International Journal of Heat and Technology
Vol. 42, No. 3, June, 2024, pp. 786-794
Journal homepage: http://iieta.org/journals/ijht

# Experimental and ANN-Levenberg-Marquardt Predictions of the Thermophysical Properties of $CoFe_2O_4$/Water Nanofluids

M. Shameer Basha[1*], L. Syam Sundar[2]

[1] Department of Mechanical Engineering, College of Engineering, Qassim University, Buraidah 51452, Saudi Arabia
[2] Department of Mechanical Engineering, College of Engineering, Prince Mohammad Bin Fahd University, Al-Khobar 31952, Saudi Arabia

Corresponding Author Email: s.manjula@qu.edu.sa



https://doi.org/10.18280/ijht.420308

**Received:** 15 October 2023
**Revised:** 26 May 2024
**Accepted:** 13 June 2024
**Available online:** 27 June 2024

***Keywords:***
*particle size, neural networks, nanoparticles, nanofluids*

**ABSTRACT**

This paper explains about the determination of thermal conductivity, viscosity, density, and specific heat of water dispersed $CoFe_2O_4$ nanofluids experimentally. The obtained data was undergone with ANN-Levenberg-Marquardt algorithm. The utilized $CoFe_2O_4$ nanoparticles were synthesized through the chemical coprecipitation method. The obtained $CoFe_2O_4$ nanoparticles were characterized with different techniques. The properties were measured under 20℃ to 60℃, and under 0.25% to 1.25% vol, respectively. The experimental results show, under the particle volume loading of 1.25%, the thermal conductivity value was raised by 27.56% at a temperature of 60℃, and the viscosity was increased by 49.36% at a temperature of 20℃, over the base fluid. Likewise, the density of nanofluids were increased and the specific heat of nanofluids were falls down over the base fluid. Results were also showing, the utilized ANN-Levenberg-Marquardt algorithm has good agreement with the obtained data. Based on Levenberg-Marquardt, the $R^2$ coefficient of thermal conductivity, viscosity, density, and specific heat values are 0.99802, 0.99217, 0.98684, and 0.99948, respectively.

## 1. INTRODUCTION

Nanofluids [1] are used in thermal applications because they have better thermal characteristics than basic fluids (water, EG, and etc). By combining several nanoparticles, including $Al_2O_3$, CuO, CNT, $Co_3O_4$, graphene oxide, $Fe_2O_3$, $Fe_3O_4$, $Mn_3O_4$, and others, one can create nanofluids. Rotating shaft seals, solar collectors, magneto-caloric pumps, shock absorbers, micro-fluidic pumps, heat pipes, bearing lubrication, liquid crystal doping, and electronic cooling are just a few of the promising uses for magnetic nanofluids. Typically, the magnetic nanoparticles like $Fe_2O_3$, $Fe_3O_4$, Ni, CoO, and $Co_3O_4$ are used to prepare the magnetic nanofluids and those are known as magnetic nanofluids or ferrofluids.

The following lists the nanofluids viscosity and thermal conductivity. $Al_2O_3$ nanofluids were generated by Chiam et al. [2] taking into account 40:60, 50:50, and 60:40 W/EG at various volume ratios. The thermal conductivity and dynamic viscosity were studied in the temperature range of 30 to 70℃, with a volume concentration of 0.2-1.0%. In addition to seeing an average dynamic viscosity enhancement of up to 50% for 60:40 (W/EG), they obtained thermal conductivity enhancement of three base ratios varying from 2.6 to 12.8%.

The impact of anionic (Sodium dodecyl sulfate, SDS) and nonionic (Polyvinyl pyrrolidone, PVP) dispersants on the thermal conductivity and stability of copper oxide (CuO) water-based nanofluids was examined by Pavithra et al. [3]. Additionally, the CuO nanoparticles were described using the following methods: XRD, EDX, FESEM, TEM, DLS, and UV. According to the results, PVP-based nanofluids outperform SDS dispersants in terms of stability. At 0.4 weight percent of SDS and PVP dispersants, the augmentation of thermal conductivity was found to be 38% and 34%, respectively.

Omiddezyani et al. [4] prepared $CoFe_2O_4$/rGO@water nanofluid by using Gallic acid as a surfactant, and hey measured thermal conductivity and Nusselt number. They found thermal conductivity ratio of $CoFe_2O_4$/rGO with 0.9 wt.% nanofluid by using Gallic acid as a surfactant, and hey measured thermal conductivity and Nusselt number., and Nusselt number enhancement of 27.8% at 0.9 wt% and at a Reynolds number of 1713. From experimental values of $Fe_3O_4$/water nanofluids, Parekh and Lee [5] have seen thermal conductivity raise by 30% at 4.7 vol% over base fluid data.

Elbeshir [6] prepared the $CoFe_2O_4$ magnetic nanoparticles through coprecipitation method from ferrous and ferric solutions, and found the average lattice parameter and the average size of $CoFe_2O_4$ were $a$ = 8.4 Å and t = 13 nm, and maximum magnetic field (H) of 9000 (Oe). Kharat et al. [7] prepared $CoFe_2O_4$/ethylene glycol nanofluid and studied the thermal conductivity with effect of magnetic field. They observed, thermal conductivity of 0.2%, 0.4%, 0.6%, 0.8%, and 1% at 0 G to 50 G and at 150 G were increasing from 0.269 W/m K, 0.278 W/m K, and 0.280 W/m K respectively. Abareshi et al. [8] found thermal conductivity augment by 11.5% under 3 vol%, over 40℃, their studied indicates by the mixing of $Fe_3O_4$ nanoparticles, the thermal conductivity is enhanced. Aguilar et al. [9] prepared $CuFe_2O_4$/water nanofluid and found at 363 K, the relative thermal conductivity enhancement of 68.5%, and also found efficiency enhancement of 35% when they flow in a concentrated solar plant.

Based on the Sundar et al. [10] observations, the thermal conductivity $(k_{nf})$ of water based $Fe_3O_4$ nanofluids is raised by 25%, and the viscosity is raised by 48% at 60℃, and at 20℃ at a volume concentration of 2%, respectively. For the case of $Fe_3O_4$/water nanofluids, Bahiraeim and Hangi [11] found thermal conductivity $(k_{nf})$ raise of 11.5% at a volume concentration of 3%, and at a temperature of 40°C. The studied have indicates that the mixing of $Fe_3O_4$ nanoparticles in the base fluid causes an enhancement in thermal conductivity.

