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Cu/Zn Thermal Conductivity: Experimental And ANFIS Modelling

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Abstract

Nanofluids are fluids within which particles of nanometre sizes are suspended. In terms of thermal characteristics, nanofluids have a greater heat transfer coefficient and thermal conductivity than other traditional fluids. Bimetallic core/shell Cu/Zn particles of nanometre sizes are novel invented nanoparticle materials with considerable variations in its applications. The particles of nanometre size were suspended in a base fluid for the preparation of nanofluids for different volume fractions. A coated transitory hot wire device were built and standardized and this was subsequently employed for the determination of heat conductivities of the nanofluids for bimetallic ratios, volume fraction, base fluid temperatures and base fluids thermal conductivity. The Adaptive neuro fuzzy inference system (ANFIS) model was subsequently employed for modelling the determined results generated. A random test of 20% from various nanofluids showed a deviation less than 1% between measured and modeled results. It was inferred that heat conductivities increase with increase in the particle volume concentrations, especially when the later one at value of 1, the heat conductivities ratio approach to 1.35. Nevertheless, the shape and the method of preparing the particles of nanometre size reveals anomalous enhancements in heat conductivities of bimetallic compared to monocular metallic nanofluids.

Keywords: Bimetallic nanofluids, Heat conductivity enhancements, ANFIS, Volume fraction.

الخلاصة:

السوائل النانوية هي اللتي تضمن عليقات نانوية الحجم. من ناحية الخواص الحرارية، السوائل النانوية لديها معامل انتقال حرارة و موصلية حرارية اعلى من السوائل التقليدية. جزيئات المواد النانوية الحجم الثنائية قلب/قشرة هي جديدة و مبتكرة، ولها اختلافات كثيرة في مجالات الاستخدام. لتحضير سائل نانوي مختلف التراكيز، علقت ذرات ذات احجام نانوية في السائل الاساسي. الجهاز ذو الاسلاك العابرة الساخنة قد نصب و اجريت معايرته للبدء بعملية حساب الموصلية الحرارية النسبية، التراكيز، درجات حرارة السائل الاساسي و الموصلية الحرارية للسوائل النانوية. بعد ذلك طبق نموذج "نظام الاستدلال العصبي العشوائي" لتوليد النتائج. اظهر اختبار عشوائي ل 20% من سوائل نانوية مختلفة ان نسبة الخطأ لاتتجاوز 1% بين النتائج المقاسة و المنمذجة. كذلك قد استنتج ان الموصليات الحرارية تزداد بزيادة التركيز للجزيئات النانوية، وخصوصا عندما يكون التركيز 1 فأن الموصلية الحرارية النسبية تساوي 1,35. مع ذلك، اظهر كلا من شكل و طريقة تحضير الجزيئات النانوية ان لها تأثير كبير في تحسين الموصلية الحرارية للجزيئات النانوية الثانوية مقارنة بالجزيئات الاحادية.

الكلمات المفتاحية :- السوائل نانوية ثنائية ، تحسين الموصلية الحرارية ، نظام الاستدلال العصبي العشوائي ، نسبة التركيز .

