A new correlation for estimating the thermal conductivity and dynamic viscosity of CuO/liquid paraffin nanofluid using neural network method

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\begin{abstract}
In this study the effects of CuO nanoparticles mass fraction and temperature was studied on the dynamic viscosity and thermal conductivity of CuO/viscous paraffin nanofluid. TEM and DLS analysis as well as zeta potential test were performed for obtaining the morphology and nanoparticles stability within the basefluid. The results of TEM and DLS images exhibited that the average CuO nanoparticles diameter was ranged from 15 to 30 nm. Moreover, Zeta potential analysis showed high stability of nanoparticles in the basefluid. In addition, the results showed that the increment of nanoparticles mass fraction and temperature ratio of the thermal conductivity of nanofluid to basefluid increased and this parameter increases significantly with the temperature at the temperature below 40 and 70 °C where the mass fraction was chosen below and higher than 2.5 wt%, respectively. Also the results showed that with the increase of temperature the ratio of dynamic viscosity of nanofluid to basefluid decreases insignificantly and with the increment of nanoparticle load this parameter enhances tangibly. Moreover, two separated correlation including temperature and mass fraction of CuO nanoparticle was estimated by using hybrid GMDH-type neural network method for estimating relative dynamic viscosity and thermal conductivity of nanofluid. The results declared that the deviation of the data obtained by correlation from the experimental values was mostly <5\% for both the thermal conductivity and dynamic viscosity. Finally, the value of relative Pr number was calculated at various temperature and mass fraction of CuO nanoparticles based on obtained correlations. The results of sensitivity analysis for relative Pr number exhibited that this parameter is more sensitive to mass fraction of nanoparticles in comparison with the temperature.
\end{abstract}

\section{1. Introduction}

Due to the interesting properties of nano-structured materials and nanoparticles, many scholars have focused their researches on the application of these fine materials. The application of nano-sized particles have been noticed because of their interesting properties in wide range of applications including separation technologies, reinforced nanocomposite, medical application, and thermal and hydrodynamic properties. It has been mentioned in previous efforts that the nanoparticles dispersed in basefluid, (called nanofluid), have especial thermal and hydrodynamic properties at the condition different nanoparticle types and loads are used. Dynamic viscosity and thermal conductivity of nanofluid are the main factor that has directly highest impact on the power needed for pumping the fluid in laminar and turbulent flows and heat transfer at various regimes, respectively. It is mentioned that the viscosity and thermal conductivity of different nanofluid are higher than that of basefluids; therefore, it is affordable to use nanofluid as heat transfer fluid due to the fact that they lead to smaller size of heat transfer equipment in industries. The main factors that directly influence the viscosity and thermal conductivity of nanofluids are temperature, particles size, nanoparticles load, and nanoparticles as well as basefluid types.

Due to the highest and direct impact of nanofluid on cooling and heating process, the application of nanofluid in heat transfer devices is taken into consideration in previous researches. As a one of the important factor, the basefluids can be chosen in wide ranges of aqueous and nonaqueous liquids. Considering the polar bonds in aqueous basefluids such as water, ethanol, and ethylene glycol, it is reasonable to use nanoparticles with highest surface polarity for prevention of nanoparticles agglomeration. Consequently, it is more affordable to use nonpolar basefluids for the nanoparticles with low surficial polarity. In addition, nonaqueous basefluids including oil and liquid paraffin can be

\begin{keyword}
Nanofluids
CuO nanoparticles
Viscosity
Thermal conductivity
Correlation

\end{keyword}

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used as basefluids for nonpolar nanoparticles due to the nonpolar structure and they can be taken into consideration in heat transfer devices in which high operational temperature are needed. On the other hand, since aqueous basefluids such as water have low boiling point, their application is restricted in heat transfer devices such as furnaces and heat exchangers that operate at the temperature higher than 100 °C [15].

The results obtained by other researchers show that different mechanisms can influence the hydrodynamic and thermal properties of nanofluid including Brownian motion of nanoparticles [16], formation of nanolayer at the surface of nanoparticles [17], clustering mechanism [18], and interaction of nanoparticles’ surface with basefluid compounds [19]. Although many researchers have investigated the effect of mass fraction, temperature on viscosity and thermal conductivity of nanofluid, but there is not fully agreement among the results obtained at the condition where different nanoparticles and basefluids are used [17–23]. Moreover, there is no wide range of data for thermal conductivity and viscosity of CuO/viscous paraffin nanofluid.

