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Research Article

Analysis of thermophysical properties of novel hybrid nanoparticles based vegetable nanofluid

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ABSTRACT

Nano additive-based vegetable-oil fluids are playing a vital role in conventional thermal applications due to their contribution to improved thermophysical properties. This work is focused on the synthesis and characterization of a novel ZnO-Ag hybrid nanoparticles-based sunflower oil for thermal applications. Firstly, the ZnO-Ag hybrid nanoparticles were prepared by a wet chemical approach and characterized using SEM and TEM. The synthesized hybrid nanoparticles were then mixed in the sunflower oil to prepare various nanofluids at different volume concentrations ranging from 0.05 to 0.20%. The stability of the prepared nanofluids was investigated as a function of Zeta potential and visual examination. Further, the thermal conductivity and viscosity of prepared nanofluids were measured by the KD2-pro analyzer and Brookfield viscometer. The result showed that the thermal conductivity of prepared nanofluids was increased up to 21.01% at 0.20% nanoparticles volume concentration. Finally, an artificial neural network model was developed to accurately predict the thermal conductivity of prepared nanofluids.

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INTRODUCTION

The application of fluids in machining plays a crucial role in improving process performance due to promising thermal properties. The impingement of fluid in the cutting zone affects the performance of the machining process in terms of tool wear, cutting forces, surface roughness, etc. During the machining process, the use of coolant reduces surface friction and heat generation between the tool and workpiece interface. The heat generated results in rising in the temperature which affects the tool life [1]. The effective use of cutting fluid also increases the tool life. In machining

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operations, different fluids such as soluble oils, synthetic oils, and semi-synthetic oils are used as a cutting fluid [2]. The cutting fluid and its management costs are 20% of the total manufacturing cost. The disposal of these cutting fluids also has a significant share of the total costs. To recover this issue, the minimum quantity lubrication (MQL) technique came into existence in the machining processes. The MQL method involves atomizing lubricant into a mist and directing it into the cutting zone. This results in decreased chip-tool interaction due to temperature reduction, thereby preserving the sharpness of the cutting edge. This technique offers both economic and ecological benefits, surpassing alternatives like flood machining. Studies reveal that not only does MQL reduce temperature, but it also leads to a 5-12% decrease in cutting forces. Consequently, adopting MQL enhances productivity, elevates product quality, and bolsters overall cost-effectiveness [3]. When employing MQL, a notable decrease in temperature was observed at lower cutting parameter levels, whereas the reduction in temperature was comparatively less pronounced at higher parameter levels [4].

MQL employs significantly less lubricant—around three to four times less—compared to traditional flood-cutting fluids. MQL's performance hinges on fluid flow rate, thermal conductivity, viscosity, and pour point. Typically, MQL flows at 50 - 500 ml/h. Mineral oil-based, synthetic, and semi-synthetic cutting fluids pose risks to the environment, causing issues like groundwater pollution, air pollution, and other environmental hazards [5]. Also, the evaporation of the lubricant takes place at higher temperature in the cutting zone and causes health problems to people involved in the metal cutting process [6]. Vegetable oil-based cutting fluids offer an alternative to these fluids (VBCFs). The chronic diseases such as Lung cancer, respiratory illness, hereditary problems, and other ailments can all be minimized by employing VBCFs. In previous research, various vegetable oils such as castor oil, soybean oil, coconut oil, sunflower oil, palm oils etc., were used to improve performance metrics [7].

Vegetable oils, as a type of biodegradable oil, are ecologically beneficial and biodegradable cutting fluid [8]. They have the features that lubricating oils require, such as a higher viscosity index, lower volatility, worthy lubricity, and ideal solvents for adding nanoparticles [9-10]. Furthermore, as compared to raw petroleum-based oils, vegetable oils can attain low friction coefficients. Mineral oils can be replaced by lubricants made from vegetable oils [11]. Moreover, the physio-chemical characteristics of several vegetable oils vary slightly. The results of a study demonstrated that coconut oil-based nanofluid reduced tool wear by 31.58% as compared to canola oil [12]. The various types of vegetable oil with its physio-chemical properties used as a cutting fluid is depicted in Table 1.

However, the use of vegetable oils hinders the effective cooling between tool and surface during machining because of the lower value thermal conductivity [26-27]. To reduce the impact of hazardous cutting oils, the use of vegetable oils in MQL approach has recently been introduced together with other innovative techniques. The addition of nanoparticles in the vegetable oil adds more effectiveness than MQL technique. This fluid, known as nanofluid or nanoparticle-based cutting fluid, in which nanoparticles are suspended and when used in MQL, it is termed nanofluids-based MQL (NFMQL) assisted machining. Sharma et al. [28] used SiO_2 nanoparticles in vegetable oil and use as cutting fluid for the machining operation. The