1. Introduction

The local base fluids are known to have lower heat conductivities whereas newer applications in heat transmission devices require greater capability for the base fluids with respect to heat transmission characteristics compared to local base fluids (Balla *et.al.*, 2013) Nanofluids are suspensions of particles of nanometre size in base fluids for enhancement in the thermal transmission characteristics of the local thermal transmission base fluid (Balla *et.al.*, 2015). Generally, solids have greater heat conductivities compared to fluids even though solid materials have wider variations in heat conductivity. The heat conductivities for materials of metallic origin is greater compared to those of oxides materials. The heat conductivities of particles of nanometre size are the most crucial variable in enhancing heat conductivities of fluids containing nanoparticles. Several scholars have investigated the effects of metallic heat conductivities of particles of nanometre size, volume fractions as well as the temperatures of fluids containing nanoparticles Enhancements of 100 nm Cu/H_2O heat conductivities for nanofluids on varying volume fraction were investigated in an earlier study (Xuan and Li, 2003). Utilising the Transitory Hot Wire (THW) technique for the determination of the heat conductivities the greatest enhancements were discovered at 54% for 5 % volume fractions. These scholars observed that enhancements might be as high as 70% in case the 3% of water volume fraction contains 10 nm of Cu nanoparticle suspensions. For the heat conductivities determination purpose, the Transitory Hot Wire THW method was adopted by (Eastman et al., 2001). The study aimed to get an enhancement of 40% by using 0.3 volume fraction of Cu and EG as a nanofluid. Silver, silica and ultra-dispersed diamond were used by (Kang *et.al.,* 2006) as a nanoparticle. The study aimed to determine the enhancements of heat conductivities in subsequent fluids containing nanoparticles utilising the Transitory Hot Wire THW technique. This offered a superior result correlations compared to the Hamilton-Crosser model with an efficient volume fractions of nanoparticle correlated for thermal conductivity. A steadiness and uniformity were observed by (Yimin and Qiang, 2000) when the Transmission Electron Microscopy (TEM) photomicrographs utilised to measure the heat transfer conductivities. The hot-wire was adopted for the mentioned purpose. The determination of Al_2O_3, TiO_2, WO_3 and Fe heat transfer conductivities necessitated the use of transient hot wire technique. The results were compared with each other by (Dae-Hwang *et.al.,* 2007). The preparation of the fluids containing nanoparticles were done in a dual-step procedures by scattering the particles of nanometre size in base fluids. The wire has two purposes, it used as thermometer and as heater at the same time. The response time and temperature determined by transient hot wire technique to sudden electrical pulsation. The nanofluid shows greater enhancements in heat conductivities in comparison with their base fluids, mainly as a result of the clustering of the nanoparticle in the fluid that was beyond the theoretic expectancy of the two-component mixture system. The comparison between several techniques of heat conductivities determination such as temperature oscillation technique, parallel plate technique, transient hot wire technique and stable-state technique were investigated in an earlier study (Kleinstreuer *et.al.,* 2011). The said scholars observed that the transient hot wire technique were more extensively employed. Nevertheless, it is not easy to directly supply the conventional hot wire method, owing to the fact that nanofluids are generally electrical conductor. (Warrier and Teja, 2011) modified the hot wire via galvanization process. The epoxy adhesive was selected to galvanized the hot wire due to it is insulation and thermal conductivity merits. They reported a model for heat conductivities of nanofluids comprising varying sizes of metallic particles of nanometre size. The data generated from the experiment were compared with models which provided attestation that the decline in the heat conductivities of solids with particle size has to be recognised during the development of models for heat conductivities of fluids containing nanoparticles. (Ali *et.al.,* 2011) studied the heat conductivities and heat diffusivity of Cr particles of nanometre size suspension in H_2O-based fluids utilising one step technique at varying volume fraction. The hot wire-laser beam deflection technique were employed for the determination of heat conductivities and heat diffusivity. The data generated demonstrated that heat conductivities and heat diffusivity of fluids containing nanoparticles increase with the increase of richness of nanofluid. In other words, with the nanopowder content increase. Several scholars have proposed models that could denote heat conductivities of nanofluids as functions of the heat conductivities of base fluids, the heat conductivities of the particles of nanometre size and the volume fractions. Electrical and thermal conductivities of two phase (solid and fluid) were investigated by (Maxwell and Clerk , 1873). In mimicking or extending the Maxwell model, the nanoparticles shape effect was examined by (Hamilton and Crosser, 1962). Artificially devised neural network was employed in predicting the heat conductivities of nanofluids. Enhancements in heat conductivities of nanofluids utilising dispersion neural networks has been previously modelled (Papari *et.al.,* 2011). The model was employed for the prediction of heat conductivities of MWCNTs-DW, MWCNTs-EG, MWCNTs-oil, MWCNTs-DE, SWCNT-epoxy as well as SECNTs-PMMA. The data generated were compared with some mathematically oriented models as well as experimentally oriented data. The heat conductivities of varying type of fluids (0.5 wt% of carboxymethyl cellulose CMC aqueous) containing nanoparticles such as γ-Al_2O_3, CuO and TiO_2 having nanometre size suspension solutions has been determined by (Hojjat *et.al.,* 2011). The effect of loading the particles of nanometre size and temperatures were investigated. A neural network model representing heat conductivities of nanofluids as functions of the nanoparticles volume fractions. Both of temperature and nanoparticles conductivities were earlier proposed (Hojjat *et.al.,* 2012; Longo *et.al.,* 2012) employed artificially devised neural network in predicting heat conductivities of oxide nanofluids utilising multi-input entries of three and four values. Both of (Tatar *et.al.,* 2016 ; Adio *et.al.,* 2016) employed ANFIS model to predict an accurate and confident data of heat transfer applications. The effect of major parameters such as volume fraction, heat transfer conductivity and temperature are set as entries to ANFIS model. The researchers observed that the four-input models were superior in the prediction of heat conductivities of nanofluids compared to the three input models. The effect of volume fractions, nanoparticles material types and temperatures on the heat conductivities of bimetallic/metallic nanofluids were determined in this study. Subsequently, adaptive neural based fuzzy inference system was utilised for the modelling of result of bimetallic nanofluid.

2. Bimetallic Nanofluid Preparation

Regarding the nanofluid researches, the preparation step is always on step ahead of all other steps. Therefore, in the current study the preparation of nanofluid was achieved first. Later, the experiments are initiated with a logical sequence and steps to ensure reasonable outcome. The on-going experiments aimed to get fully understanding about the multi-metallic heat conductivities quantification and investigate the variables which influence heat conductivity including the entire nanoparticles volume fractions, the temperature of the base fluids and the ratios of metallic/metallic particles of nanometre size. The volume of nanoparticles is depicted in Equation 1.

$$\text{Ø} = \frac{v_{np}}{V_t} \qquad (1)$$

Where Ø denotes nanofluid volume fractions, v_{np} represents the volume of the nanoparticle suspended in the base fluids and v_t denotes the overall volume fractions of entire particles of nanometre size suspended and H_2O.

The Dual-step technique was employed for the preparation of the samples of nanofluids. Figure 1 shows the SEM of the bimetallic nanoparticles. Bimetallic Cu/Zn nanoparticles 100 nm size in which the core was 50nm thick and the shell has the 50nm, the volume fraction for the bimetallic nanofluids are 0.2, 0.4, 0.6, 0.8 and 1%. The different metallic volume fractions were prepared with the following volume fractions (0.2, 0.4, 0.6, 0.8 and 1) %. Ultrasonic vibrations were employed for six hours to guarantee appropriate mixture and dispersion of the particles of nanometre size into the base fluids. Sediments were not found up to 24 hours post onset. Since surfactant could induce alterations in the characteristics of the nanofluid, it wasn't employed.