1.1. Nanofluid thermal conductivity

Chon et al. measured the thermal conductivity of Al2O3/water nanofluid at the condition where different nanoparticle sizes were used [20]. Their results showed that with the increase of nanoparticle size the thermal conductivity of nanofluid declined significantly. Chopkar et al. studied the impacts of volume fraction and particle size on thermal conductivity of metal based nanofluid containing Al2Cu and Ag2Al nanoparticles. Their findings showed that the relative thermal conductivity of nanofluid decreased with particle size and enhances with nanoparticles volume fraction [24]. Previous researches exhibited that the enhanced thermal conductivity of nanoparticles also depends on the clustering or aggregation effect, pH, surfactant, and the base fluid thermal conductivity. Vajjha et al. presented a new correlation, (Eq. (1)), to state the thermal conductivity of oxide nanoparticles dispersed in ethylene glycol and water mixture [25].

\[
\frac{k_{nf}}{k_w} = 0.8938(1 + \varphi)^{1.35}
(1 + \frac{T - 273.15}{70})^{0.277}
(1 + \frac{D_p}{150})^{-0.0336}
\left(\frac{\varphi}{\alpha_w}\right)^{0.01737} \\
(1)
\]

This model proposed that thermal conductivity of nanofluids as a function of the nanoparticle volume fraction, temperature, and the physical properties of nanoparticle and the base fluid is valid for water based nanofluid.

Chon et al. proposed a new correlation, (Eq. (2)), for estimating the thermal conductivity of Al2O3/water nanofluid in term of Re, Pr. Their result validated for nanoparticle sizes between 11 and 150 nm, temperatures ranged from 294 to 344 K and for volume fractions of 1% and 4%.

\[
\frac{k_{nf}}{k_w} = 1 + 64.7\varphi^{0.746}
\left(\frac{D_p}{D_f}\right)^{0.369}
\left(1 + \frac{k_p}{k_{nf}}\right)^{0.746}
Pr^{-0.9955Re^{-1.2321}} \\
(2)
\]

Chevalier et al. measured the relative viscosity of SiO2/ethanol nanofluids. The results of their experimentation showed that the viscosity of nanofluid increases with the increase in volume fraction [26]. Schmidt et al. measured the viscosity of Al2O3 dispersed in decane, isoparaffinic, and polyalphalcoel. They also reported that with the increase of the nanoparticle volume fraction from 0.25 to 1% the viscosity of nanofluid increases [27]. Einstein presented a correlation, (Eq. (5)), for viscous fluid containing spherical particle at low volume concentrations (\(\varphi < 0.02\)) [28].

\[
\frac{\mu_{nf}}{\mu_{ff}} = 1 + 2.5\varphi \\
(5)
\]

This formula shows that the viscosity increases with particle volume fraction. The mentioned correlation cannot consider structure and particle-particle interaction for the high nanoparticle concentration. Hosseini et al. [41] presented an empirical formula, (Eq. (6)), for Al2O3/water nanofluids. This correlation is dimensionless model for consideration of nanoparticles volume fraction, temperature, size as well as properties of the capping layer.

\[
\frac{\mu_{nf}}{\mu_{ff}} = \exp\left(m + \frac{T}{T_0} + \beta(\varphi) + \gamma\left(\frac{d}{1 - r}\right)\right) \\
(6)
\]

Considering the previous correlations proposed for viscosity and thermal conductivity of nanofluids, there is not a unique and comprehensive correlation for estimating mentioned properties of nanofluid at different condition. Thus, it is required to obtain a new correlation independent to nanoparticles and basefluid types for estimating nanofluid’s thermophysical properties. The aim of this study is to measure viscosity and thermal conductivity of CuO/viscous paraffin nanofluid and find a comprehensive correlation for prediction of these properties. For this purpose, the viscosity and thermal conductivity of nanofluid was measured at different CuO nanoparticle mass fractions and various temperatures. Finally an empirical relation incorporating temperature and mass fraction was proposed to predict Pr number of nanofluid at various conditions.

2. Experiments

2.1. Materials

In this research CuO nanoparticles were prepared by using the precipitation of Cu(NO3)2·3H2O with 99.9% purity, purchased from Merck Co. Germany. For this purpose sodium hydroxide, (NaOH with 99.99% purity, purchased from Merck Co. Germany), was used for
precipitation of Cu$^{2+}$ ions. Moreover, in order to prepare the nanofluid, viscous paraffin (VP), with detailed physical properties, (presented in Table 1), was purchased from Merck Co. Germany and used as basefluid. Deionized water was used for washing the glassware jaws [29].

