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# Effect of temperature and mass fraction on viscosity of crude oil-based nanofluids containing oxide nanoparticles

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ABSTRACT

In this study the effects of various oxide nanoparticles on viscosity of crude oil-based nanofluid were investigated. Furthermore, the effects of temperature and mass fraction of $TiO_2$, NiO, $Fe_2O_3$, ZnO and $WO_3$ nanoparticles on relative viscosity of nanofluid were studied. The morphology and stability of nanoparticles were characterized by using TEM and DLS analysis. The results of characterization showed that the average nanoparticle diameter ranged from 10 to 40 nm for different oxide nanoparticles. Also the results of experiments showed that with the increment of temperature the ratio of the nanofluid viscosity to basefluid declined. Moreover, for nanofluid containing nanoparticles with higher density the relative viscosity increases significantly and with the temperature enhancement higher than 50 °C the values of relative viscosities are less than unity declaring a lower viscosity of nanofluids with respect to basefluid. Finally, an empirical correlation comprising nanoparticle density, temperature, and mass fraction was obtained based on regression analysis for estimation of relative viscosity of nanofluid. The results exhibited that the deviation of the correlation from the experimental values was mostly less than 20% and the results of other researchers agree well with the data predicted by the correlation of this study.



## 1. Introduction

With the development of technology the application of nanomaterials in various fields of science has been noticed by researchers [1–6]. The use of nanomaterials have been intensively developed for its many interesting properties leading to various important applications in almost all the fields ranging from reinforced nanostructure and catalyst to medical application [4]. A dispersion of nanometer size particles dispersed in a basefluid is called nanofluid [7]. These fluids have some special thermal and hydrodynamic properties so that many researchers have paid attention to them [8,9]. One of the important properties of fluid is viscosity that has impact on the flows of fluid and mainly affects the power required for fluid transportation by means of pipeline systems. Two main parameters which are influenced by the viscosity of fluid include power needed for pumping fluid and pressure reduction in laminar and turbulent heat transfer flows. In many cases the viscosity of nanofluid is higher than that of basefluids [10], thus heat transfer rate is enhanced owing to the increase in heat transfer coefficient [11]; consequently, smaller equipment may be used. Viscosity of nanofluids depends on several parameters such as temperature, particle size, volume fraction of nanoparticles, and types of nanoparticles and basefluid [12].

Thermo-fluidic behavior of nanofluid mainly depends on viscosity; therefore, the analysis of viscosity is one of the key factors for determining hydrodynamic behavior. Wide range of studies for determination of the nanoparticle effect on viscosity of nanofluid has been conducted [13]. There are a number of researches that have been reported about the impacts of nanoparticle morphology, nanoparticle size, nanoparticle load, and temperature on viscosity of nanofluid [14]. Although there is wide range of studies on effect of these parameters on viscosity, there is no full agreement about the results concerning interaction effect and nanoparticle types within oxide nanoparticle/oil-based nanofluid. Moreover, other effects such as the surfactant concentration, shear rate at various temperatures and pH value have been discussed in previous efforts properly.

### *1.1. Effect of volume fraction*

There are a number of researches that have been done for investigation of the effect of nanoparticle volume fraction on the viscosity of nanofluids. These expressed that with the increase of nanoparticle volume fraction in the basefluid the viscosity of nanofluid increased intensely. Prasher et al. [15] reported that with the increment of $Al_2O_3$ nanoparticle concentration in water as basefluid the viscosity of nanofluid enhances. They also showed that enhancement in viscosity

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**Nomenclature**

| | |
|---|---|
| $\varphi$ | Volume fraction of nanoparticles (%) |
| $w$ | Mass fraction of nanoparticles (%) |
| $T$ | Temperature (°C) |
| $T_0$ | Reference temperature, 25 °C |
| $\mu$ | Viscosity (mPa·s) |
| $\rho$ | Density (kg/m$^3$) |
| $S.D.$ | Standard deviation |
| $E$ | Experimental viscosity at fixed mass fraction and temperature (mPa·s) |
| $\bar{E}$ | Average of experimental viscosity at fixed mass fraction and temperature (mPa·s) |
| $n$ | Number of measured viscosity at fixed mass fraction and temperature, equal to 5 |
| $M.D.$ | Margin of deviation (%) |
| $M$ | Momentum that could be transferred using nanoparticles (kg/m$^2$·s) |
| $\nu$ | Brownian velocity of nanoparticles (m/s) |
| $k$ | Constant value of Brownian Velocity (kg$^{1/2}$/m$^{1/2}$·s) |

*Subscripts*

| | |
|---|---|
| nf | Nanofluid |
| bf | Basefluid |
| p | Nanoparticle |
| 0 | Reference condition |

of nanofluid in fixed nanoparticle load is higher than the enhanced thermal conductivity which is declaring the intense effect of nanoparticles on viscosity. Duangthongsuk et al. [16] showed that for the nanoparticle volume fractions of 0.2–2.0% the viscosity of $TiO_2$-water nanofluid increases 4–15% with respect to pure water within a temperature range of 15–53 °C. Murshed et al. [17] measured experimentally and theoretically the viscosity and thermal conductivity of nanofluid. They showed that the thermo-fluidic properties of nanofluids are found to be higher than their basefluids and both the viscosity and thermal conductivity of nanofluids are enhanced with the nanoparticle load. Schmidt et al. [18] indicated that with the increase in $Al_2O_3$ nanoparticle load from 0.25 to 1 vol% in isoparaffinic polyalphaolefin (PAO) and decane the viscosity of nanofluid increased. Naina et al. [19] did a research in order to measure the viscosity of $TiO_2$ nanoparticles dispersed in water at the temperature and volumetric concentration range of 10–40 °C and 0.5–2.5% respectively. They showed that for nanofluid containing 2.5 vol% of $TiO_2$ the viscosity of nanofluid increased up to 50%.