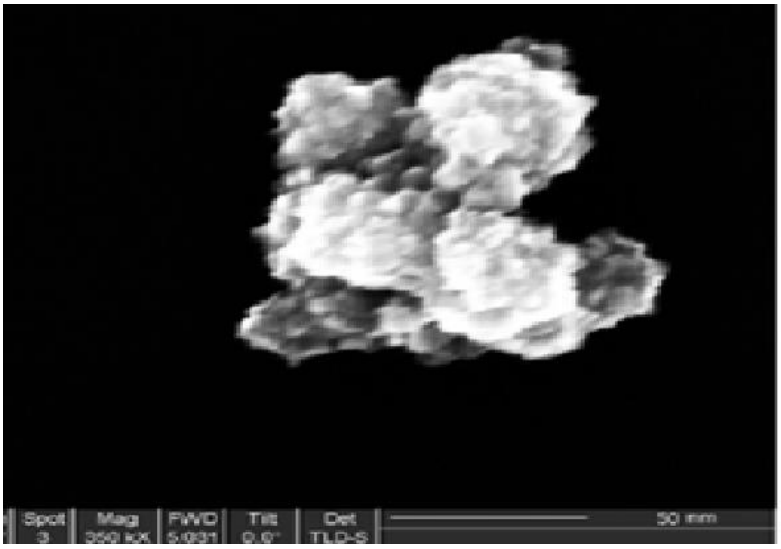

Figure 1. Cu/Zn characteristics

3. Heat Conductivities Measurement

The THW sensor technique is commonly employed for the determination of heat conductivities of liquid and gas samples. This was established through the past decade for studying heat characteristics of solid samples subjected to pressure. The cell used in the experiment comprises of a wire which was enclosed by media whose heat characteristics are to be quantified. The THW method for the determination of heat conductivities in fluids is centered on detecting the temporary increase in temperatures of the thin wire submerged in the material to be tested, firstly at heat equilibrium, subsequent to the supply of a step-by-step electrical current. The 100 micro meter wire was prepared from Platinum and it acted source of heat. It generates time dependent temperatures within the material to be tested. The theoretic model which describes the THW method was a derivative of the systematic solutions of the thermal conductivity equations for a source of line heat with radius r_0 and length l_1 of insignificant thermal mass that was accurately entrenched with no resistance in heat contact in an unrestrained thermal sink, firstly at even temperatures T_0. The sink was regarded as to be prepared from homogeneous and isotropic materials which have fixed heat transmission characteristics. Where a fixed electric current is supplied in a step-by-step manner, the wire will promptly and completely release the output of the source of heat for every unit length q, to the samples to be tested, in which it is transferred outward and completely kept. The alterations in the resistance of the wire could be computed utilising Equation 2.

$$\Delta Rw = \frac{(Rw*R_3)^2*\Delta V}{V*R_3}\pi r^2 \quad (2)$$

In which, the voltage drop is quantified using voltmeter and documented/second.

$$R_w = \mathrm{R}_0(1+\alpha\mathrm{T}) \quad (3)$$

$$\Delta\mathrm{T}(\mathrm{r},\mathrm{t}) = \frac{\mathrm{q}}{4\pi\mathrm{k}}\ln\frac{\mathrm{t2}}{\mathrm{t1}} \quad (4)$$

In which T represents the quantified temperatures of the nanofluids, K represents the heat conductivities of the nanofluids, t_1, t_2 representing the time for the increment to raise the temperature, r denoting the wire radius, and q denotes the current provided by the hot wire.

Probe checking should made Prior to initiate other sequences. It was achieved via a standard samples of well coded heat conductivity of pure water. Prior to commence the experiment, the temperature range was adjusted to be within 20-60 °C to measure the heat conductivity. A 0.6% deviation was detected for the water (H_2O), a flask of glass sample was used as an enclosure for 100 mm of each sample. figures 2 and 3 containing other details, descriptions and further specifications.