2.2. Instruments

In this research the thermal conductivity of nanofluid was measured by using a thermal properties analyzer, (KD2 Pro. Deacagon, USA). Also for measuring dynamic viscosity of prepared nanofluid a cylindrical viscometer, (Brookfield model DV2T, U.S.A.), was used within the experimentation. For estimating the stability of nanoparticles within the basefluid, Zeta Potential analysis was performed on nanofluids and was reported by plotting total counts of nanoparticles vs. total electrostatic voltage, (obtained from ZetaSizer, Malvern, ZetaSizer Nano ZS, United Kingdom). In addition Dynamic Light Scattering (DLS), (Malvern, ZetaSizer Nano ZS, United Kingdom), was used for determination of nanoparticles size distribution in the viscous paraffin. Transmission Electron Microscopy (TEM), (Hitachi, 9000 NA, Japan), was used to characterize the shape and size of prepared CuO nanoparticles. For preparation of nanofluid and prevention of nanoparticles agglomeration within the basefluid, ultrasonic processor, (Hielscher, UP200St, Germany), was implemented during dispersing of CuO nanoparticles in viscous paraffin. Furthermore, the weight of dried CuO nanoparticles was measured by using a precise electric balance, (HT series, Che Kingdun Co., Hong Kong), and the temperature was set on constant value during the experimentation by using isothermal circulator bath, (~40 °C, 7 L Ref. Circulator, PolyScience Co., U.S.A.). A syringe pump, (Villettechmeda Plus SEP21S), was used for adding NaOH solution into the Cu(NO$_3$)$_2$·3H$_2$O solution during nanoparticles synthesis.

2.3. Nanofluid preparation

In this research precipitation method was implemented for preparation of CuO nanoparticles in which 2.416 g Cu(NO$_3$)$_2$·3H$_2$O was dissolved in 100 ml deionized water to obtain Cu$^{2+}$ ions, then the synthesis started by adding 250 ml 0.1 M NaOH solution by means of a viscometer, (Brookfield, Germany), was implemented during dispersing of CuO nanoparticles in which 2.416 g Cu(NO$_3$)$_2$·3 H$_2$O was prepared for CuO nanoparticles. 

<table>
<thead>
<tr>
<th>Value</th>
<th>Properties</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>8012-95-1, 232-384-2</td>
<td>CAS-no. and EC no.</td>
<td>1</td>
</tr>
<tr>
<td>Lower than 0.01 Pa (@20 °C)</td>
<td>Vapor pressure</td>
<td>2</td>
</tr>
<tr>
<td>Density 0.860 g/cm$^3$</td>
<td>Specific gravity</td>
<td>3</td>
</tr>
<tr>
<td>230 °C</td>
<td>Flash point</td>
<td>4</td>
</tr>
<tr>
<td>300-500 °C</td>
<td>Boiling point</td>
<td>5</td>
</tr>
<tr>
<td>300 °C</td>
<td>Ignition temperature</td>
<td>6</td>
</tr>
<tr>
<td>8-13 °C</td>
<td>Melting point</td>
<td>7</td>
</tr>
</tbody>
</table>
of thermal conductivity measurement the following equation was used:

\[ U_{\text{Thermal Conductivity}} = \pm \sqrt{\left( \frac{\Delta k}{k} \right)^2 + \left( \frac{\Delta \rho}{\rho} \right)^2 + \left( \frac{\Delta T}{T} \right)^2} \]  

(10)

where the accuracy of KD2 Pro was ± 1%. Therefore, the maximum of uncertainty of thermal conductivity measurement was 6.7%.

3. Results and discussion

3.1. Characterisation

According to the results of TEM analysis, (presented in Fig. 1), CuO nanoparticles were synthesized with mean diameters ranged from 15 to 30 nm. Moreover, it is concluded from the results of this figure that the CuO nanoparticles morphology was semispherical without a significant agglomeration. Due to the importance of nanoparticle size as well as the agglomeration of nanoparticles and their effects on thermophysical properties of nanofluid, it must be noticed to investigate and measure the stability of CuO nanoparticles in the viscous paraffin. For this purpose, Dynamic Light Scattering, (DLS), and Zeta potential analysis were performed on CuO/VP nanofluid. The results presented in Fig. 2a exhibit that the mean diameters of CuO nanoparticles in viscous paraffin ranges from 10 to 50 nm with Poly Dispersity Index of 0.124. In order to apply DLS and Zeta Potential analysis samples were diluted with further viscous paraffin for eliminating any experimental errors. In addition the results presented in Fig. 2a declared that there is no significant agglomeration for CuO nanoparticles within the viscous paraffin and these results are consistence with the findings obtained from TEM analysis.