Table 1. Physio-chemical characteristics of different vegetable oils

Vegetable oil	Density (gm/ml)	Kinematic Viscosity (mm^2/s)	Viscosity Index	Saponification Value	Iodine Value	Pour Point °C	Flash Point °C
Coconut oil [13]	0.915	27.90	155	250-2264	12	20	240
Palm oil [14]	0.91	41.90	189	196-210	50-55	12	304
Sunflower oil [15]	0.89	38.20	205	186-196	113-148	-15	272
Soybean oil [16]	0.907	30.30	224	115-145	189-195	-12	254
Castor oil [17]	0.97	239.00	85	170-185	85-90	-31	260
Groundnut oil [18]	0.914	36.84	144	185-195	84-95	-3	336
Rapeseed oil [19]	0.0918	49.20	208	171-181	110-115	-21	316
Shea butter oil [20]	0.927	83.29	-	160-195	39-41	3	350
Rice bran oil [21]	0.92	40.60	210	176	94	-31	318
Olive oil [22]	0.912	4.02	-	183-193	79-92	-9	315
Mustard oil [23]	0.967	63.04	150-159	125.6	8.1	18	310
Neem oil [24]	0.91	48.32	40	172.8	93.12	7	250
Jatropha oil [25]	0.917	36.90	186	190	82-98	-3	273

investigation demonstrates conclusively that SiO_2 nanofluid outperforms conventional cutting fluids in terms of cutting force, surface roughness, tool flank wear, and chip morphology when applied in wet/MQL and dry machining. With the aid of pressured air, nanoparticle-based vegetable oil is injected into the cutting zone in the form of oil-mist or aerosol. Nanoparticles increase tribological qualities by increasing the heat conductivity of base oil [29]. However, use of single nanoparticles in vegetable oil limits the thermal conductivity due to less stability or the use of metal oxide nanoparticles. Hybrid nanoparticles have recently been discovered by researchers to represent an answer to this issue. Hybrid nanomaterials combine the chemical and physical characteristics of their component materials into one or more nanoparticles fused by either by mixing or a similar approach [30]. These hybrid nanoparticle gets mixed in a base fluid such as water, EG, vegetable oil and engine oil etc. The use of hybrid nanoparticles instead of the single nanoparticle in base fluid enhances the thermo-physical properties [31]. It is evident from the previous research the use of hybrid nanoparticles in the sunflower oil as a cutting fluid is still part of the research.

In most scenarios, hybrid nanoparticles-based vegetable oil is created by combining and sonicating two nanoparticles with varying weight or volume percentages [32]. However, the inadequate stability and insufficient blending of nanoparticles in the base fluid prevents further advancement of thermal conductivity [33]. In the beginning, Jadhav et al. developed a unique method to cover nanoparticles with better thermal conductivity over the nanoparticle with a lower thermal conductivity (ZnO-Ag) [34]. Recently, a significant improvement in the thermal conductivity was reported by using ZnO-Ag nanofluid at smaller concentration for water-based/glycol-based nanofluid [35]. The use of ZnO-Ag nanoparticles in sunflower oil could significantly enhance the thermal conductivity and such nanofluid will be important for NFMQL assisted machining operations. Therefore, this works aims to prepare and characterize the ZnO-Ag-based hybrid nanofluid with sunflower vegetable oil as base fluid. Further, models concerning to the study of the thermal conductivity of hybrid nanofluids using curve fitting and artificial neural network has been developed and compared in terms of prediction accuracy [36].

METHODOLOGY

The ZnO-Ag hybrid nanoparticles are produced using the wet chemical process with a bottom-up approach [37]. This nanoparticle synthesis process was done in a two-step. Initially, the ZnO precursor is prepared with zinc nitrate. This ZnO prepared in the first step act as a precursor for the next step. Finally, ZnO-Ag is synthesized by calcination of the ZnO-Ag precursor at 500ºC. The systematic process is presented in the following paragraphs.

Synthesis and Characterization of Hybrid Nanoparticles

Initially, PVA-sucrose was mixed in the water and stirred for 24 hours in magnetic stirrer. After 24 hours, the PVA-sucrose water mixture was cooked up to 60-65°C, and then an aqueous state of zinc salt (0.2 M concentration) was added dropwise to the PVA-sucrose-water solution. By adding the NH_4OH, the balance hydrogen in $Zn2^+$ cations and the pH of the reaction mixture was kept constant at 9. The mixture was kept at 25°C for 24 hours after the reaction was completed before gently draining out the transparent and colorless top layer of the polyvinyl alcohol-sucrose. To get the white bulk of polymer-covered ZnO-precursor particles, the obtained solution was extensively rinsed with methanol and dried at a temperature of around 50°C -60°C. After heating up 400°C-500°C in the furnace up to 2 hours the precursor powder is converted into pure recrystallized ZnO nanoparticles.

Later, for the formulation of ZnO-Ag hybrid nanoparticles, the zinc oxide precursor was used in dried powder form and mixed with water (5 grams by weight). This solution was mixed with a water-mixed solution of silver nitrate with 0.25 M concentration stirred magnetically at 50°C - 60°C in dark conditions. The powders were recovered after 20-30 minutes of reaction by progressively draining off the $AgNO_3$ combination, washing in hot water, and dehydrating at 20-25°C under reduced pressure (10-100 mbar). After that, the dehydrated powders were heated in ambient

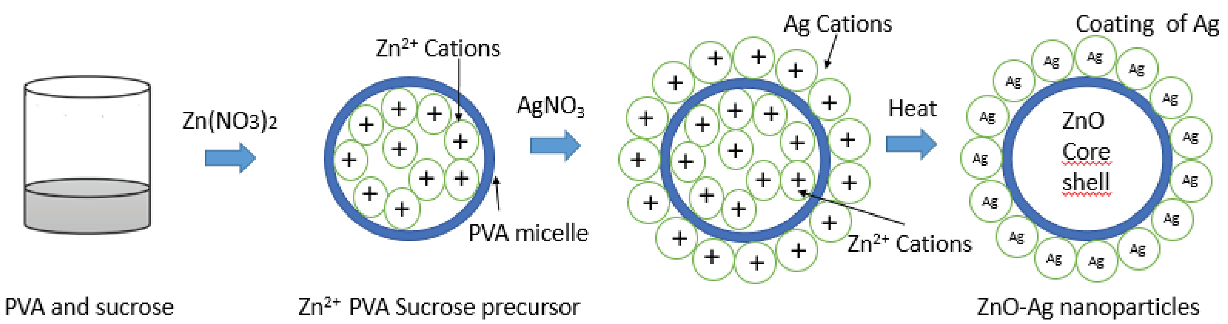

Figure 1. Schematic illustration of the fusion of ZnO-Ag hybrid nanoparticles [38].