Chevalier et al. [20] revealed that the viscosity of nanofluid containing $SiO_2$ nanoparticles dispersed in ethanol increases with the increase in volume concentration. Hemmat Esfe et al. [21] studied the dynamic viscosity of alumina-engine oil nanofluid in different solid volume fractions and temperatures. They prepared samples in volume fractions from 0.25 to 2% under the temperature range of 5 to 65 °C. Also they presented a new correlation for predicting the dynamic viscosity of nanofluid at different temperatures. Their results posited that the viscosity of the nanofluid highly depends on volume fraction and increases with the increments of this parameter. Putra et al. [22] showed that $Al_2O_3$-water nanofluid with volume fraction between 1 and 4% behaves as Newtonian fluid and showed that with the increase of nanoparticle load the viscosity of nanofluid increased. Also Chandrasekar et al. [23] studied the effect of volume fraction on viscosity of alumina–water nanofluids at the range of 0.33–5% and also expressed a correlation for nanofluid viscosity.

Although there are many studies declaring that the increment in nanoparticle concentration enhances the viscosity and thermal properties of nanofluid, the viscosity enhancement by increasing nanoparticle load was not reported by other researchers. Hojjat et al. [24] studied the rheological behavior of nanofluids containing $Al_2O_3$, $TiO_2$ and CuO nanoparticles at different temperatures. They found that with the increase in $Al_2O_3$ and $TiO_2$ nanoparticle volume fraction the relative viscosity of nanofluid increases and the viscosity of nanofluid containing different volume fractions of CuO nanoparticles was constant.

### *1.2. Effect of temperature*

Obviously, according to a large number of studies, temperature influences the viscosity of nanofluid intensively. The major reports on the effect of temperature on viscosity of nanofluid posit that with the increase in temperature the viscosity of nanofluid decreases the same as pure basefluids due to the fact that with the increase in temperature the intermolecular attraction forces between the nanoparticle surface and basefluids weaken [25].

Nguyen et al. [26] investigated the effect of temperature and the particle size on the dynamic viscosities of $Al_2O_3$-water and CuO-water nanofluids. The experimentations were carried out for temperatures ranging from 25 to 75 °C and $Al_2O_3$-water nanofluid containing nanoparticle diameters of 36 nm and 47 nm, and CuO-water nanofluid nanoparticle diameter of 29 nm. The results showed that with the increase in temperature the dynamic viscosity of both nanofluids with different nanoparticle sizes decreases. Namburu et al. [27] showed that with the increment in temperature at the range of −35 to 50 °C the viscosity of nanofluids decreases. Sundar et al. [28] investigated the effect of temperature on viscosity of magnetic $Fe_3O_4$-water nanofluid. They presented that with the increase of the temperature at the range of 20–60 °C the viscosity of nanofluid diminishes. Aladag et al. [29] investigated the effect of temperature on the viscosity for $Al_2O_3$-water and CNT-water nanofluids at low concentrations. They showed that with the increment in temperature the viscosity of CNT-water and $Al_2O_3$-water nanofluid declines.

Although a large number of studies showed that with the increase in temperature the viscosity of nanofluid decreases, there are some studies that declare no change with the increment of temperature. Prasher et al. [15] and Chen et al. [30] used $Al_2O_3$ and $TiO_2$ nanoparticles in water. They indicated that with the enhancement in temperature at the range of 20–60 °C no change in relative viscosity of nanofluid was observed.

### *1.3. Empirical correlations*

As it has been expressed in previous researches the most effective parameters that influence the viscosity of nanofluids are temperature, volume fraction, basefluid and nanoparticle type. The attraction forces between nanoparticle surface and basefluid is affected by temperature and nanoparticle surficial chemical functional groups [25]. Based on Einstein's theory [31] and experimental methods several studies have been performed to find a correlation that relates the viscosity of

**Table 1**
Selected empirical correlations for viscosity of various nanofluid.

| | | |
|---|---|---|
| $\mu_{nf} = \mu_{bf}(1+1.5\varphi)\exp(\frac{\varphi}{1+\varphi_m})$ | (1) | Nielsen et al. [32] |
| $\mu_{nf} = \mu_{bf}(1+10.6\varphi+(10.6\varphi)^2)$ | (2) | Chen et al. [33] |
| $Log(\mu_{nf}) = Ae^{-BT}$ | (3) | Namburu et al. [34] |
| For CuO/EG-Water nanofluid:<br>$A = 1.8375(\varphi)^2 - 29.643(\varphi) + 165.56$<br>$B = 4\times10^{-6}(\varphi)^2 - 0.001(\varphi) + 0.0186$ | | |
| For $Al_2O_3$/EG-Water nanofluid:<br>$A = -0.29956(\varphi)^3 + 6.7388(\varphi)^2 + 55.444(\varphi) + 236.11$<br>$B = (-6.4745(\varphi)^3 + 140.03(\varphi)^2 - 1478.5(\varphi) + 20341)/10^6$ | | |
| For $SiO_2$/EG-Water nanofluid:<br>$A = 0.1193(\varphi)^3 - 1.9289(\varphi)^2 - 2.245(\varphi) + 167.17$<br>$B = (-7(\varphi)^2 - 400(\varphi) + 19200)/10^6$ | | |