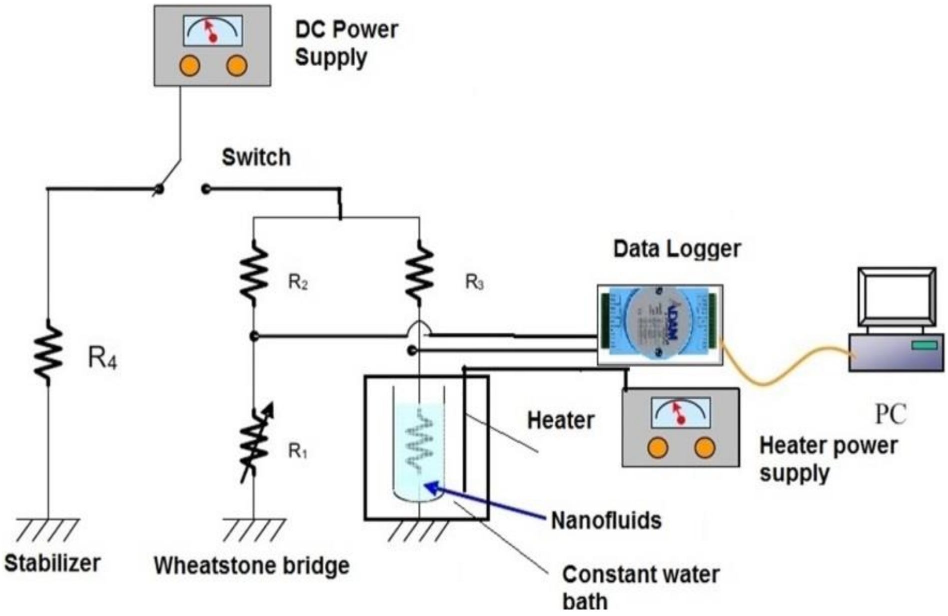

Figure 2. Transient hot wire description

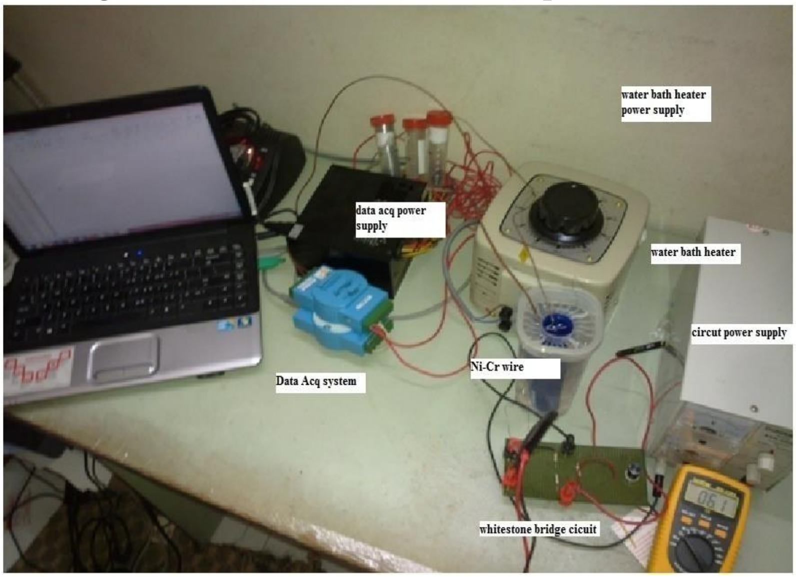

Figure 3. Experimental rig of THW

4. Anfis Model

A fuzzy inference system (ANFIS) represents some kind of synergy which usually came out from the engaging between adaptive neural networks and another predicting model like fuzzy inference system. The potential of getting sophisticated relations from data obtaining by the experimental work was one of the reasons behind utilising ANFIS. The followed ANFISI arrangement of the resulted experimental data is presented as in figure 4. Where, the algorithm arrangement of the ANFIS shows three input entries, they are T, Ø and K_{np}.

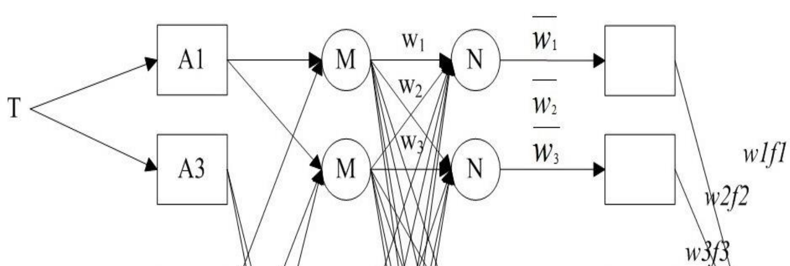

Figure 4. Three input entries and five layers presenting ANFIS model

The outcomes of the ANFIS process are the heat conductivities (nanofluids conductivities). The first order model (Sugen model) was used to occupy the fuzzy IF-THEN rules. It could be explicit as follow

Where, A_1 represents x, B_1 represents y and C_1 holds for z. then

$$f_i = p_1 x + q_1 y + r_1 z + r_1 \qquad (5)$$

Layer (1) contains square nodes, represented by a letter (i). It has a function that formulate as follow

$O_{1,i} = \mu_{Ai}(x)$, for i= 1, 2, 3 $O_{1,i} = \mu_{Bi}(y)$, for i= 4, 5, 6 $O_{1,i} = \mu_{Ci}(z)$, for i= 7, 8, 9

From last expression has unfamiliar variables like Ai, Bi and Ci. In current case, these variables represent an entries. While $O_{1,i}$ represents their membership function.

The Gaussian-shaped should own a membership function. Therefore, it may be expressed as

$$\text{Gaussian } \mu(x, y, z) = \text{EXP}\left[-\frac{(x_i - c_i)^2}{2{a_i}^2}\right] \qquad (6)$$

the premise variables in the last expression are presented by a_i and c_i.