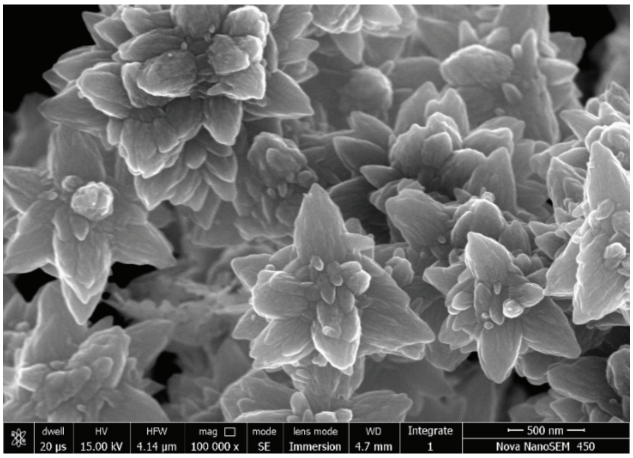

Figure 2. Microscopic image of ZnO-Ag hybrid nanoparticles.

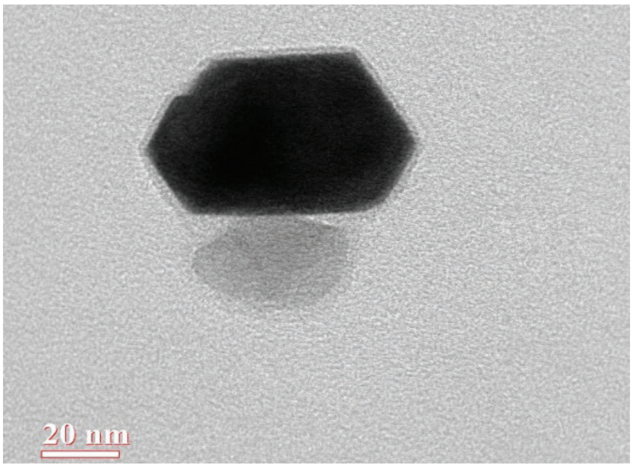

Figure 3. TEM images of ZnO-Ag hybrid nanoparticles [40].

air for 2 hours at 400°C-500°C. The resulting recrystallized zinc oxide nanoparticles are now capped with a thin and homogeneous Ag shell layer. Figure 1 shows a schematic representation of the manufacture of ZnO-Ag hybrid nanoparticles.

The characterization of the manufactured samples was done using SEM and TEM. The Figure 2 shows the SEM image of the prepared nanoparticles. It shows that flower petals like surface morphology of ZnO-Ag nanoparticles in the clustered form [39]. The prepared powder was also characterized for TEM analysis. A closer look at the particles using TEM indicates that the Ag ions create a homogeneous coating/layer on the periphery of the hexagonal ZnO nanoparticles (Figure 3). This Ag layer on ZnO helps to generate the uniform Brownian motion in all directions. This interface layer is the layering of the liquid at the solid interface in the suspension helps to increase the thermal transport mechanism as this layer is more ordered than bulk liquid like in crystalline solids which display more thermal conductivity than liquid. These nanoparticles have an average diameter of 40 nm, which is much greater than the estimated crystallite size from the X-ray diffraction (XRD) analysis depicted by Jadhav et al [40].

Preparation of Hybrid Nanoparticles-Based Vegetable Oil

Cutting fluids based on nanoparticles are typically created using either a one-step or two-step technique. To prepare the cutting fluid, two crucial components like base fluid and nanoparticle material are required. A variety of materials, including metals (Cu, Ag, Au), semiconductors (TiO_2, SiC), oxide ceramics (ZnO, SiO_2), carbide ceramics (SiC, TiC), and CNT are utilized to make the nanoparticles used in cutting fluid. The typical liquids include vegetable oil, ethylene glycol, and water [106].