Since, the $Fe_3O_4$ nanoparticles are magnetic nanoparticles and hence the prepared nanofluids are also called as ferrofluids. There are few reports available in the open literature on this topic. By increasing the magnetic field from 0.05 Tesla to 0.1 Tesla, Altan et al. [12] noticed thermal conductivity $(k_{nf})$ raise from 1.93% to 5.2% at a weight concentration of 1.63% of water dispersed $Fe_3O_4$ nanofluids. So, $k_{nf}$ is also depends on the applied magnetic field. By applying the magnetic field of 300 Gauss at a volume loading of 0.6% of $Fe_2O_3$/water nanofluid, Nurdin et al. [13] found thermal conductivity enhancement of 39%. Moreover, the similar results were found by Gavili et al. [14] under field of 1000 Gauss, and noticed $k_{nf}$ raise of 200% at a volume concentration of 5% of $Fe_3O_4$/water nanofluids. Above studies reveals that the addition of nanoparticles, temperature, and the magnetic field, the thermal conductivity of nanofluids have been increased.

Kim and Peterson [15] observed 37% thermal conductivity $(k_{nf})$ augmentation with 1.0% volume concentration of CNT/water nanofluids. Wen and Ding [16] observed high $k_{nf}$ of CNT/water nanofluids with an increased temperature from 60-70°C. Li and Nakayama [17] have observed an enhanced alumina-water nanofluid thermophysical properties and for the evaluation of laminar forced-convective heat transfer coefficient and observed an enhanced thermophysical properties. Di Nicola et al. [18] have analyzed experimental thermal conductivity of organic liquids and predicted with multilayer perceptron proposed ANN and observed the artificial neural network reproduces the selected data with an average absolute deviation of 3.5%.

Agarwal et al. [19] conduced thermal conductivity experiments for $Fe_2O_3$/water and $Fe_2O_3$/EG nanofluids and observed $k_{nf}$ enhancement of 16.45% and 19.76% for $Fe_2O_3$/water and $Fe_2O_3$/ethylene glycol nanofluids at 2 vol.% at 70℃ compared to water and ethylene glycol. They also used ANN approach to predict the experimental data and observed that the ANN results are good agreement with experimental results. The ANN results of Rostami et al. [20] for MWCNT/water nanofluids for $k_{nf}$ giving root mean square accuracy of 0.972 with a correlation coefficient of 0.993, when predicted with experimental thermal conductivity. Moreover, the study of Hemmat Esfe et al. [21] reveals, the ANN $k_{nf}$ data of 5% MgO/EG nanofluids provides a maximum absolute error of 0.003, whereas, they also observed maximum $k_{nf}$ raise of 10% over base fluid. Sundar et al. [22] noticed very good agreement of $k_{nf}$ experimental values with ANFIS algorithm data.

The transition metal oxide based $CoFe_2O_4$ (cobalt ferrite) magnetic nanofluids are widely used in variety of applications. The viscosity $(\mu_{nf})$ property of water based $CoFe_2O_4$ magnetic nanofluids was studied by Chand et al. [23] and they noticed that, the $\mu_{nf}$ of nanofluids prepared by small size nanoparticles are producing larger $\mu_{nf}$ than the nanofluids prepared by higher size nanoparticles. They also noticed that by increasing the magnetic field, the viscosity is increased. Djurek et al. [24] studied the $k_{nf}$ of water and n-decane mixture $CoFe_2O_4$ nanofluids and observed external magnetic field is also one of the influencing parameters on $k_{nf}$ values.

The goal of the current research is to experimentally assess the thermophysical characteristics, such as $k_{nf}$ and $\mu_{nf}$, in relation to particle volume loadings, and temperatures. Co-precipitation was used to create the $CoFe_2O_4$ (cobalt ferrite) nanoparticles, which were then examined with X-ray diffraction (XRD), transmission electronic microscopy (TEM), and vibration sample magnetometer (VSM). $CoFe_2O_4$ nanofluids based on water were prepared and used for analysis. The generated data is verified against different types of nanofluids data. In order to forecast thermal conductivity and viscosity an empirical correlation was presented. The experimentally determined thermal conductivity and viscosity values are compared with the literature values.

## 2. EXPERIMENTAL SECTION

Purchased from Merck, India, Co $(NO_3)_2 6H_2O$ (99.9%), Fe $(NO_3)_3$ $9H_2O$ (99.9%), and $NH_4OH$ (99.9%) were used without additional purification. The $CoFe_2O_4$ nanoparticles were synthesized at atmospheric temperature. The nanoparticles were synthesized by using chemical co-precipitation method. To avoid the increase of the size of the nanoparticles with influence of temperature, the nanoparticles were synthesized under atmospheric temperature. Using 1:2 weight concentration ratio, the ferric nitrate, and cobalt nitrate were dissolved in distilled water and stirred continuously for 45 minutes. After that, the water diluted $NH_4OH$ was added slowly to the above solution and maintain the solution pH of 10 and continue the stirring process. The time taken to complete the reaction was 30 mins, and it was observed the formation of black-colored precursor. The black color product was cleaned larger times with water and then divided with centrifuge, and cleaned over 70℃ and for 10 hrs. This procedure was repeated several times in order to obtain the large quantity of nanoparticles.

The X-ray diffraction patterns (XRD) of hybrid nanoparticles was observed from the Phillips X'PERT PRO instrument with $CuK_\alpha$ radiation source and also characterized with JEOL 2010 (200kV) high-resolution Transmission Electron Microscope. Vibrating sample magnetometer, Cryogenic, UK, was used to examine the sample's magnetic measurement. Figure 1(a) displays the produced $CoFe_2O_4$ nanoparticles' X-ray diffraction patterns (a). It was noted that the XRD spectra of the $CoFe_2O_4$ [JCPDS 22-1086] showed diffraction peaks. There was no impurity phase and only pure, single-phase $CoFe_2O_4$ was seen to develop. The synthesized $CoFe_2O_4$ was found to have 8.37 Å, which were matches to the original value of 8.39 Å for $CoFe_2O_4$ nanoparticles. For $CoFe_2O_4$, the corresponding 2θ angles are 30.07°, 35.47°, 36.98°, 43.14°, 53.41°, 56.35°, and 62.59°, respectively, while the distinctive peaks are (220), (311), (222), (400), (422), (511), and (440). From Scherrer's formula ($d=0.9\lambda/\beta\cos\theta$)

under the peak (311), the particle size of $CoFe_2O_4$ was determined around 38.32 nm. From the Figure 1(b) of HRTEM, the particle size was approximated by 39 nm.

With an applied field of 15,000 Oe, room temperature magnetization of the produced $CoFe_2O_4$ nanoparticles was evaluated using VSM (Figure 1(c)). For the sample, ferromagnetic behavior was seen. The Ms of $CoFe_2O_4$ was analyzed to be 91.12 emu/g and a coercivity (Hc) of 9.441 Oe. These values are comparable to those reported by other writers [25] who used various preparation methods.

## 2.1 Preparation of nanofluids

The stable $CoFe_2O_4$/water nanofluids were made by dispersing $CoFe_2O_4$ nanoparticles in water. Also used as a surfactant is 9 ml of 26% tetramethylammonium hydroxide to produce homogeneous and stable combination nanofluids. Loadings of 0.25%, 0.5%, 0.75%, 1.00% and 1.25 vol.% with mixing of 0.262, 0.526, 0.792, 1.05, and 1.326 g into 20 g of distilled water, the nanofluids were developed, respectively. The density of $CoFe_2O_4$ nanoparticles considered as 5230 kg/m$^3$.