Layer (2) contains rounded nodes presented by (π). Onset, these node will multiply by inside signal. Later, they expelled out the products.

$$O_{2,i} = w_{i=} \mu_{Ai}(x). \mu_{Bi-3}(y). \mu_{Ci-6}(z), \text{ i=1, 2, 3......27} \qquad (7)$$

The last layer involves some kind of computation by "i" nodes. These "i" nodes are rounded and has a rule. In this stage, the rule firing strength and summation are being computing.

$$O_{3,i} = \overline{w_i} = \frac{w_i}{w_1 + w_2 + \cdots w_{27}}, \text{ i=1, 2, 3,..., 27} \qquad (8)$$

The 4th layer has only square nodes presenting by letter (i). Furthermore, each one has a function expressed by

$$O_{4,i} = \overline{w_i} \cdot f_i = w_i(p_i x + q_i y + r_i z + rr_i),\ r= 1, 2, 3,..., 27 \quad (9)$$

The consequences variables in the mentioned expression are rr_i p_i, r_i and q_i

The summation symbol (∑) represent the nodes in fifth layer. Solitary is the type of the rounded nodes in this layer

$$O_{i,5} = \text{overall output} = \sum_i \overline{w_i}\, f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \quad (10)$$

Bell shaped, Gaussian shaped, Trapezoidal shaped and Triangular shaped member functions are estimated to adopt the greater one.

$$RMSE = \sqrt{\frac{1}{N}\sum_i^N (K_{experiment} - K_{predict})^2} \quad (11)$$

The gap or difference between the quantified and predicted heat conductivities is presented by the root mean square error (RMSE). The N variable holds for the data set amount. On the other hand, the heat conductivities ratio was determined and predicted (through ANFIS) by both variables $K_{expermint}$ and $K_{predict}$ respectively. The selection or assessment process secreted the Gaussian-shaped as a best member function in term of performance and error. It has maximum error of 2% and best performance. In term of RMSE computation and reduction, three member functions are selected among 10 member functions at the commence of estimation process. Referee to table 1.

Table 1: ANFIS model characteristics

Activation functions	Log-sigmoid
Parameter adaptation of the initial step size	0.01
Maximum Number of epochs	800
Fuzzy rules number	216
Individual variables number of fuzzy partitions	3
Input node numbers	3
Layer numbers	5
Membership numbers	9

5. Results And Discussion

The comparison between Cu/Zn and both of Cu an Zn nanofluids are shown in figure 5.

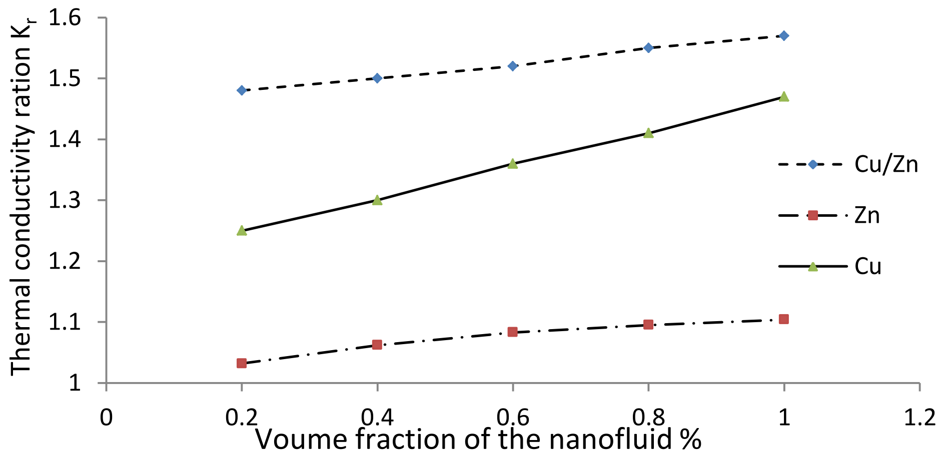

Figure 5. Volume fraction against thermal conductivity ratio of different type nanofluids.

This comparison achieved at 30 °C and shows the heat conductivity against the volume fractions. The heat conductivities of the fluids containing nanoparticles were determined by means of galvanised transitory hot wire technique. The rig used in this experiment were authenticated via the determination of the heat conductivities of the H_2O at particular temperatures and the obtained heat conductivities for H_2O were compared with the standard heat conductivities as acquired in an earlier study [5]. The rise in volume fractions leads to rise in heat conductivities of the fluids containing nanoparticles. In accordance with energy transfer mechanisms proposed to elucidate the enhancements in heat conductivities in nanofluids [9]. Within the nanofluid, the exchanging of the thermal energy increases as the nanoparticle concentration increase. When the rise in the volume fractions means rise in the particles of nanometre size enclosed in the nanofluids, whereas the solid particles of nanometre size have greater capability to transfer the energy compared to the fluids.

On the other hand, the highest thermal conductivity ratio at 1.57 for the bimetallic nanofluids were acquired at 1% volume fractions. The rise in the ratios of heat conductivities could be as a result of the production of nanolayers at the interfacing boundary that contacting both of base fluid and nanoparticles. The solid and liquid phases of nanofluid are connected by cloudy intermediary nanolayer. A homogenous and undisturbed situation is dominate at that nanolayer has already reported [9]. On the basis of earlier conceptions, the heat conductivities of the nanolayers would be uninterruptedly disseminated. Some scholars have presumed the heat conductivities of the nanolayer is fixed not minding the interactions between the particles of nanometre size and the fluids. The thickness of the nanolayer is hinged on several variables, which include the shape, size and heat conductivities of particles of nanometre size. In addition, both of the nanoparticles and base fluid specific heat capacities have the same behaviour. Actually the bimetallic nanofluid as a core/shell will produce higher thickness nanolayer compared to the Cu and Zn nanolayer. In addition, there is nothing preventing the combination of both the energy transport mechanism and the increases in the nanolayer generated around the nanoparticles.