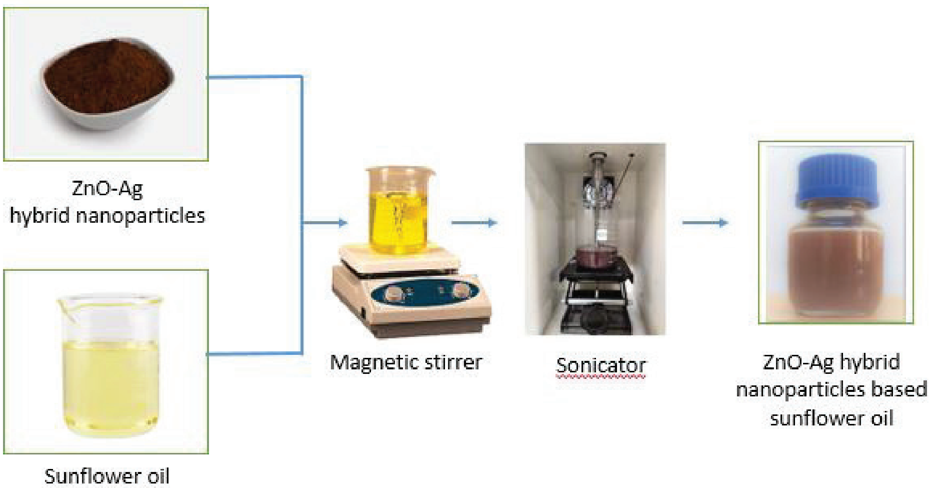

Figure 4. Systematic procedure of preparation of the hybrid nanoparticles based vegetable oil.

Table 2. Properties of sunflower oil

Oil	Sunflower
Kinematic viscosity	38.20 mm^{2s-1}
Viscosity index	205
Flash point	272 °C
Pour point	-15 °C
Thermal conductivity	0.168 $Wm^{-1}K^{-1}$

ZnO-Ag are dense nanoparticles due to higher density of Ag ions. The good stability of the highly dense particles is one challenge for preparing the cutting fluid. However, the % of Ag in ZnO-Ag hybrid nanoparticles is 6% by atomic weight. Taking evidence from the literature, the fluid prepared with the volume concentration varies form 0.05%, 0.10%, 0.15%, and 0.20%. In this study, the cutting fluid was prepared with sunflower oil as a base fluid by a two-step technique. The properties of the sunflower oil were mentioned in Table 2 [41]. Figure 4 shows the preparation of the cutting fluid at different volume concentrations.

Characterization of Hybrid Nanoparticles Based on Vegetable Oil

The prepared hybrid nanoparticles-based vegetable oil is characterized for thermal conductivity improvement. The stability of the hybrid nanoparticles in based fluid is also important for the good physical properties. The measurement of stability and thermal conductivity of the hybrid nanoparticles-based vegetable oil is presented in the following subsections.

Thermal Conductivity

The successful application of the hybrid nanoparticles-based vegetable oil in machining operation demands better cooling and thermo-physical characteristics. The thermo-physical characteristics of the coolant are based on the methods of synthesis, higher stability, improved cooling capacity and lower viscosity which decreases pumping requirements. Nanoparticles stability in a base fluid is influenced by their surface energy, Vander Waals forces, and Brownian motion [42,43]. A higher surface charge causes volatility and clustering of the nanoparticles, reducing the overall heat transfer capability of fluids [21].

Here, the effectiveness of hybrid nanoparticles-based vegetable oil was experimentally evaluated by using thermal analyzer (KD2 Pro, Decagon Device) with connection with a thermal bath. During measurement, the sensor needle (KS-1) in the KD2 Pro gadget was constructed of SS material and measured 60 mm in length and diameter 0.13 mm. A calibration was performed using evaluating the thermal conductivity of known fluids. The thermal conductivity of distilled water and glycerin were measured to be 0.63 $Wm^{-1}K^{-1}$ and 0.292 $Wm^{-1}K^{-1}$ respectively.

RESULTS AND DISCUSSION

This work investigates the influence of temperature and volume concentration of hybrid fluids on their viscosity, stability and thermal conductivities were explored. Then, based on results obtained through the experiments, an empirical correlation and ANN model for forecasting the thermal conductivity of hybrid nanoparticle-based sunflower oil was established.

Viscosity Measurement

Viscosity is the one the important property needs to evaluate for the cutting fluid. The fluid's resistance to deformation is evaluated by its viscosity. The viscosity of the fluids increases with the addition of nanoparticles into the basic fluid. The shape, size, volume percentage, and temperature of the nanofluid's. The goal of the current investigation is to investigate how temperature and nanoparticle concentration affect viscosity. Measurements of the viscosity of several known fluids, including glycerin and DI water, were used to calibrate the viscometer.

Figure 5 depicts the viscosity of ZnO-Ag at varying temperatures (45-75 °C). The viscosity of nanofluids increases with an increase in nanoparticle concentration in base fluids. However, the increases in temperature the dynamic viscosity of the nanofluid in decreases.

Stability

The stability of the hybrid nanoparticles-based vegetable oil is measured by zeta potential analyzer (Nano-ZS; Malvern Instrument). The zeta potential is an element of the electrophoresis theory, and it is the repulsion force between two particles in the same fluid that is used to stabilise colloidal suspensions. If this repulsive force outweighs Van der Waal's forces, the suspension of nanoparticles becomes

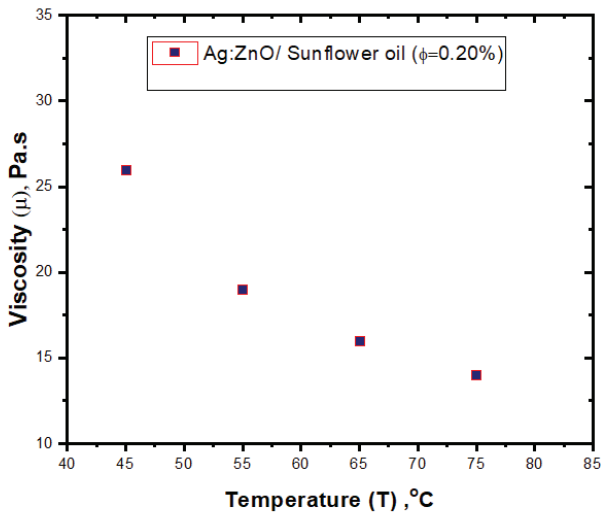

Figure 5. Viscosity of ZnO-Ag at varying temperature (45-75 °C).