The prepared water mixed $CoFe_2O_4$ nanofluids stability was checked with Malvern Instruments' ZetaSizer nano ZS. The stable $CoFe_2O_4$/water nanofluids were made by dispersing $CoFe_2O_4$ nanoparticles in water. Also used as a surfactant is 8 ml of 25% tetramethylammonium hydroxide to produce homogeneous and stable combination nanofluids.

The surfactant in the base fluid attracts the nanoparticles, giving them a positive or negative charge. Both the benefits and drawbacks of the findings are considered for comprehension. The following zeta potentials were measured: -43.3, -42.8, -41.2, -40.2, and -38.7 mV, in that order.

## 2.2 Thermal conductivity of nanofluids

With an accuracy of 3.5%, the $CoFe_2O_4$/water hybrid nanofluids were examined using the Decagon devices, USA, KD-2 pro instrument KS-1 sensor. The sensor needle made of stainless-steel measures 60 mm in length and 1.3 mm in diameter. The apparatus has coils for heating and thermistorization. At 20 to 60°C, the $k_{nf}$ was computed. The $k_{nf}$ was measured five times, and the final values were derived from the average results.

## 2.3 Viscosity of nanofluids

With a 3.5% margin of error, the $\mu_{nf}$ of samples of nanofluid was analyzed using an AND Vibro-Viscometer (SV-10, Japan). Water bath is used to regulate the temperature of hybrid nanofluid samples. When the instrument is turned on, the $CoFe_2O_4$/water nanofluids sample immersed in gold-plates for movement, and the response signal is shown on the display screen. The two plates with gold coatings were vertically dipped with the sample. The temperature range used to measure the viscosity of nanofluids was 20°C to 60°C. Every sample underwent five tests, with the average results serving as the ultimate measurement.

## 2.4 Density of nanofluids

The Archimedes principle was used to calculate the $\rho_{nf}$ of $CoFe_2O_4$/water nanofluids. Its $\rho_{nf}$ is determined using the fluid volume that is known. Density is equal to mv. The weight of the 20 ml of nanofluid added to an empty 50 ml beaker at 20°C is then measured using an advanced weighing machine with a 0.001 mg precision to find the $\rho_{nf}$.

## 2.5 Specific heat nanofluids

A scanning calorimeter with a refrigerated cooling system (DSC 2920 modified, TA Instruments, USA) was used to determine the specific heat of $CoFe_2O_4$/water nanofluids. A universal analysis program (TA Instruments, Version 4.1D) was used to analyze the data. Indium was used to compute the cell constant, and indium, tin, and water were used to confirm the enthalpy calculations. Before using the nanofluid samples, the sample pan was cleaned for fifteen minutes using acetone and methanol. An aluminum pan contained the nanofluid sample (10 mg). To calculate the $C_{p,nf}$ a temperature differential of 10°C between 20°C and 60°C was utilized.

## 2.6 Artificial neural network

The evaluated properties of $CoFe_2O_4$/water nanofluid should be predicted in the current investigation using $\phi$ and $T$ as input parameters. The temperature is monitored as 20°C to 60°C and $\phi$ from 0.25% to 1.25%, respectively. The mathematical model of neurons is given in Eq. (1).

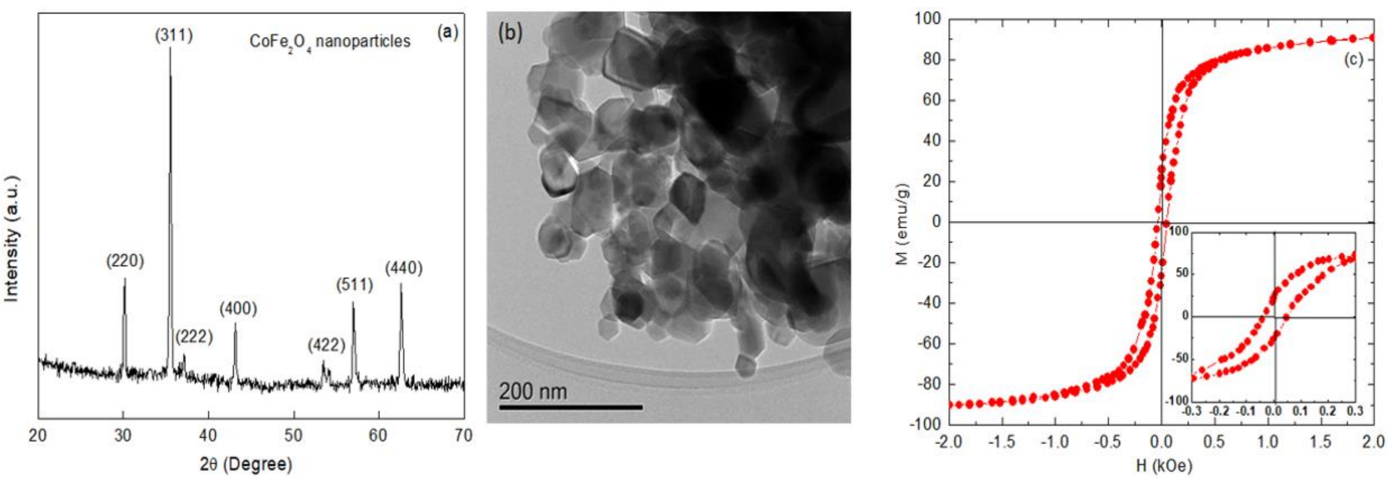


**Figure 1.** Prepared $CoFe_2O_4$: (a) XRD spectra, (b) TEM image, and (c) VSM magnetization curve

$$Y_j = f\left(\sum_{i=1}^{n} W_{j,i}x_i + b_j\right) \quad (1)$$

$$f(x) = \frac{1}{1 + exp(-x)} \quad (2)$$

$$purelin\ (x) = x \quad (3)$$

2.6.1 Levemberg-Marquardt algorithm

It was first developed by Kenneth Levenberg in the 1940s. For the case of non-linear parameters, Donald Marquardt in 1963 was used.

$$r_i = y_i - Y_i \quad (4)$$

Then $Y$ is $[x_1, x_2 \ldots\ldots\ldots\ldots . x_n]$ values, the $r$ Jacobean (Eq. (5)):

$$J(X) = \begin{bmatrix} \frac{\partial r_1}{\partial x_1}(X) & \frac{\partial r_1}{\partial x_1}(X) & & \frac{\partial r_1}{\partial x_1}(X) \\ \frac{\partial r_1}{\partial x_1}(X) & \frac{\partial r_1}{\partial x_1}(X) & \vdots\ \vdots\ \vdots & \frac{\partial r_1}{\partial x_1}(X) \\ \vdots & \vdots & \cdot\ \cdot\ \cdot & \vdots \\ \frac{\partial r_1}{\partial x_1}(X) & \frac{\partial r_1}{\partial x_1}(X) & & \frac{\partial r_1}{\partial x_1}(X) \end{bmatrix} \quad (5)$$