Figure 6 shows the acquired enhancement ratios of Cu/Zn, Cu and Zn nanofluids (at a temperature range of 20-60 °C) in heat conductivities

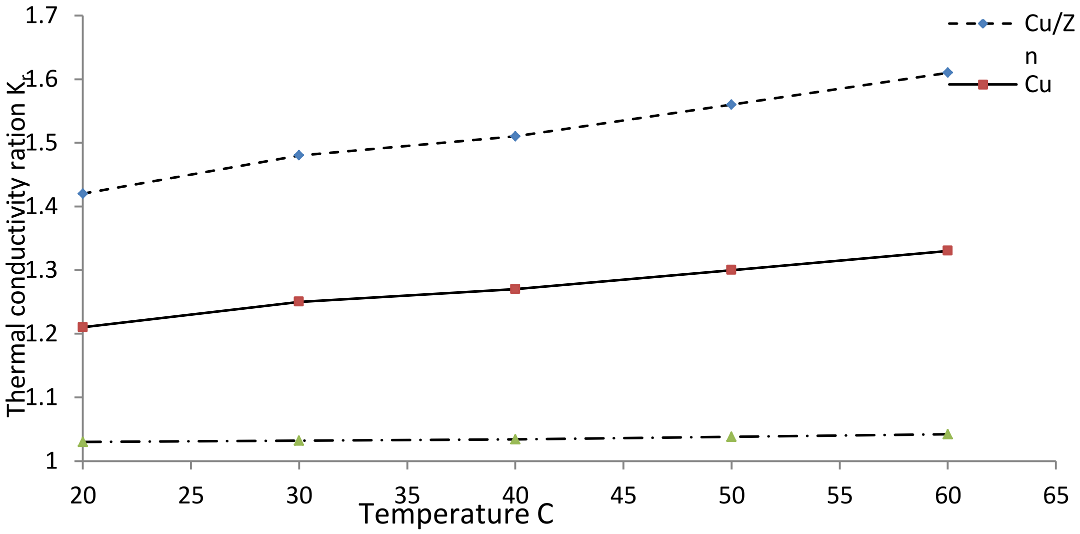

Figure 6. Temperature against thermal conductivity ratio of different nanofluid types and at nanoparticle concentration of 1 %.

The heat conductivities ratio increase when the temperatures increase. The greatest ratios of heat conductivities was 1.72 at 60°C, for the 1% volume fractions Bimetallic nanofluid. As mentioned above, the increase in ratios of heat conductivities of the nanofluids with rise in temperature possible to explained using the energy transport [9]. Where the rises of the temperature increase the energy transport then increase the energy carried for each nanoparticles.

6. ANFIS Model Result

The effect of each temperature, nanoparticles material type and volume fractions were employed as input to the ANFIS model while Kr and ratios of the fluids containing nanoparticle heat conductivities to the base fluids heat conductivities were outputs from the ANFIS model. Flow charts of the ANFIS model is depicted in figure 7, whereas figure 8 displays the role of preliminary membership for the earliest inputs with 3 membership role.

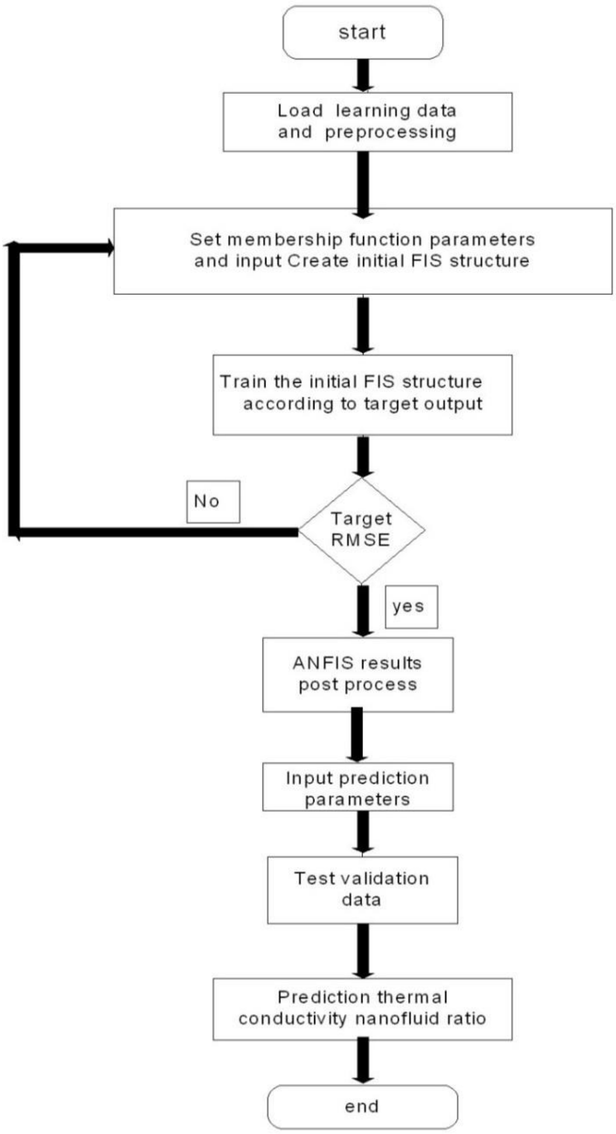

Figure 7. ANFIS flow chart (trained)