The results of Zeta Potential analysis for CuO nanoparticles dispersed in viscous paraffin is presented in Fig. 2b. This results exhibits that the dispersed CuO nanoparticles within base fluid has the highest zeta potentials less than −40 mV and showing high stability of nanoparticles in viscous paraffin [31,32].

3.2. Viscosity

Fig. 3 shows the results of viscosity measurement. In this figure the ratio of dynamic viscosity of CuO/VP nanofluid to basefluid is plotted versus various temperatures at condition where different nanoparticles mass fractions were chosen. It is concluded from these results that with the increase of CuO nanoparticles mass fraction from 0.25 to 6 wt% the ratio of viscosity increases from 1.01 to 1.75 at the condition where temperature was set on 25 °C. In addition, with the increment of nanoparticles load from 0.25 to 6 wt% the dynamic viscosity ratio increases from 1.03 to 1.64 for those where inserted into the hot water bath with the temperature of 100 °C. Also, it is evidence that with the temperature enhancement the ratio of dynamic viscosity declines insignificantly. Therefore, for the condition where the mass fraction of nanoparticles is 6 wt%, with the temperature enhancement from 25 to 100 °C the ratio of dynamic viscosity decreases from 1.75 to 1.64 and for those contains 0.25 wt% CuO nanoparticles, with the increases in temperature from 25 to 100 °C the ratio of dynamic viscosity decrease < 5%. In this figure it can be concluded that CuO nanoparticles load has highest impact on the ratio of dynamic viscosity of CuO/VP nanofluid; although, it has been noticed in other previous researches [3,20,32] that the temperature has intense effect on thermophysical properties.
properties of nanofluid.

3.3. Thermal conductivity

The results of the ratio of thermal conductivity of nanofluid to basefluid at various temperatures and the condition where mass fraction of CuO nanoparticles was chosen to be 0.25 wt% are presented in Fig. 4a. It is concluded from these results that with the increase of temperature from 25 to 100 °C the ratio of thermal conductivity increases from 1.03 to 1.17. In addition, these results indicate that with the increase of temperature from 25 to 40 °C the ratio of thermal conductivity of nanofluid increases significantly while for the temperature above 40 °C the value of thermal conductivity ratio change insignificantly. Accordingly, it is evidence that with the increase in temperature from 40 to 100 °C the value of thermal conductivity ratio increases about 3% and for temperature below 40 °C, with the increase of temperature from 25 to 40 °C the ratio of thermal conductivity enhances about 11% declaring high impact of temperature below 40 °C.

Fig. 4b shows the results of the ratio of nanofluid thermal conductivity to basefluid at various temperatures and the condition where mass fraction of CuO nanoparticles was chosen to be 0.5 wt%. The results of this figure also indicate that with the increase of temperature from 25 to 100 °C the ratio of thermal conductivity increases from 1.06 to 1.23. Moreover, it is evident that with the increase of temperature from 25 to 40 °C the ratio of thermal conductivity of nanofluid increases significantly. Therefore, with the temperature enhancement from 40 to 100 °C the value of thermal conductivity ratio increases about 5.3% and for temperature below 40 °C the enhancement in thermal conductivity ratio, (for temperature enhancement from 25 to 40 °C), is about 10.4%.

Fig. 5a exhibits the results of relative thermal conductivity measurement for CuO/VP nanofluid at various temperatures and mass fraction of 1.5 wt%. Similar to the results of Fig. 4a and b, the results of this figure also show that with the increase of temperature from 25 to 100 °C the ratio of thermal conductivity increases from 1.08 to 1.32. Also, it is concluded from this figure that with the increase of temperature from 25 to 40 °C the ratio of thermal conductivity of nanofluid increases significantly and for the temperatures ranged from 40 °C to 70 °C the value of thermal conductivity ratio does not change tangibly.
however, this property increases significantly at temperature near to 100 °C. Thus, with the temperature enhancement from 70 to 100 °C the value of thermal conductivity ratio enhances about 5.6% and for temperature enhancement from 25 to 40 °C the increase in thermal conductivity ratio is about 12.9%.

Also Fig. 5b shows the results of thermal conductivity measurement for CuO/VP nanofluid at various temperatures and mass fraction of 2.5 wt%. Similar to the results of Fig. 5a, this figure also exhibit that with the increase of temperature from 25 to 100 °C the ratio of thermal conductivity increases significantly and for temperature above 70 °C the ratio of thermal conductivity changes insignificantly in comparison to lower temperatures. Thus, with the temperature enhancement from 25 to 70 °C the value of thermal conductivity ratio increases about 29% while for temperature enhancement of 70 to 100 °C the value of thermal conductivity ratio increases only 3.5%.