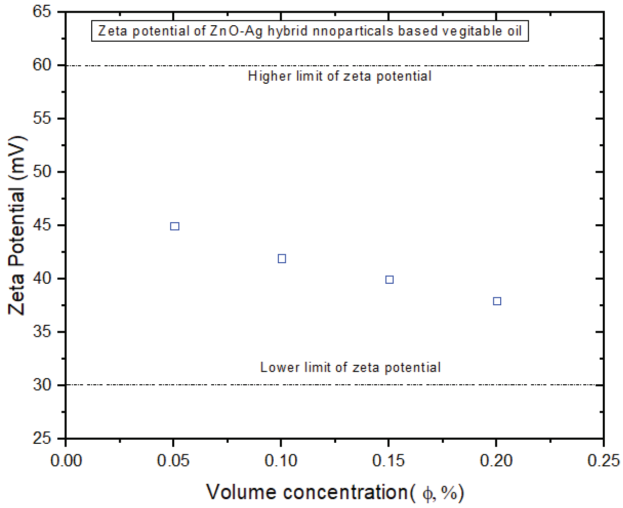

Figure 6. Zeta potential of ZnO-Ag hybrid nanoparticles-based sunflower oil.

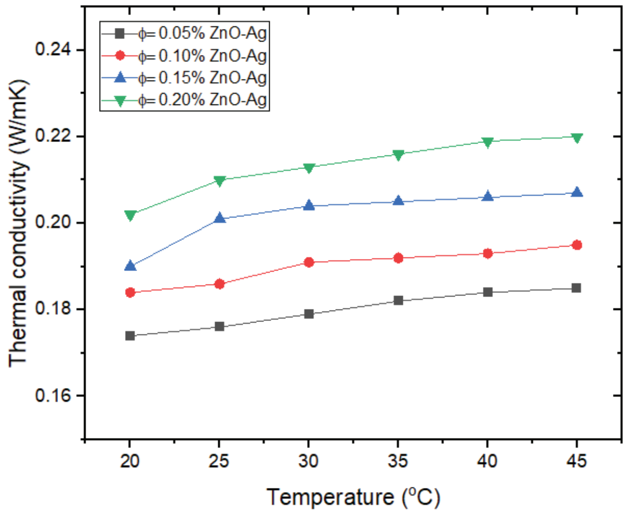

Figure 8. Thermal conductivity as a function of temperature and percentage of volume concentration.

more stable. Colloidal stability is reduced when the zeta potential is less than 30 mV. The experimental values of the zeta potential for variable concentrations (F= 0.05% to 0.20%) of ZnO-Ag based sunflower oil are shown in the Figure 6. It is observed that the absolute value of zeta potential falls between +/- 30 mV to +/- 60 mV. These values of zeta potential show the good dispersion of the ZnO-Ag nanoparticles in the base which makes the fluid stable.

Evaluating Thermal Conductivity

The thermal conductivity of ZnO-Ag hybrid nanoparticles-based sunflower oil was measured by a thermal analyzer. Figure 7 show the deviation of thermal conductivity of ZnO-Ag hybrid nanoparticles-based vegetable oil at 25°C.

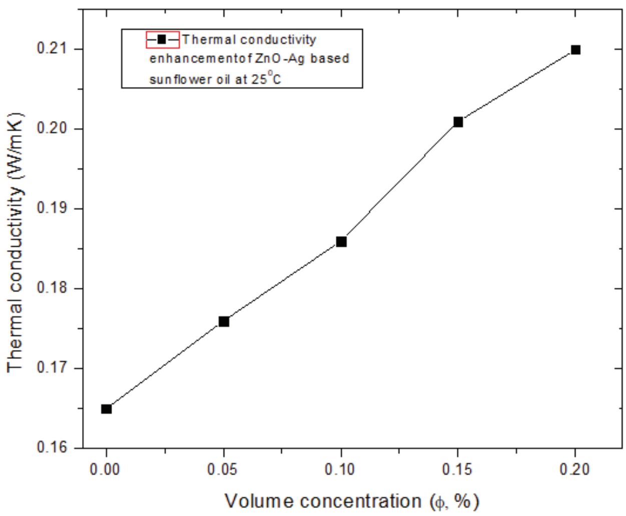

Figure 7. Variation of thermal conductivity of ZnO-Ag hybrid nanoparticles based sunflower oil at 25°C.

The thermal conductivity of ZnO-Ag hybrid nanoparticles based sunflower oil is found to be higher than sunflower oil for every concentration. The highest increase in the thermal conductivity is observed to be 21.01% in comparison with sunflower oil 25°C. The synthesis of hybrid nanoparticles by wet chemical technique allows the consistent coating of Ag nanoparticles ZnO micelle (Figure 3), resulting in improved nanoparticle stability. Higher conductivity of Ag coated ZnO nanoparticles increases the thermal conductivity of ZnO-Ag-based sunflower oil. The effect of the temperature changes with thermal conductivity at varying concentrations of ZnO-Ag hybrid nanoparticles-based vegetable oil is shown in Figure 8.