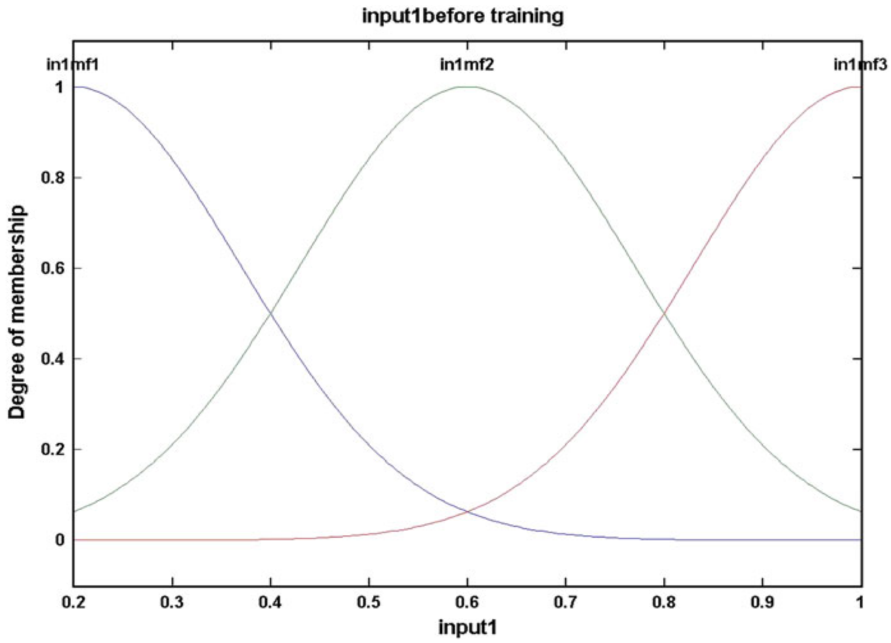

Figure 8. Pre-training membership functions of first entries in ANFIS model

The membership functions following training are illustrated in figure 9. The comparison between figure 8 and figure 9 evidently demonstrates the alterations in the membership functions prior and following training in ANFIS models.

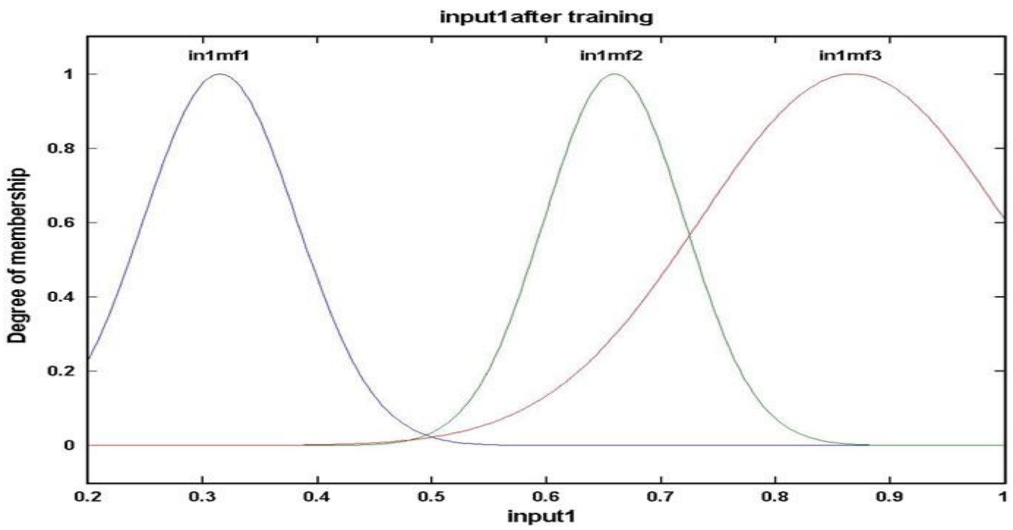

Figure 9. Post-trained membership functions of the first entry

The comparisons between the determined heat conductivity ratios and the predicted heat conductivity ratios is presented in the plot in figure 10. It depicts the collective data generated from each conducted experiment. It means three nanofluid types(Cu/Zn, Cu and Zn), five temperature values (20-60 °C) and five volume fraction values (0.2-1%). This corroborate that the ANFIS is capable of accounting the enhancements in the heat conductivities as function of the nanoparticles concentrations and the temperatures.