The results presented in Fig. 4a are the thermal conductivity ratio of CuO/VP nanofluid at various temperatures and the condition where the mass fraction of CuO nanoparticles was chosen to be 4.0 wt%. Similar to the results of previous figures, (Figs. 4 and 5), the results of this figure declare that with the enhancement in temperature from 25 to 100 °C the ratio of thermal conductivity increases from 1.2 to 1.6. Moreover, similar to the results of Fig. 5b this figure exhibits that with the enhancement in temperature from 25 to 70 °C the ratio of thermal conductivity of nanofluid increases tangibly and for temperature above 70 °C the ratio of thermal conductivity of nanofluid changes insignificantly in comparison to temperatures lower than 70 °C. Accordingly, with the increase in the temperature from 25 to 70 °C the value of thermal conductivity ratio enhances about 29.1% and for the increase in the temperature from 70 to 100 °C the value of thermal conductivity ratio enhances about 3.2%.

Fig. 6b present the values of thermal conductivity ratio for CuO/VP nanofluid at various temperatures and the condition where the mass fraction of CuO nanoparticles was chosen to be 6.0 wt%. The results of this figure also show that with the increase in temperature from 25 to 100 °C the relative thermal conductivity of CuO/VP nanofluid increases significantly. Consequently, with the increase in the temperature from 25 to 70 °C the value of thermal conductivity ratio increases about 28.9% while for the increase in the temperature from 70 to 100 °C the value of thermal conductivity ratio increases 3.0%.

3.4. Temperature effect

It is evident from the results presented in Fig. 3 that the experimental values for CuO/VP nanofluid show that with the increase in temperature the values of dynamic viscosity ratio decrease insignificantly. This declination for CuO/VP nanofluid viscosity is attributed to the motion of nanoparticles at micron dimension. According to the results obtained by other scholars [9,14,20,28,33], with the enhancement in micro-convection of nanoparticles in basefluid the inter-
molecular forces between basefluid molecules and nanoparticles surface decreases. According to the results obtained by Koo et al. [16], (based on Brownian motions of nanoparticles), with the increase of temperature the random velocity of nanoparticles increase significantly [16]. Therefore, it is apparent that with the temperature enhancement the value of Brownian velocity of CuO nanoparticles increases and this enhancement lead to decrease the inter-molecular forces between basefluid and nanoparticles surface resulting lower viscosity at higher temperature. The results obtained in this study showed that with the temperature enhancement, the ratio of dynamic viscosity decreases and the values of nanofluid dynamic viscosity would be higher than basefluid at the temperature range of 25 to 100 °C.

The experimental measurement of thermal conductivity of nanofluid declares that with the increases of temperature the value of thermal conductivity ratio increases at fixed CuO nanoparticles mass fraction, (results of Figs. 4 to 6). In addition, for the nanofluids containing CuO nanoparticles below 2.5 wt%, with the increase of temperature from 25 to 40 °C the ratio of thermal conductivity increases significantly while for those contain CuO nanoparticles higher than 2.5 wt% this range would be 25 to 70 °C. The main mechanism for effect of temperature on thermal conductivity of nanofluid is Brownin velocity of nanoparticles resulting micro-convection by using nanoparticles in basefluid [20]. With the increase of the numbers of micro-convection in nanofluid, more basefluid molecules with higher thermal energy can be transferred and higher thermal conductivity is resulted [20]. Thus, the results of this research show that the main factor that can satisfy the effect of temperature is attributed to the impact of temperature on the magnitude of Brownin velocity or micro-convection caused by nanoparticles, that has been described by Koo et al. [16,20].

3.5. Mass fraction effect

In this research it is evident that with the increase of CuO nanoparticles in the nanofluid the value of both thermal conductivity ratio and dynamic viscosity ratio increases, (Figs. 3 to 6), which is attributed to the solid content of nanofluid. With the increase of nanoparticles mass fraction the numbers of micro-convection by means of CuO nanoparticles increases and this lead to increase of nanofluid thermal conductivity. The results of this research showed that with the increment in the mass fraction of CuO nanoparticles in viscous paraffin from 0.25 to 6 wt% at the temperatures of 25, 40, 55, 70 and 100 °C the ratio of dynamic viscosity nanofluid enhance 75, 60, 60, 58 and 57% and the ratio of thermal conductivity increases 24, 27, 38, 43, 45%.