$X^{(k+1)}$, the Eq. (6) is obtained:

$$X^{(k+1)} = X^{(k)} + \Delta X^{(k)} \quad (6)$$

where, $\Delta X^{(k)}$ can be obtained by Eq. (7):

$$(J^T(X).J(X) + \mu l)\Delta X^{(k)} = -J^T(X).r(X) \quad (7)$$

## 3. RESULTS AND DISCUSSION

### 3.1 Thermal conductivity of nanofluids

According to particle volume loadings and temperatures, the $CoFe_2O_4$/water nanofluids' acquired thermal conductivity is shown in Figure 2(a). According to the graph, as temperatures and particle volume loadings increase, nanofluids' thermal conductivity increases. When, 0.25%, 0.5%, 0.75%, 1.0%, and 1.25% vol. are diluted in water at 20°C, the $k_{nf}$ is raised to 7.8%, 8.3%, 9.96%, 12.12% and 14.45%, whereas at 60°C, the $k_{nf}$ is raised to 12%, 15.73%, 20%, 24.34%, and 27.56%, respectively.

The data available for various kinds of nanofluids are used to compare the thermal conductivity of the current nanofluids. It's beneficial to compile a list of logical justifications. It might be caused by variations in nanoparticle size, shape, and distribution. In Figure 2(b), the $CoFe_2O_4$/water nanofluids thermal conductivity ratio from the current work is compared to that of $Fe_3O_4$/water from Parekh and Lee [5] and $Fe_3O_4$/water from Abareshi et al. [8]. The highest volume concentration in this investigation is 1.25%, while Abareshi et al. [8] and Parekh and Lee [5] employed larger maximum particle volumes of 3% and 4.7%, respectively. While $Fe_3O_4$ nanoparticles were utilized by Parekh and Lee [5] and Abareshi et al. [8] for the synthesis of nanofluids, $CoFe_2O_4$ nanoparticles were also used in the current analysis. The current study's $k_r$ =1.25 at $\phi$=1.25% and 60°C, however Abareshi et al. [8] obtained $k_r$ data of 1.156 at $\phi$=3.0% of $Fe_3O_4$/water and at 45°C, and Parekh and Lee [5] observed $k_r$ data of 1.221 at $\phi$=4.7% of $Fe_3O_4$/water and at 75°C. Compared to the $Fe_3O_4$ nanofluids, the $k_r$ is greater.

### 3.2 Viscosity of nanofluids

$CoFe_2O_4$/water measured viscosity is plotted in Figure 3(a). It's interesting to note that rise of viscosity values, yet at temperatures over 60°C. The $\mu_{nf}$ values steadily decline. The friction factor and pumping power rise as $\mu_{nf}$ increases. The $\mu_{nf}$ rise of 0.25%, 0.5%, 0.75%, 1.0% and 1.25% vol. of nanofluid is 21.51%, 27.84%, 34.17%, 43.03% and 49.36% at 20°C; however, the $\mu_{nf}$ augment is 8.33%, 16.66%, 25%, 33.33%, and 41.66% at 60°C, over the base fluid.

The present study $CoFe_2O_4$/water nanofluids viscosity ratio is provided in Figure 3(b) in comparison with Duangthongsuk and Wongwises [26] of $TiO_2$ nanofluid and Wilk et al. [27] of Cu nanofluid. Figure indicates the study offers viscosity ratio raise than the literature values. Duangthongsuk and Wongwises [26] used particle volume loading of 2% for the preparation of $TiO_2$/water nanofluid and Wilk et al. [27] used particle volume concentration of 0.101%, whereas, at the present analysis, particle volume loading of 1.25%, and the base fluid is same. The viscosity ratio is higher for $CoFe_2O_4$/water nanofluids than $TiO_2$ and Cu nanofluids because the $CoFe_2O_4$ offers higher resistance in the base fluid.

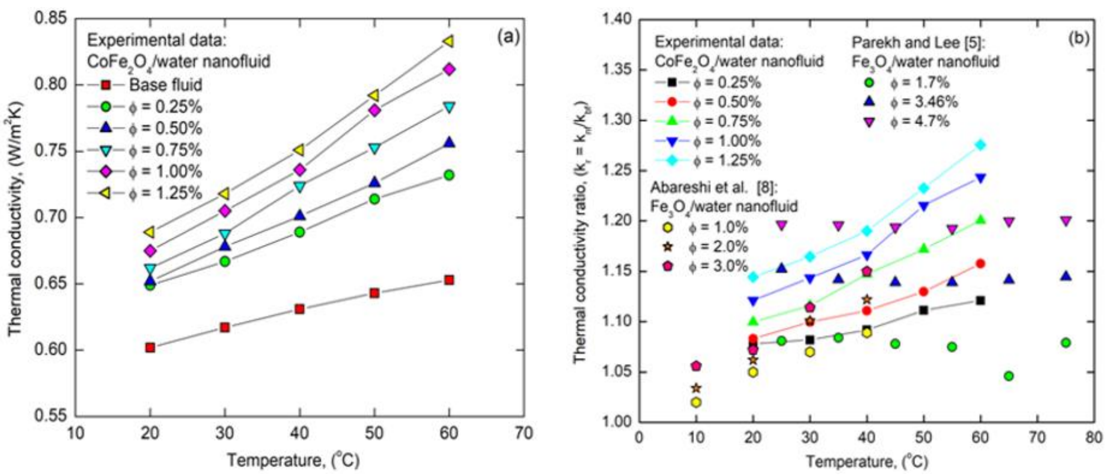


**Figure 2.** (a) Experimental $k_{nf}$ of $CoFe_2O_4$/water nanofluid and (b) $k_r$ is compared with Abareshi et al. [8] and Parekh and Lee [5]

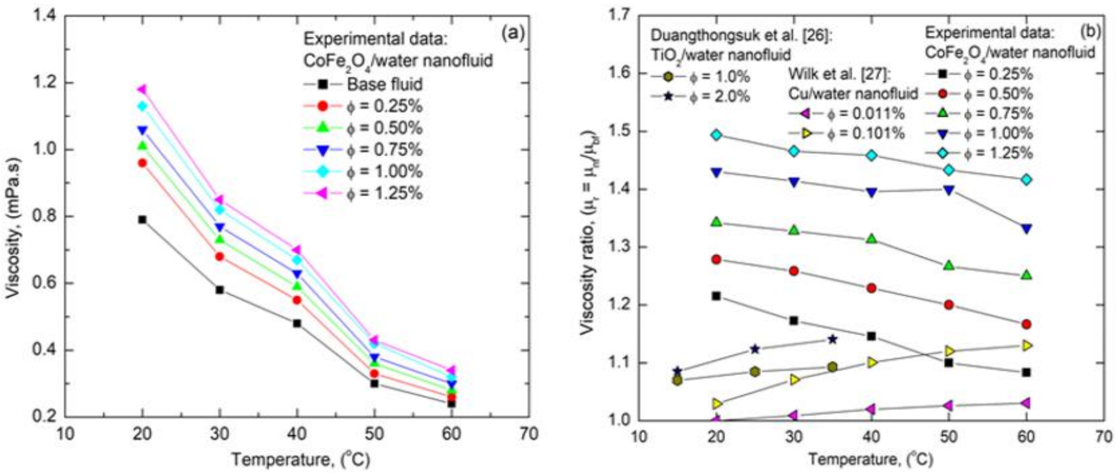


**Figure 3.** (a) Experimental $\mu_{nf}$ of $CoFe_2O_4$/water nanofluid and (b) $\mu_r$ is compared with Duangthongsuk and Wongwises [26] and Wilk et al. [27]