It was witnessed that the thermal conductivity of the ZnO-Ag hybrid nanoparticle-based sunflower oil increases with rise in temperature. Hybrid nanoparticles move more freely under the influence of Brownian motion as the temperature rises, increasing their thermal conductivity. The maximum thermal conductivity of the ZnO-Ag hybrid nanoparticles-based vegetable oil is found to be 22.5% at 45°C.

A Mathematical Model for Thermal Conductivity

Their ability to handle precise information has been a key factor in the increasing demand for soft computing methods, e.g., regression analysis curve fitting, response surface methodology, artificial neural network, genetic algorithm, fuzzy logic, adaptive neuro-fuzzy inference system, etc. Soft computing methods aim to predict the outcome with high accuracy based on known experimental results. It is mostly used in engineering applications to perceive the specific relation between experimental data and expected outcomes. Many researchers have usually preferred linear regression methods such as curve fitting to predict the model. For linear correlations, the mean of the dependent variable always changes by a predetermined amount when the independent variables rise by one unit. This relationship is valid for straightforward problems. But in the real world, thermal engineering problems are complex in nature which usually have nonlinear relationships. Besides, from the many non-linear regression analysis methods specifically an adaptive neuro-fuzzy inference system (ANFIS) and optimal artificial neural network (ANN) methods have shown better accuracy which makes them the best predictor method for thermal engineering problems [44]. Initially, mathematical model equation for the prediction of thermal conductivity of hybrid nanoparticles based sunflower oil was developed by a simple curve fitting method, later the ANN method was employed to develop the correlation for the getting better accuracy.

Curve Fitting

In this study, a correlation between thermal conductivity, the volume concentration of the nanoparticles, and the cutting fluid temperature has been deduced using a parabolic function. To develop a correlation showing great accuracy, several hit and trial scenarios were employed. Equation (1) represents the relationship obtained by curve fitting.

$$k_{nf} = 0.00081\,T + .051\,\emptyset + .0142 \tag{1}$$

The statistical indicator R-squared value predicted by the curve fitting model is 0.940. According to the principle of R-squared value, the value nearer to unity shows maximum accuracy. This deficiency in accuracy gives rise to the use of new and advanced methods developed to predict thermal conductivity.

ANN Model for Thermal Conductivity

The ANN model was created using the neural network function in MATLAB. The construction of popular neural network designs and their current engineering applications are covered by artificial neural networks. It is frequently used in mechanical engineering applications to detect a direct correlation between experimental and projected data. The ANN architecture contains 3 layers, namely, input, hidden and output (see, Figure 8). The experimental data was divided into three data sets including training, validation, and testing. Throughout each epoch, the model was trained to discover a broad trend amid the input and output factors. In addition to training, the model validated the data for each epoch. The data in the test set was used to assess the model's correctness once it has been trained and verified. For the model to be more realistic, a certain number of neurons and hidden layers must be chosen. The neural architecture cannot suit the right behavior of the input data if the number of hidden layers and neurons is too low, and the error is too large. The training process will be speed up and a local minimum will be reached if the network comprises too many neurons and hidden layers. As a result, for the best-fit model, choosing the right neurons and hidden layers is critical. Each architecture is made up of neurons that operate by Equation (2).

$$y_j = \sum_{i=1}^{p} (w_{ji}\, x_i + b_j) \tag{2}$$

Here p is the total number of input neurons, w_{ji} is the weight that corresponds to the relationship between neurons i and j, and b_j is the bias of the j neuron. The architecture's setting of w_{ij} yields the value y_j which represents the output neuron. The trial-and-error method is used to anticipate the optimal number of neurons in the hidden layer. The model was created using 90 experimental readings. To get a more experimental data set and decrease measurement error, several observations at the same concentration and temperature are obtained. This is done to avoid the model becoming overfit. In the instance of overfitting, the model accurately predicts the data in the training set but fails to do so for the data in the test set. The network was trained with 70% of the available data, 15% of the data was utilized for validation, and the remaining 15% was used for testing. The output layer's transfer function was chosen as a PURELIN which is a linear transfer function. Two distinct transfer functions, hyperbolic tangent sigmoid (TANSIG) and log sigmoid (LOGSIG), were used to identify the optimum performance for the hidden layers. The formula for the transfer functions utilized is shown in Eq. (3) to (5).

$$tansig\ (n) = \frac{2}{(1 + e^{-2n})} - 1 \tag{3}$$

$$radbas\ (n) = e^{-n^2} \tag{4}$$

$$purelin\ (n) = n \tag{5}$$

The various statistical indicator such as R-squared, mean squared error (MSE), and average absolute relative deviation (AARD) values are taken into consideration for to get the optimal model for thermal conductivity. The following is a list of the equations related to these parameters Eq. (6) to (8).

$$R\ squared = 1 - \frac{\left(\sum_{i=1}^{N} (k_{exp} - k_{predicted})_i\right)^2}{\left(\sum_{i=1}^{N} k_{exp})_i\right)^2} \tag{6}$$

$$MSE = \frac{1}{N}\left(\sum_{i=1}^{N} (k_{exp} - k_{predicted})_i\right)^2 \tag{7}$$

$$AARD\ \% = \frac{100}{N} \sum_{i=1}^{N} \left(\frac{|k_{exp} - k_{predicted}|}{k_{exp}}\right)_i \tag{8}$$