3.6. Correlation

According to the previous researches, various methods was implemented for deriving a new correlation to estimate the dynamic viscosity and thermal conductivity of nanofluid at specified temperature range and nanoparticle loads. It was by Attari et al. and Darvanjooghi et al. [20,32] that the temperature and interfacial forces have major effect on the thermo-fluidic properties of nanofluid [34]; however, other researches declares that the Brownian random motion has high effect on dynamic viscosity and thermal conductivity of nanofluid due to the micro-convection produced by nanoparticles within the basefluid.

According to theories based on nanoparticles random motion [35] and experimental values of thermal conductivity and viscosity, mathematical regression analysis were applied for obtaining a new correlation to estimate the viscosity and thermal conductivity of nanofluid at different nanoparticle loads and temperatures.

In this research hybrid group method of data handling (GMDH)-type neural network was implemented for obtaining a new correlation for estimating thermal conductivity and dynamic viscosity of CuO/VP nanofluid [36]. For this purpose, GMDH Shell DS software was used for estimating polynomial correlations. The correlation for estimating the ratio of dynamic viscosity of CuO/VP nanofluid was obtained by hybrid GMDH-type neural network as function of nanofluid temperature (°C) and CuO mass fractions (%wt). The following correlation was obtained with R² = 0.99 for estimating the ratio of dynamic viscosity of nanofluid:

\[
\frac{\mu_{nf}}{\mu_{bf}} = A_1 + A_2 T + A_3 T^2 + A_4 w
\]

where:

\[
A_1 = 0.995246, \quad A_2 = -0.000293119, \quad A_3 = 0.125761
\]

Moreover, a polynomial correlation for the ratio of thermal conductivity of nanofluid to basefluid was obtained as function of temperature (°C) and mass fraction of CuO nanoparticles (%wt) as follow:

\[
\frac{k_{nf}}{k_{bf}} = B_1 + B_2 w + B_3 T + B_4 w T + B_5 w^2 + B_6 T^2
\]

where:

\[
B_1 = 0.792194, \quad B_2 = 0.0547913, \quad B_3 = 0.00998805, \\
B_4 = 0.000730423, \quad B_5 = -0.000293119, \quad B_6 = -0.0000643292
\]

In order to assess the correlation obtained for estimation of nanofluid thermal conductivity or dynamic viscosity ratio the margin of deviation was calculated according to the following equation:
In Fig. 7, a, Margin of deviation for estimating the relative dynamic viscosity of nanofluid and b, Margin of deviation for estimating the relative thermal conductivity of nanofluid. 

\[ \text{Margin of deviation} = \frac{R_{\text{cal}} - R_{\text{exp}}}{R_{\text{exp}}} \times 100 \]  

(13)

According to the results presented in Fig. 7a it is concluded that the Eq. (11) can estimate the ratio of dynamic viscosity of nanofluid to basefluid at various temperatures and nanoparticle mass fractions with low deviation from experimental values. These results exhibit that deviations of estimated data from experimental values are majorly < 5%. In addition this figure shows that the calculated relative dynamic viscosity has lower deviation from experimental values at condition where mass fraction of nanoparticles was chosen to be 4 wt% and for the temperature of 40 and 55 °C the margin of deviation has minimum values. Therefore, Eq. (11) can estimate the relative dynamic viscosity of nanofluid containing CuO nanoparticles dispersed in viscous paraffin at temperature range of 25 °C to 100 °C and the mass fraction within 0.25% to 6 wt%.

Also in order to assess the correlation obtained for estimation of thermal conductivity ratio of nanofluid to basefluid the margin of deviation was calculated according Eq. (13). According to the results presented in Fig. 7b it is evident that the Eq. (12) can estimate the ratio of dynamic viscosity of nanofluid to basefluid at various temperatures and nanoparticle mass fractions. These results exhibit that deviations of estimated data, (obtained by means of proposed correlation), from experimental data are < 5%. Moreover, this figure exhibits that the calculated ratio of thermal conductivity of nanofluid to basefluid has lower deviation from experimental values at condition where mass fraction of nanoparticles was chosen to be 4 and 6 wt% at the temperature lower than 55 °C the margin of deviation has minimum values. Thus, Eq. (12) can estimate the relative thermal conductivity of CuO/VP nanofluid at temperatures ranged from 25 °C to 100 °C and the mass fraction within 0.25% to 6 wt%.