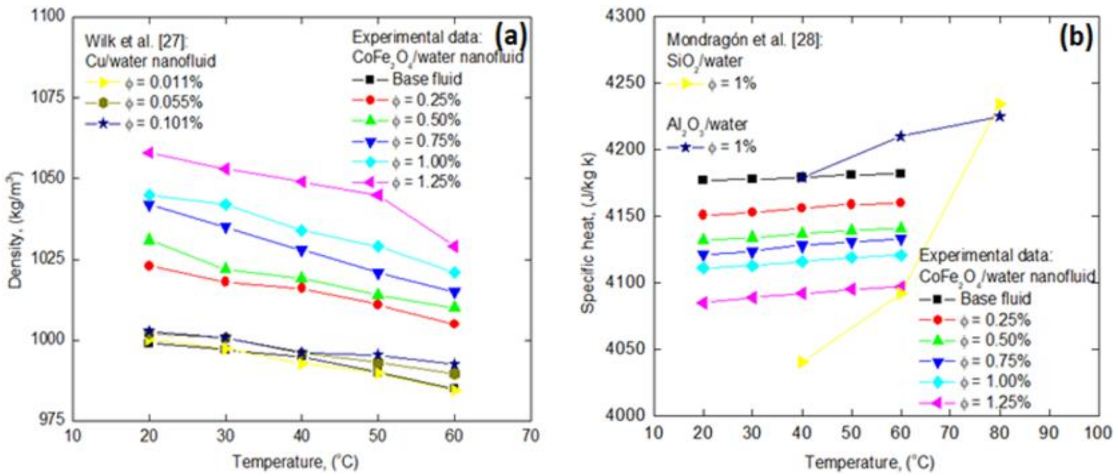


**Figure 4.** (a) Density of nanofluids, and (b) specific heat of nanofluids

### 3.3 Density and heat of nanofluids

The $\rho_{nf}$ variation of the $CoFe_2O_4$/water nanofluid at various T and $\phi$ and the values are presented in Figure 4(a). The $\rho_w$ is raised from 1000 to 1059 kg/m$^3$ at 20°C for the case of 1.25% vol. which is also raised from 986 to 1030 at 60°C. Wilk et al. [27] also seen the same trend. Figure 4(b) presented the calculated $C_p$ of nanofluids. It's interesting to note that at values, nanofluids offer lower $C_p$ values than water. However, the $C_p$ also increases with increasing values. Additionally, when the temperature rises, the $C_p$ of each sample rises. In other words, as a fluid warms up, the molecules' kinetic energy rises, causing them to vibrate and increasing the fluid's capacity to store energy. $Al_2O_3$/water and $SiO_2$/water nanofluids have been observed by Mondragón et al. [28] to have the same character. The $C_{p,nf}$ is lowered from 4178 to 4086 J/kg K at 20°C and at 1.25% vol., which is also lowered from 4183 to 4099 J/kg K at 60°C.

### 3.4 ANN performance

All the $k_{nf}$ data is 30 points in which 20 were used for training, 5 for testing and 5 for validation. The gradient is 8.6559e-9 at epoch 14 (Figure 5(a)), and the best performance results are 8.8457e-05 at epoch of 12 (Figure 5(b)). The error value seen in 0.0005, through the histograms (Figure 5(c)). The $R^2$ values were 0.99998, 0.98939, 0.99726, and 0.99802, and the MSE is 0.00341761 (Figure 5(d)).

All the $\mu_{nf}$ data is 30 points in which 20 were used for training, 5 for testing and 5 for validation. The gradient is 0.00012595 at epoch 11 (Figure 6(a)), and the prefer values are 0.007518 at 5 epoches (Figure 6(b)). Deviation values seen in 0.0053, through the histograms (Figure 6(c)). The $R^2$ values were 0.99903, 0.99367, 0.99929, and 0.99217, respectively, and MSE is 0.0783499 (Figure 6(d)).

All the $\rho_{nf}$ data is 30 points in which 20 were used for training, 5 for testing and 5 for validation. The gradient is 0.2022 at epoch 14 (Figure 7(a)), and the best performance results are 13.3773 at epoch of 8 (Figure 7(b)). The error value seen in 0.1406, through the histograms (Figure 7(c)). The $R^2$ values are 0.99831, 0.99227, 0.9895, and 0.9868, respectively (Figure 7(d)). The MSE is 0.0783499.

All the $C_{p,nf}$ data is 30 points in which 20 were used for training, 5 for testing and 5 for validation. The gradient is 1.4186e-11 at epoch 10 (Figure 8(a)), and the best performance results are 2.8278 at epoch of 5 (Figure 8(b)). The error value seen in 0.0396, through the histograms (Figure 8(c)). The $R^2$ values are 0.99903, 0.99367, 0.99929, and 0.99217 (Figure 8(d)). The MSE is 0.0396.