The trials with a single hidden layer are represented by cases 1 to 23 (Table 3). In the hidden layer, only a single neuron is initially included [case 1 to case 10]. Regardless of the transfer function, the R-square value is quite low in these circumstances. The value of R-squared improves as the number of neurons grows. The value of the R-square does not increase significantly when a certain number of neurons are added. An additional hidden layer can be added to overcome this problem. Even though the second hidden layer has fewer neurons, the R-squared increases significantly. The transfer functions were examined in all feasible combinations. The findings of TANSIG-TANSIG [case 11] and LOGSIG-LOGSIG [case 12] were quite accurate. The R-squared again improves when increases for TANSIG-TANSIG combination. For further neurons this transfer function combination were used. To improve the model's accuracy, the number of neurons was raised even further. The addition of neurons beyond instance 15 did not result in a substantial increase in R-squared or MSE values, like the case of the first hidden layer.

Different trials were taken on the ANN architecture. It is observed that case 21 (Table 3) shows the higher value of R-square (approaches to unity) and the lower values for MSE (approaches to zero). Hence, the optimal neural network architecture consists of 2 hidden layers of 15 neurons each with TANSIG and TANSIG transfer function. R-squared values for training data, testing data, and all data were found to be 0.988, 0.983, and 0.989 respectively, for the selected ANN design. Figure 9 displays the graphical depiction of the specified ANN model. It displays the number of hidden layers, the number of neurons in each hidden layer, and the distinct transfer functions applied to each layer. The MSE reduces and converges to its optimal value as the number of epochs (iterations) grows. At case 21 iterations, MSE was found to be 1.7704 E-06. This displays the ANN model's great accuracy.

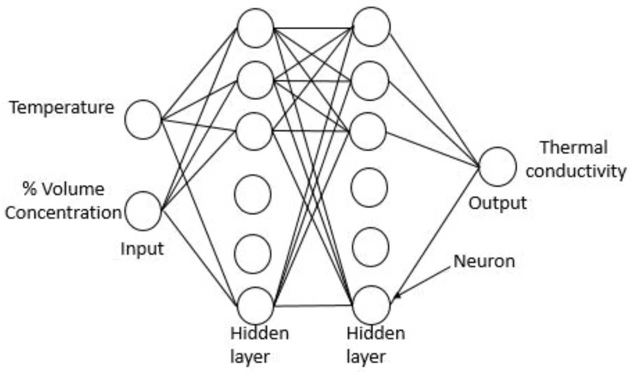

Figure 9. ANN architecture for prediction of thermal conductivity.

Table 3. Performance results of ANN network for different number of neurons in the hidden layer and different transfer functions for testing data set

Case	Layers	Transfer function		R Squared	MSE	MAPE
1	[1]	Tansig		0.909	1.5130 E-05	4.05
2	[1]	Logsig		0.893	1.4503 E-05	4.23
3	[3]	Tansig		0.912	1.54305 E-05	4.11
4	[3]	Logsig		0.901	1.8508 E-05	4.12
5	[5]	Tansig		0.919	1.5043 E-05	3.92
6	[5]	Logsig		0.908	1.8905 E-05	4.16
7	[7]	Tansig		0.926	1.6015 E-05	3.89
8	[7]	Logsig		0.912	1.9105 E-05	3.95
9	[9]	Tansig		0.928	1.2309 E-05	3.87
10	[9]	Logsig		0.922	1.2255 E-05	3.79
11	[1 1]	Tansig	Tansig	0.95	1.2235 E-05	2.56
12	[1 1]	Logsig	Logsig	0.94	1.2315 E-05	2.89
13	[2 2]	Tansig	Tansig	0.951	1.5505 E-05	2.51
14	[2 2]	Logsig	Logsig	0.939	1.0505 E-05	3.15
15	[5 5]	Tansig	Tansig	0.956	1.2305 E-05	2.89
16	[5 5]	Logsig	Logsig	0.942	1.1205 E-06	2.95
17	[7 7]	Tansig	Tansig	0.973	1.3205 E-06	2.12
18	[9 9]	Tansig	Tansig	0.974	1.5005 E-06	2.11
19	[11 11]	Tansig	Tansig	0.976	1.6125 E-06	1.89
20	[13 13]	Tansig	Tansig	0.981	1.7115 E-06	1.12
21	[15 15]	Tansig	Tansig	0.989	1.7705 E-06	0.61
22	[17 17]	Tansig	Tansig	0.989	1.7103 E-06	0.57
23	[19 19]	Tansig	Tansig	0.987	1.6907 E-06	0.56

Various iterations are displayed in Figure 10 along with the trend of changes in the MSE related to anticipated thermal conductivity values and the train, validation, and test data. The best outcome is then shown as the model output. According to the graph, the average error decreases to a minimum value as the number of weight change and bias repetitions increases. the MSE value is 0.0000017705 on iteration 3.

Figure 11 shows a difference of two models such as the correlation and the ANN, in terms of actual experimentation findings for experimental data. Mathematical and visual measurements show that ANN is more capable of accurately forecasting the thermal conductivity of nanofluids than the suggested curve fitting correlation. The ANN model's accuracy is unaffected by volume concentration or temperature.