It has been mentioned in previous researches that the two main factors which have highest impact on heat transfer devices such as heat exchanger are the hydrodynamic of fluid flows within the heat exchanger as well as thermal and physical properties of heat transfer fluid, reported as Pr number. Although there are large numbers of studies focused on the fluid regimes on heat exchanger devices as well as fluid properties, there is no wide range of studies focused on hydrothermal properties of nanofluid at condition where different temperatures and nanoparticles loads are applied. For this purpose, in this research the value of the ratio of nanofluid Pr number to basefluid was obtained by using the thermo-fluidic correlations which were proposed by hybrid GMDH-type neural network method. The value of relative Pr was calculated according to the Eq. (14).

\[ R_{\text{pr}} = \frac{Pr_{\text{cal}}}{Pr_{\text{exp}}} = \left( \frac{C_{\text{p}_{\text{nf}}}}{C_{\text{p}_{\text{bf}}}} \right) \left( \frac{\mu_{\text{nf}}}{\mu_{\text{bf}}} \right) \left( \frac{k_{\text{nf}}}{k_{\text{bf}}} \right) \]  

(14)

where the values of heat capacity for nanofluid was obtained according to the following equation:

\[ C_{\text{p}_{\text{nf}}} = w \cdot C_{\text{p}_{\text{np}}} + (1 - w) \cdot C_{\text{p}_{\text{bf}}} \]  

(15)

Therefore, by substituting Eqs. (11), (12) and (15) into the Eq. (14) the following equation would be obtained for the ratio of nanofluid Pr number to basefluid:

\[ R_{\text{pr}} = \frac{Pr_{\text{cal}}}{Pr_{\text{exp}}} = \left( \frac{C_{\text{p}_{\text{nf}}}}{C_{\text{p}_{\text{bf}}}} \right) \left( \frac{\mu_{\text{nf}}}{\mu_{\text{bf}}} \right) \left( \frac{k_{\text{nf}}}{k_{\text{bf}}} \right) \]  

(16)

For CuO nanoparticles the specific heat capacity, (j/kg·K), can be obtained by the correlation proposed by Leitner et al. as follow [37]:

\[ C_{\text{p}_{\text{np}}} = 471.75 + 181.53(T + 273.15) + \frac{4.338 \times 10^5}{(T + 273.15)^2} - \frac{1.279 \times 10^{10}}{(T + 273.15)^3} \]  

(17)

Fig. 8 shows plot of R_{\text{pr}} vs temperature and mass fraction of CuO nanoparticles in the basefluid. In this figure the value of R_{\text{pr}} was calculated by using R_{k} and R_{Pr} that was obtained by using the hybrid GMDH-type neural network method. According to the results of this figure, it is evident that with the increase of the mass fraction of CuO nanoparticles the value of relative Pr number increases significantly; on the other hand, it is concluded from the results presented in this figure that with the increase of temperature the value of Pr number decreases insignificantly. In addition for the condition where the temperature and CuO nanoparticle mass fraction were set on 25 °C and 6 wt% the value of mass fraction is below 0.5 wt% relative Pr number is below unity declaring lower value of nanofluid Pr in comparison to basefluid and for the condition where the temperature and mass fraction of CuO nanoparticles were set on 100 °C and 0.25 wt% respectively the relative Pr number has minimum value, (equal to 0.95).

Furthermore, for validating the correlation proposed for relative Pr number, an experimental data set was prepared from the results of other scholars and represented in Table 2. The results were gathered from those that nanofluids contain CuO and Al₂O₃ nanoparticles dispersed in deionized water at the condition were different nanoparticle volume fractions and temperature was used during measuring viscosity and thermal conductivity. These findings show that the proposed correlation can estimate the experimental results of other studies at the temperature range of 25 °C to 100 °C, volume fractions up to 4 vol% with deviations ranged from -28.1 to 18.4%. In addition, at the condition where the temperature and volume fraction of CuO nanoparticles...
dispersed in water were set on 21 °C and 3 vol% respectively. The deviation of experimental relative Pr number from the calculated one is below 10% and for the condition where Al2O3/water nano fluid was used this deviation is below 10% for volume fractions of 2 and 4 vol% and temperatures of 36 and 51 °C, respectively.