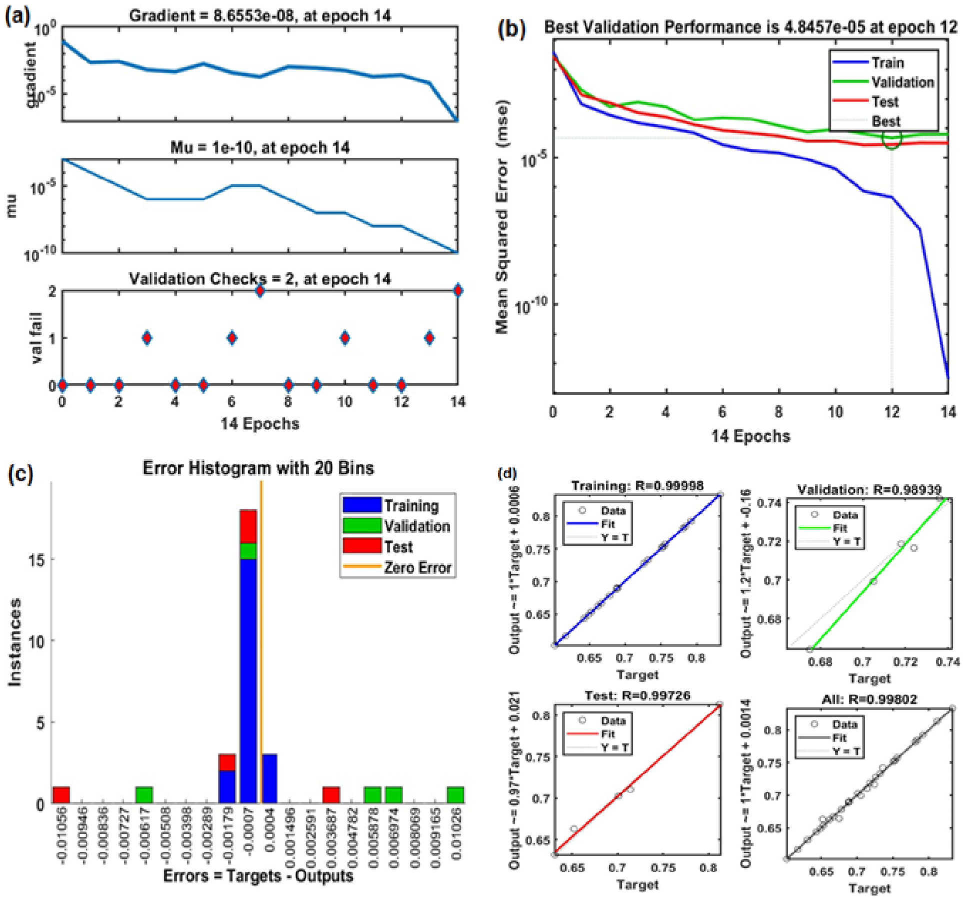


**Figure 5.** ANN thermal conductivity results: (a) gradients, (b) performance curve, (c) deviation histograms, and (d) $R^2$

