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# Prediction of graphite nanofluids' dynamic viscosity by means of artificial neural networks☆

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ABSTRACT

Recently, nanofluids have been studied extensively by the researchers as a result of the developments in nanotechnology. It is essential for researchers to know nanofluids' physical properties in order to make calculations regarding their specific research topics. Determination of viscosity issue is an actual one due to its common usage in heat transfer and thermodynamics. In this study, graphite particles are selected to have nanofluid mixture with its base fluid of pure water. Their volumetric concentrations are varied from 0 to 2% in pure water. Once the stabilized nanofluid is prepared by a sonicator and ultrasonic bath, viscosity is measured by a viscosity meter for the temperatures ranging from 20 °C to 60 °C. Validation of the experiments have been done by means of the comparison of them with the 32 empirical correlations in the literature. Then, Artificial Neural Network (ANN) analyses have been performed in order to have better empirical correlation than those in the literature. Furthermore, detailed information on the preparation nanofluids, measurement of viscosity, a list of measured data, numerical model by Matlab software, and alteration of viscosity with temperature and concentration have been given in the paper. It was concluded that viscosity correlations in the literature can predict different types of nanofluids' viscosity although they have been derived using specific type and diameter of nano particles and their base fluids.



## 1. Introduction

In recent years, many researchers have proposed ways to enhance the thermo-physical properties of widely utilized fluids, however, the most effective method to achieve this aim is to add small metallic or non-metallic solid particles having quite better thermal properties. Yet, these mixtures may cause destructive effects, as well. Micrometer and millimeter size particles may lead to clogging and wear out ducts in the following periods. Consequently, though these mixtures have better rheological properties, they were not evaluated useful due to abovementioned reasons [1].

With the discovery of nanotechnology, these problems have been remarkably averted. In conclusion of the investigations in the Argonne National Laboratory, Choi [2] has put forth the nanofluid term to account for the particles in the order of nanometer suspended in widely used base fluids. To date, nanofluids have been thoroughly acknowledged with their better thermo-physical properties and further stabilities. From this point of view, especially in the context of the present study which is focused specifically on viscosity, it should be stated that a great number of experimental and numerical papers have been granted to the relevant literature by numerous scientists thus far [3–8].

Viscosity is a thermo-physical parameter which carries utmost significance and can be defined as the internal resistance of fluids against flow [9]. In various engineering applications, viscosity affects the pumping power as well as the fundamental heat transfer characteristics and thus it is clear that a further understanding of the underlying phenomena that determine the rheological behavior of nanofluids is quite essential [10].

It is a widely known fact that viscosity of a nanofluid is higher than that of base fluids. Viscosity rises with concentration and nanoparticle size. Though augmenting concentration may result in aggregation of nanoparticles and thus forming big clusters, this subject has not been adequately issued thus far [11]. The most recent studies in the literature

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**Nomenclature**

| | |
|---|---|
| ANN | Artificial Neural Network |
| B | Bias |
| $f_i$ | Predicted Value |
| g | gravitational force constant, $m/s^2$ |
| h | capillary height, m |
| MSE | Mean Square Error |
| N | Pattern Number |
| N | Neurons |
| R | Pipe diameter |
| $W_{hydro}$ | Hydrometer weight, kg |
| $V_{sub}$ | Sinking volume of bowl, $m^3$ |
| $y_i$ | Real Value |

*Greek symbols*

| | |
|---|---|
| $\mu_{bf}$ | Dynamic viscosity of base fluid, kg/ms |
| $\mu_{nf}$ | Dynamic viscosity of nano fluid, kg/ssms |
| $\varphi$ | Volume fraction |
| $Cos \cdot \phi$ | Contact angle between fluid and glass |
| $\phi$ | Transfer function |
| $\rho$ | Density, $kg/m^3$ |
| $\sigma_s$ | Surface stress of water in capillary pipe, N/m |

regarding the parameters affecting the viscosity of nanofluids can be summarized as follows:

Singh et al. [11] investigated relationship between the viscosity of nanofluids -made up of magnetite nanoparticles and toluene- and particle concentration and temperature. As expected, it was evident that viscosity increased with particle concentration. They also demonstrated that despite the fact that nanoparticles aggregated and made up clusters with rising concentration, the cluster size was fairly monodisperse and therefore the viscosity could be shown as a function of merely the particle concentration. The relationships found were expressed by means of an equation, so as to be able to be utilized in proper engineering fields.

Pak and Cho [12] investigated the thermal performance of $Al_2O_3$ and $TiO_2$ nanoparticles with diameters of 13 nm and 27 nm within a water flow in a horizontal circular pipe. They examined the thermal conductivity and viscosity of the nanofluids and found that fluids that contain $Al_2O_3$ and $TiO_2$ particles with a volume concentration of 10% have viscosities of 200 and 3 times higher than water, respectively. Viscosity results were greater than the predictions found via formulations. In addition, one novel correlation valid for fluids containing submicron oxide particles has been explored.

