)^{2.5}} \quad (2)$$

$$\mu_{nf} = \left(1+2.5\varphi_{np}+6.2\varphi_{np}^{\ 2}\right)\mu_{bf} \quad (3)$$

Where subscripts np is nanoparticles, nf is nanofluids and bf is base fluid. $\Phi$ is volume concentration, $\varphi$ is volume fraction, $T$ is working temperature and $d$ is particle diameter.

From Figure 3, the same trend of viscosity against temperature curve from past models verifies the viscosity measured in present study. Surprisingly, experimental data of both 0.025 and 0.05 vol.% CuO nanofluids (40 nm) is close to estimated viscosity from Brinkman's model rather than correlation which considers the nanoparticles diameter. However, this is not valid for CuO nanofluids (40 nm) with concentration more than 0.1 vol.%. On the other side, Batchelor's model and Azmi's correlation display slight underestimation at all concentrations. Even though Batchelor's model does not include the effect of particles size, the effect of Brownian remarked in the model is proven to be significant for spherical-shaped nanoparticles. Be noted that the CuO nanoparticles used in present study exhibit exactly the same shape (spherical).

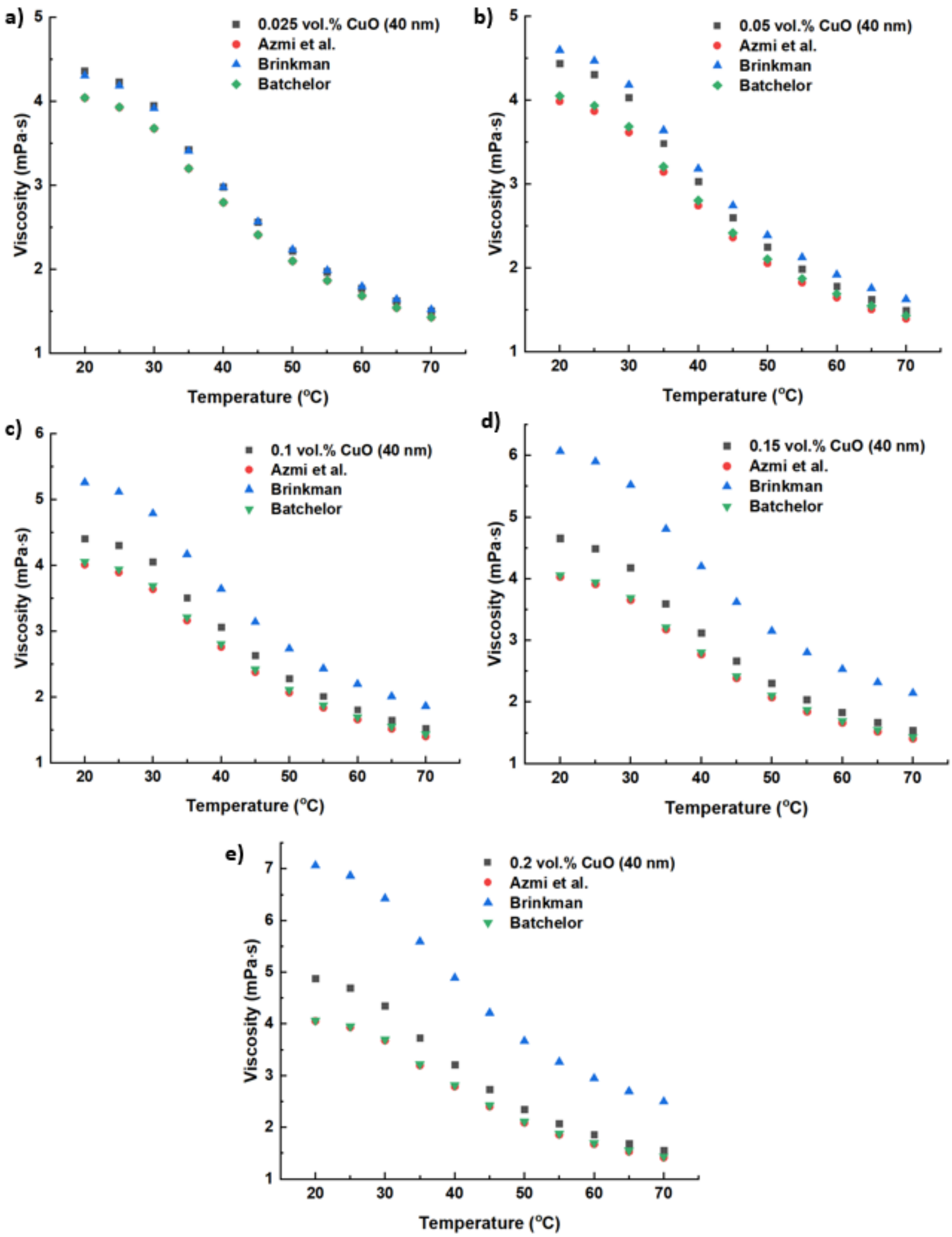


**Fig. 3.** Viscosity of 40 nm CuO nanofluids obtained from measurement and correlations. (a) 0.025 vol.% (b) 0.05 vol.%

## 4. Conclusions

This study has investigated the effect of CuO particle size on the viscosity of nanofluid. It was found that:

1. At constant concentration, smaller sized particles indicate increased number of nanoparticles and hence nanofluid would exhibit higher viscosity.
2. At low concentration (0.025 vol.%), the effect of varying particle size on viscosity is insignificant, as in-line with past studies.
3. From the comparison with models proposed in past studies, it was found that Brownian effect is responsible for the viscosity variation.

### Acknowledgement
Authors would like to thank Universiti Teknologi Malaysia for the funding from Takasago Thermal Engineering Co. Ltd (R.K130000.7343.4B631). Also, R. Saidur would like to acknowledge the laboratory equipment provided by the Research Centre for Nano-materials and Energy Technology (RNCMET) in Sunway University.

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