Initially neural network model was trained using Levenberg-Marquardt backpropagation (LM) and generate the optimized model for the prediction of thermal conductivity. Later the dataset was trained by learning algorithms such as resilient backpropagation (RP), scaled conjugate gradient backpropagation (SCG) [37-38]. The comparison of ANN models was done among these two (PA and SCG) trainings algorithms with the optimized model generated by LM training algorithm. Table 4 shows the R- squared, MSE and MAPE values for various training algorithms. It was observed that, for MSE, the LM algorithm provided the least errors. For the R- squared, in comparison with SCG and RP training algorithms, the LM algorithm shows R-squared value closer to unity. For the MAPE values also the LM algorithm shows a low error in comparison with SCG and RP training algorithms.

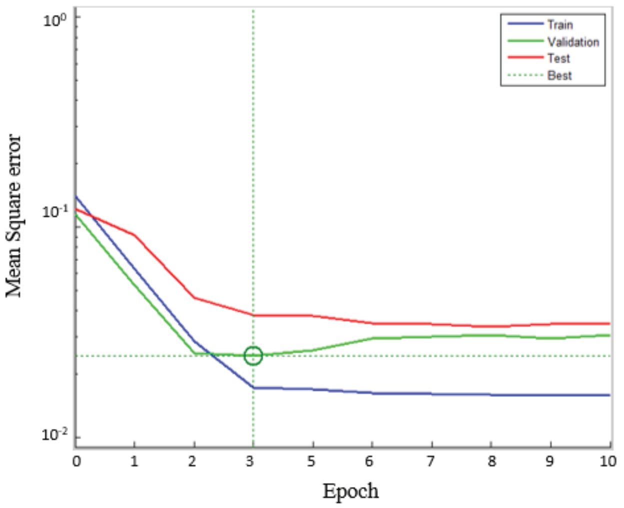

Figure 10. Thermal conductivity value by experimentation and ANN method.

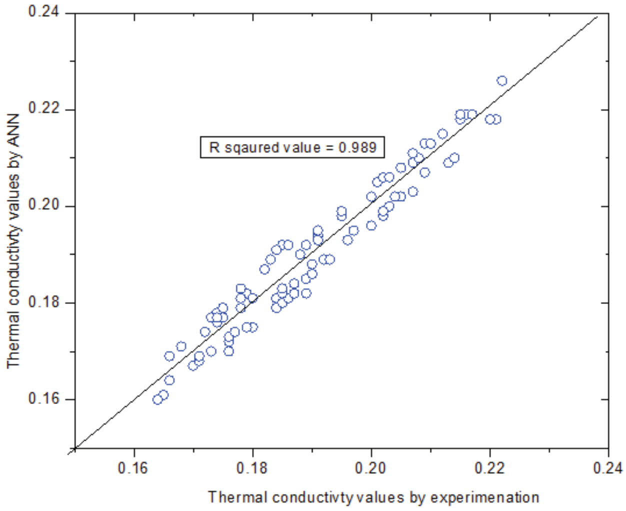

Figure 11. Thermal conductivity value by experimentation and ANN method.

Table 4. Statistical indicators performance for LM, SCG, and RP training algorithms

Algorithm	ANN model	transfer function used	R squared	MSE	MAPE
LM	[15 15]	[Tansig Tansig]	0.989	1.7705 E-06	0.61
	[17 17]	[Tansig Tansig]	0.989	1.7103 E-06	0.57
	[19 19]	[Tansig Tansig]	0.987	1.6907 E-06	0.56
SCG	[15 15]	[Tansig Tansig]	0.968	1.9043 E-05	1.24
	[17 17]	[Tansig Tansig]	0.975	1.9605 E-05	1.11
	[19 19]	[Tansig Tansig]	0.979	1.9235 E-05	1.09
RP	[15 15]	[Tansig Tansig]	0.91	2.2133 E-05	4.23
	[17 17]	[Tansig Tansig]	0.895	2.6141 E-06	4.51
	[19 19]	[Tansig Tansig]	0.856	2.4152 E-07	4.56

CONCLUSION

The current study aimed to synthesize and characterize a ZnO-Ag hybrid nanoparticles based sunflower nanofluid. The study investigated the thermal conductivity and stability of sunflower oil based nanofluids at different volume concentrations of ZnO-Ag nanoparticles. A correlation was established to forecast the thermal conductivity of the prepared nanofluids. Further, an ANN model is used for the prediction of the thermal conductivity of fluids. Finally, the accuracy of both models was compared.

The experiment results reveal that 21.01% augmentation in the thermal conductivity of ZnO-Ag-based sunflower oil at 0.2% volume concentration and 25°C temperature. This augmentation in thermal conductivity is attributed to the mixing of uniformly coated Ag ions on the ZnO nanoparticles in sunflower oil. The stability of the cutting fluid also adds to the enhancement in the thermal conductivity observed by the zeta potential values at different volume concentrations.

The established ANN model had 2 hidden layers and 15 neurons in each layer. The accuracy the confirmed by the R-squared value in higher order and the lowest MSE values in the lower order. The results reveal that the thermal conductivity prediction by ANN technique was more accurate and reliable than the correlation obtained by curve fitting technique. Further, the performance of Levenberg-Marquardt backpropagation training algorithm was superior to the resilient and scaled conjugate gradient algorithms.

ABBREVIATIONS

ANN	Artificial neural network
CNT	Carbon nanotubes
MBCF	Mineral oil-based cutting fluid
MSE	Mean square error
MQL	Minimum quantity lubrication
SEM	Scanning electron microscopy
TEM	Transmission electron microscopy
VBCF	Vegetable oil-based cutting fluid

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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