Rudyak [13] presented a review paper to detect the parameters which determine nanofluid's viscosity. The relations between the viscosity of nanofluid and the concentration of particles, their size and temperature were examined. It was also accounted for why the nanofluid viscosity was not defined through the classical theories. As a result, it was indicated that nanoparticle size was the key characteristic for nanofluids.

Nikkam et al. [14] studied the production of nanofluids composed of copper nanoparticles and a base fluid of diethylene glycol, as well as the thermal conductivity and rheological characteristics of them. The thermal conductivity and viscosity of nanofluids were determined at the nanoparticle concentration values between 0.4% and 1.6% and within the temperature interval of 20–50 °C. It was found that improvement in thermal conductivity was better than that of the enhancement in viscosity and this was evaluated as the nanofluids to be employed as coolants in heat transfer applications.

Mehrali et al. [15] composed homogeneous graphene nanoplatelet nanofluids (GNP) in distilled water with no surfactant but with high-power ultrasonic dispersion. The nanofluid concentration values were determined 0.025, 0.05, 0.075 and 0.1% for three surface areas of 300, 500 and 750 $m^2/g$. As a results, it was seen that the rheological properties of GNP nanofluids converged at Newtonian and non-Newtonian phenomena in which viscosity decreases with the increase of temperature. Also, the thermal conductivity outcomes revealed that the highest improvement was observed to be 27.64% at the concentration value of 0.1% and at the surface area of 750 $m^2/g$.

Masoumi et al. [16] proposed a novel correlation to estimate the viscosity of nanofluid through taking Brownian motion of nanoparticles into account. The correlation they found gives the viscosity of the nanofluid dependent on the temperature, the mean particle diameter, the nanoparticle concentration, the particle density and the thermos-physical properties of the base fluid. Afterward, the determined outcomes were compared with the extant experimental literature and a plausible consistency was obtained.

Mishra et al. [17] stated that viscosity was a significant property which required a great attention due to its large influence on heat transfer. They also added that the nanofluid viscosity should be meticulously examined prior to be utilized in heat transfer applications. For this reason, they presented a concise review on theoretical models as well as the review of the influences of various specialties of nanoparticles.

Juneja and Gangacharyulu [18] experimentally analyzed the influences of temperature and volume fraction of nanoparticles on thermal conductivity, viscosity and density of $Al_2O_3$/water/ethylene glycol based nanofluids. The data they derived showed that thermal conductivity increased with nanoparticles concentration and temperature. On the other hand, it was observed that that viscosity and density diminished with temperature and rose with nanoparticles concentration.

Singh et al. [19] carried out many experiments in a temperature range of 30 to 80 °C and at the volume fraction values of (0.1%, 0.2%, and 0.5%) and at the size of 20 nm $Al_2O_3$ nanoparticles, to examine the thermos-physical properties of nanofluid. It was reported that as the temperature increased, the thermal conductivity also increased at a definite nanofluid concentration, however the viscosity diminished.

Mariano et al. [20] presented experimental data regarding the thermos-physical properties of $Co_3O_4$/ethylene glycol nanofluids. Thermal conductivity and rheological property measurements were conducted at the nanoparticle concentration values of up to 25%. It was observed that the thermal conductivity demonstrated an increase with nanoparticle concentration and a decrease with temperature. Also, the measurements implemented to obtain thermos-physical properties indicated that the viscosity was roughly independent of the shear rate. This also proved that the nanofluid drew a characteristic of a Newtonian fluid.

Zhao et al. [21] stated that the viscosity of nanofluids could be influenced by various parameters and suggested a novel viscosity prediction model established on radial basis function neural networks. They proposed two neural network models, one of the models used 4 input variables and considered the influences of nanoparticle volume concentration, nanoparticle diameter, nanoparticle density and the viscosity of base fluid. The other approach taking into account 5 input variables, additionally evaluated the influence of temperature. $Al_2O_3$–water and CuO–water nanofluids were chosen to estimate the correctness of the proposed models. The results revealed that the calculated viscosity values through the suggested models were consistent with the experimental data, while it was also deduced that the performance of the model could be enhanced when the temperature was included as an input.

Huminic et al. [22] aimed to examine the effects of temperature and eight concentration on the thermos-physical properties of nanofluids composed of FeC-water mixtures. They fabricated the nanoparticles by means of laser pyrolysis technique and between the temperature interval of 10 and 70 °C and at three weight concentrations (0.1, 0.5, 1.0%) examined the thermal conductivity, viscosity and surface tension of these nanofluids. As a viscosity issue result, it was observed that at the temperature values over 55 °C, the effect of nanoparticle weight concentration on nanoparticle viscosity had become less significant.