3.7. Sensitivity analysis

The sensitivity analysis declares that which parameters, (temperature and mass fraction of nanoparticles), has highest impact on dynamic viscosity and thermal conductivity of CuO/VP nano fluid. In the present research, for analyzing the sensitivity of the relative Pr number the sensitivity analysis was performed by applying ± 5, ± 10, ± 15, ± 20, ± 25, ± 30, ± 35 and ± 40% change in mass fraction of CuO nanoparticles (wt%) and the temperature (°C). Therefore, for a CuO/VP nano fluid containing 1.5 wt% CuO nanoparticles and temperature of 50 °C the sensitivity of relative Pr number is obtained by considering ± 5% change in temperature according to the following equation:

\[
\text{Sensitivity \(\%\)} = \frac{R_{\text{Pr}}(T = 50 \, ^\circ C, \, w = 1.5 \, \text{wt\%}) - R_{\text{Pr}}(T = 50 \, ^\circ C, \, w = 1.5 \, \text{wt\%})}{R_{\text{Pr}}(T = 50 \, ^\circ C, \, w = 1.5 \, \text{wt\%})} \times 100
\]

(18)

Fig. 9 shows the results of the sensitivity of relative Pr number vs. temperature and mass fraction of CuO nanoparticles in viscous paraffin. It is evident from the results presented in this figure that the relative Pr number is more sensitive to CuO nanoparticles mass fraction in comparison to temperature. These results also express that with +20% and −20% change in temperature the value of sensitivity for relative Pr number is 25% and 27% respectively. In addition, with +20% and −20% change in CuO nanoparticle mass fraction the value of sensitivity for relative Pr number is 4% and 2% respectively.

4. Conclusion

In this study the effects of CuO nanoparticles load and temperature was studied on the dynamic viscosity and thermal conductivity of CuO/viscous paraffin. TEM and DLS analysis as well as zeta potential test were performed for obtaining the morphology and shape as well as nanoparticles stability within the base fluid. The results of TEM and DLS images exhibited that the average CuO nanoparticles diameter was ranged from 15 to 30 nm. In addition, Zeta potential analysis showed high stability of nanoparticles in the base fluid and no significant agglomeration of nanoparticles.

Moreover, the results showed that with the increment of nanoparticles mass fraction and temperature the ratio of the thermal conductivity of nano fluid to base fluid increased while for the relative viscosity an insignificant declination was observed with temperature increment. In addition, the thermal conductivity ratio increases significantly with the temperature at the temperature below 40 and 70 °C where the mass fraction was chosen below and higher than 2.5 wt% respectively.

Finally, a correlation, (for estimating the ratio of thermal conductivity and dynamic viscosity of nano fluid to base fluid), including temperature and mass fraction of CuO nanoparticle was proposed by using hybrid GMDH-type neural network method. The results declared

Table 2

<table>
<thead>
<tr>
<th>(\phi) (%)</th>
<th>(T(, ^\circ C))</th>
<th>Nanofluid type</th>
<th>(R_{\text{Pr, exp}})</th>
<th>(R_{\text{Pr, cal}})</th>
<th>Error (=\frac{R_{\text{Pr, exp}} - R_{\text{Pr, cal}}}{R_{\text{Pr, exp}}} \times 100)</th>
<th>Ref.</th>
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<tbody>
<tr>
<td>2</td>
<td>21</td>
<td>CuO-water</td>
<td>2.05</td>
<td>1.84</td>
<td>10.1</td>
<td>[38,39]</td>
</tr>
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<td>3</td>
<td>21</td>
<td>CuO-water</td>
<td>2.15</td>
<td>2.32</td>
<td>8.5</td>
<td>[38,39]</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>CuO-water</td>
<td>2.33</td>
<td>2.88</td>
<td>23.9</td>
<td>[38,39]</td>
</tr>
<tr>
<td>2</td>
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<td>1.81</td>
<td>1.53</td>
<td>15.4</td>
<td>[38,39]</td>
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<tr>
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<td>2.14</td>
<td>13.2</td>
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<tr>
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<td>1.75</td>
<td>14.2</td>
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<td>2.52</td>
<td>17.9</td>
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<td>1.19</td>
<td>10.3</td>
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<td>1.18</td>
<td>1.05</td>
<td>10.2</td>
<td>[28,39,40]</td>
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<td>1.21</td>
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<td>1.23</td>
<td>18.4</td>
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<tr>
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<td>1.43</td>
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<td>[28,39,40]</td>
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</table>
that the deviation of the data obtained by correlation from the experimental values was mostly < 5 for both the thermal conductivity and dynamic viscosity. Finally based on the correlations, the value of relative Pr number was calculated and plotted vs temperature and mass fraction of CuO nanoparticles. The results of sensitivity analysis for relative Pr number exhibited that this parameter is more sensitive to mass fraction of nanoparticles in comparison with the temperature.

References