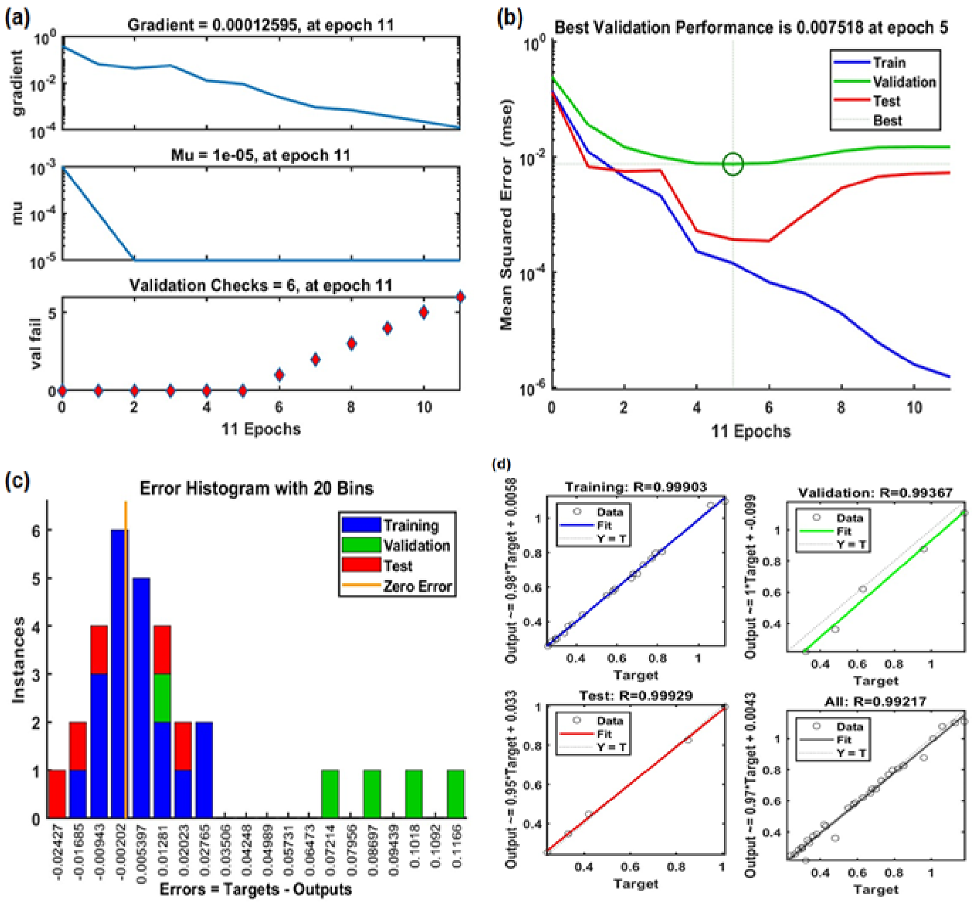


**Figure 6.** ANN viscosity results: (a) gradients, (b) performance curve, (c) deviation histograms, and (d) $R^2$

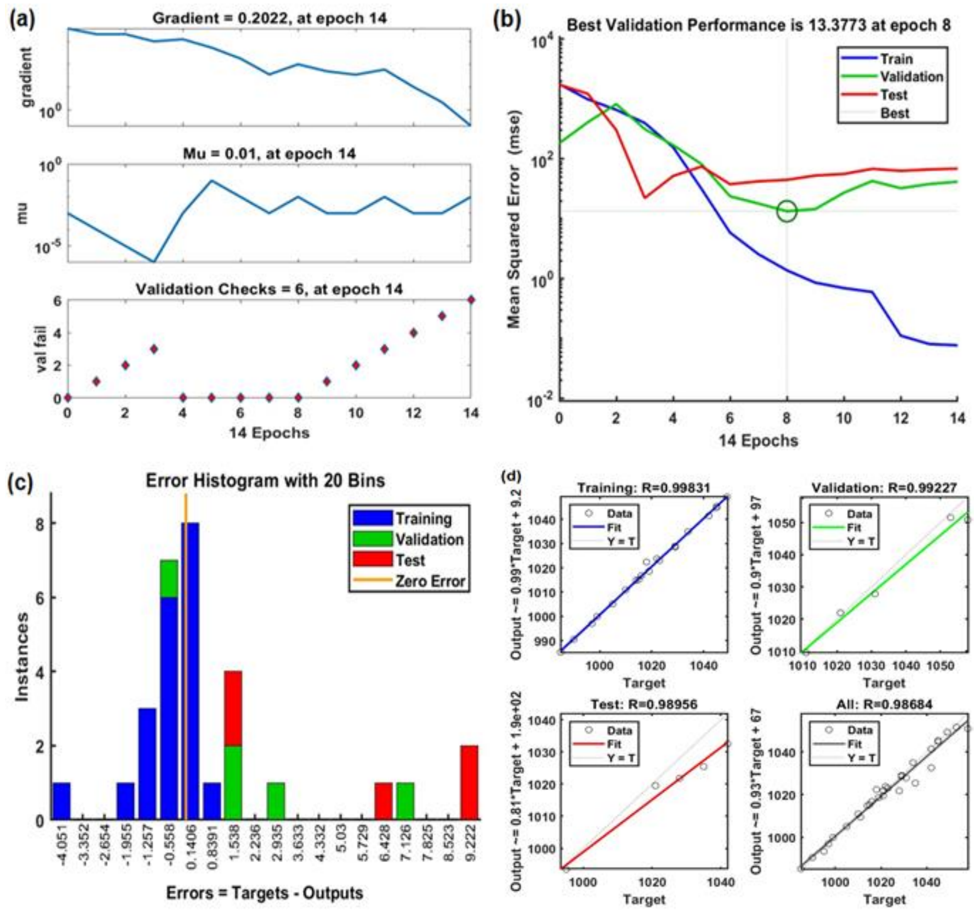


**Figure 7.** ANN density results: (a) gradients, (b) performance curve, (c) deviation histograms, and (d) $R^2$

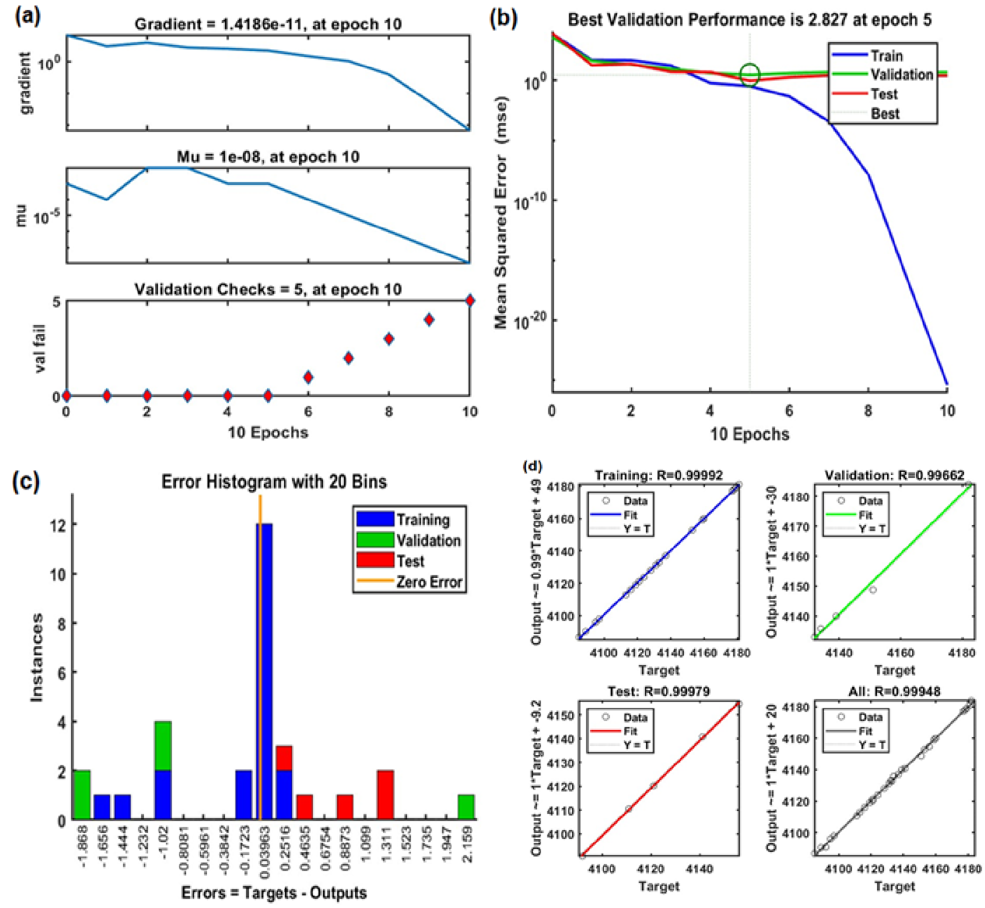


**Figure 8.** ANN specific heat results: (a) gradients, (b) performance curve, (c) deviation histograms, and (d) $R^2$

## 4. CONCLUSIONS

Experimental approach was used to determine the thermophysical properties of the $CoFe_2O_4$/water nanofluids under different temperatures and particle volume loadings. The chemical coprecipitation technique was used to prepare the $CoFe_2O_4$ nanoparticles and later those were characterized using several techniques. The XRD and TEM analyses are confirming that, the prepared $CoFe_2O_4$ nanoparticles size is 39 nm their shape is spherical shape. The VSM analysis confirming that, the magnetization of the prepared $CoFe_2O_4$ nanoparticles is 90.77 emu/g. The water based stable nanofluids were prepared and tested their stability and its zeta potential value is higher than ± 30mV, so, the prepared nanofluids stands for stable nanofluids.

It was discovered through experimentation that using $\phi$ = 1.25% volume loadings resulted in greater thermal conductivity at 60°C and viscosity at 20°C when compared to base fluid. Similarly, when volume loadings are applied to the $CoFe_2O_4$/water nanofluid, the density increases but the specific heat decreases.

The ANN-LM method was utilized to comprehend the features of ideal conditions using the collected thermophysical attributes. MSE and $R_2$ values were examined by the model. For heat conductivity and viscosity, the ANN-LM predicts the smallest predicted RMSE values with a correlation coefficient of 0.99802 and 0.99217, respectively. found data on nanofluids using a range of data with greater accuracy.

## REFERENCES


[1] Choi, S.U.S., Eastman, J.A. (1995). Enhancing thermal conductivity of fluids with nanoparticles (No. ANL/MSD/CP-84938; CONF-951135-29). Argonne National Lab. (ANL), Argonne, IL (United States).

[2] Chiam, H.W., Azmi, W.H., Usri, N.A., Mamat, R., Adam, N.M. (2017). Thermal conductivity and viscosity of $Al_2O_3$ nanofluids for different based ratio of water and ethylene glycol mixture. Experimental Thermal and Fluid Science, 81: 420-429. https://doi.org/10.1016/j.expthermflusci.2016.09.013

[3] Pavithra, K.S., Fasiulla, Yashoda, M.P., Prasannakumar, S. (2019). Synthesis, characterization and thermal conductivity of CuO-water based nanofluids with different dispersants. Particulate Science and Technology, 38(5): 559-567. https://doi.org/10.1080/02726351.2019.1574941

[4] Omiddezyani, S., Gharehkhani, S., Yousefi-Asli, V., Khazaee, I., Ashjaee, M., Nayebi, R., Shemirani, F., Houshfar, E. (2021). Experimental investigation on thermo-physical properties and heat transfer characteristics of green synthesized highly stable $CoFe_2O_4$/rGO nanofluid. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 610: 125923. https://doi.org/10.1016/j.colsurfa.2020.125923

[5] Parekh, K., Lee, H.S. (2010). Magnetic field induced enhancement in thermal conductivity of magnetite nanofluid. Journal of Applied Physics, 107(9): 09A310. https://doi.org/10.1063/1.3348387

[6] Elbeshir, E.I.A. (2018). Magnetic and thermal properties of $CoFe_2O_4$ nanoparticles for magnetic hyperthermia treatment. International Journal of Advanced and Applied Sciences, 5(8): 34-36.

[7] Kharat, P.B., Somvanshi, S.B., Khirade, P.P., Jadhav, K.M. (2020). Effect of magnetic field on thermal conductivity of the cobalt ferrite magnetic nanofluids. In Journal of Physics: Conference Series, 1644(1): 012028. https://doi.org/10.1088/1742-6596/1644/1/012028

[8] Abareshi, M., Goharshadi, E.K., Zebarjad, S.M., Fadafan, H.K., Youssefi, A. (2010). Fabrication, characterization and measurement of thermal conductivity of $Fe_3O_4$ nanofluids. Journal of Magnetism and Magnetic Materials, 322(24): 3895-3901. https://doi.org/10.1016/j.jmmm.2010.08.016

[9] Aguilar, T., Carrillo-Berdugo, I., Alcantara, R., Navas, J. (2022). Enhanced thermophysical properties in spinel $CuFe_2O_4$-based nanofluids for concentrated solar power. International Journal of Energy Research, 46(4): 4908-4918. https://doi.org/10.1002/er.7484

[10] Sundar, L.S., Singh, M.K., Sousa, A.C. (2013). Investigation of thermal conductivity and viscosity of $Fe_3O_4$ nanofluid for heat transfer applications. International Communications in Heat and Mass Transfer, 44: 7-14. https://doi.org/10.1016/j.icheatmasstransfer.2013.02.014

[11] Bahiraeim, M., Hangi, M. (2016). An empirical study to develop temperature-dependent models for thermal conductivity and viscosity of water-$Fe_3O_4$ magnetic nanofluid. Materials Chemistry and Physics 181: 333-343. https://doi.org/10.1016/j.matchemphys.2016.06.067

[12] Altan, C.L., Elkatmis, A., Yüksel, M., Aslan, N., Bucak, S. (2011). Enhancement of thermal conductivity upon application of magnetic field to $Fe_3O_4$ nanofluids. Journal of Applied Physics, 110(9): 093917. https://doi.org/10.1063/1.3658868

[13] Nurdin, I., Yaacob, I.I., Johan, M.R. (2016). Enhancement of thermal conductivity and kinematic viscosity in magnetically controllable maghemite ($\gamma$-$Fe_2O_3$) nanofluids. Experimental Thermal and Fluid Science, 77: 265-271. https://doi.org/10.1016/j.expthermflusci.2016.05.002

[14] Gavili, A., Zabihi, F., Isfahani, T.D., Sabbaghzadeh, J. (2012). The thermal conductivity of water base ferrofluids under magnetic field. Experimental Thermal and Fluid Science, 41: 94-98. https://doi.org/10.1016/j.expthermflusci.2012.03.016

[15] Kim, B.H., Peterson, G.P. (2007). Effect of morphology of carbon nanotubes on thermal conductivity enhancement of nanofluids. Journal of Thermophysics and Heat Transfer, 21(3): 451-459. https://doi.org/10.2514/1.18341

[16] Wen, D., Ding, Y. (2004). Effective thermal conductivity of aqueous suspensions of carbon nanotubes (carbon nanotube nanofluids). Journal of Thermophysics and Heat Transfer, 18(4): 481-485. https://doi.org/10.2514/1.9934

[17] Li, W., Nakayama, A. (2015). Temperature dependency of thermophysical properties in convective heat transfer enhancement in nanofluids. Journal of Thermophysics and Heat Transfer, 29(3): 504-512. https://doi.org/10.2514/1.T4460

[18] Di Nicola, G., Pierantozzi, M., Petrucci, G., Stryjek, R. (2016). Equation for the thermal conductivity of liquids and an artificial neural network. Journal of Thermophysics and Heat Transfer, 30(3): 651-660.

https://doi.org/10.2514/1.T4863

[19] Agarwal, R., Verma, K., Agrawal, N.K., Singh, R. (2021). Correction to: Comparison of experimental measurements of thermal conductivity of $Fe_2O_3$ nanofluids against standard theoretical models and artificial neural network approach. Journal of Materials Engineering and Performance, 30(11): 8687. https://doi.org/10.1007/s11665-021-06145-w

[20] Rostami, S., Kalbasi, R., Sina, N., Goldanlou, A.S. (2021). Forecasting the thermal conductivity of a nanofluid using artificial neural networks. Journal of Thermal Analysis and Calorimetry, 145: 2095-2104. https://doi.org/10.1007/s10973-020-10183-2

[21] Hemmat Esfe, M., Saedodin, S., Bahiraei, M., Toghraie, D., Mahian, O., Wongwises, S. (2014). Thermal conductivity modeling of MgO/EG nanofluids using experimental data and artificial neural network. Journal of Thermal Analysis and Calorimetry, 118: 287-294. https://doi.org/10.1007/s10973-014-4002-1

[22] Sundar, L.S., Sambasivam, S., Mewada, H.K. (2022). ANFIS modelling with fuzzy C-mean clustering of experimentally evaluated thermophysical properties of zirconia-water nanofluids. Journal of Molecular Liquids, 364: 119987. https://doi.org/10.1016/j.molliq.2022.119987

[23] Chand, M., Kumar, S., Shankar, A., Porwal, R., Pant, R.P. (2012) The size induced effect on rheological properties of Co-ferrite based ferrofluid. Journal of Non-Crystalline Solids, 361: 38-42. https://doi.org/10.1016/j.jnoncrysol.2012.10.003

[24] Djurek, I., Žnidaršič, A., Košak, A., Djurek, D. (2007). Thermal conductivity measurements of the $CoFe_2O_4$ and g-$Fe_2O_3$ based nanoparticle ferrofluids. Croatica Chemica Acta, 80(3-4): 529-532.

[25] Rajput, A.B., Hazra, S., Ghosh, N.N. (2013). Synthesis and characterisation of pure single-phase $CoFe_2O_4$ nanopowder via a simple aqueous solution-based EDTA-precursor route. Journal of Experimental Nanoscience, 8(4): 629-639. https://doi.org/10.1080/17458080.2011.582170

[26] Duangthongsuk, W., Wongwises, S. (2009). Measurement of temperature-dependent thermal conductivity and viscosity of $TiO_2$-water nanofluids. Experimental Thermal and Fluid Science, 33(4): 706-714. https://doi.org/10.1016/j.expthermflusci.2009.01.005

[27] Wilk, J., Smusz, R., Grosicki, S. (2017). Thermophysical properties of water based Cu nanofluid used in special type of coil heat exchanger. Applied Thermal Engineering, 127: 933-943. https://doi.org/10.1016/j.applthermaleng.2017.08.078

[28] Mondragón, R., Segarra, C., Jarque, J.C., Julia, J.E., Hernández, L., Martínez-Cuenca, R. (2012). Characterization of physical properties of nanofluids for heat transfer application. Journal of Physics: Conference Series, 395(1): 012017. https://doi.org/10.1088/1742-6596/395/1/012017