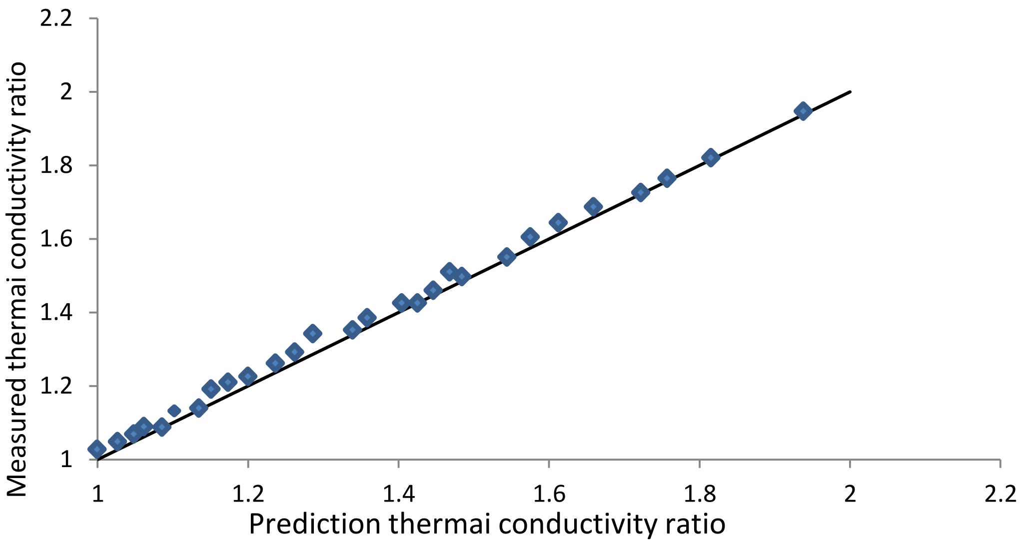

Figure 10. Cu/Zn comparison between measured and predicted heat conductivities ratio

For comparing purpose of the ANFIS model with other models documented by scholars. Comparisons between the projected heat conductivity ratios using ANFIS and the data obtained via the H.C. model in Equation 12 is shown in figure 11. In addition, it contains Xie et al. model given in equation 13.

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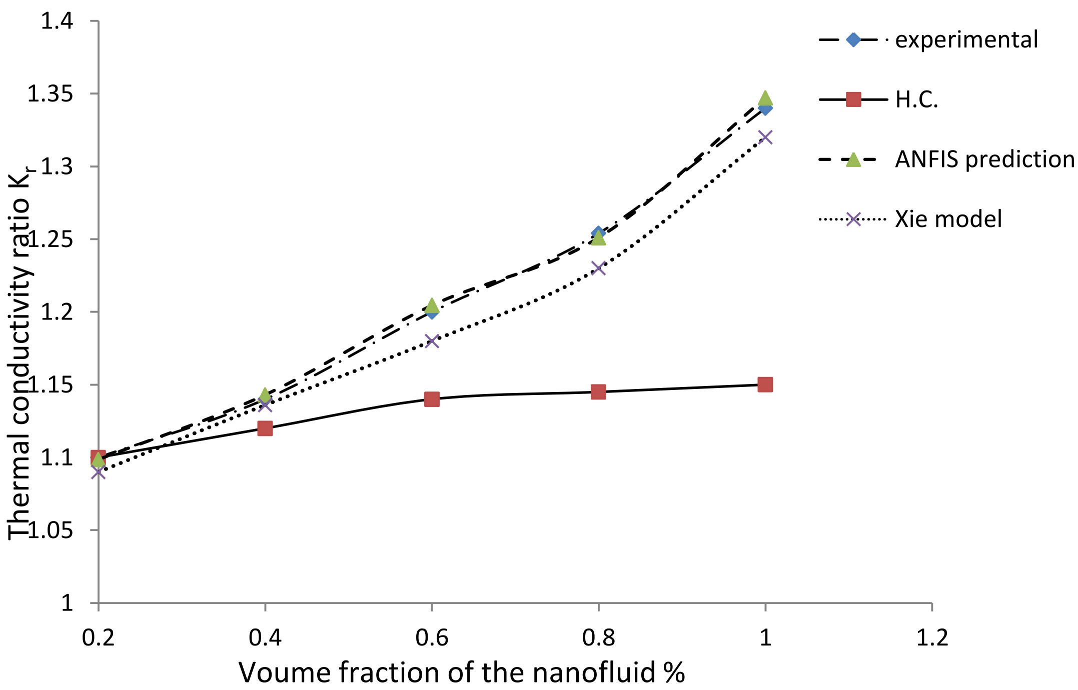

Figure 11. Volume fraction against heat conductivity of the obtained ANFIS and other related models regarding Cu/Zn.

$$\frac{k_{nf}}{k_b} = \frac{\frac{k_{nf}}{k_f} + (n-1) - (n-1)\left(1 - \frac{k_{nf}}{k_f}\right)\emptyset}{\frac{k_{nf}}{k_f} + (n-1) + \left(1 - \frac{k_{nf}}{k_f}\right)} \tag{12}$$

$$\frac{k_{nf}}{k_f} = 3\theta\emptyset_T + 3\,\frac{3\theta^2{\emptyset_T}^2}{1 - \theta\emptyset_T} \tag{13}$$

In predicting heat conductivities of small overall volume fractions, the H.C. model has proved an eligibility. Whereas the Xie model appeared to be better in predicting with a deviation of 1.3 as depicted in figure 11. The finest model for predicting heat conductivity ratios, as depicted in figure 11, is the ANFIS model which corroborate with data generated from experimental setup.

7. Conclusion

The bimetallic core/shell fluids containing nanoparticles employed in this study is a novel mixture of metallic particles of nanometre size suspension in H_2O for enhancements in heat conductivities of fluids containing nanoparticles. The capacity to alter the densities as well as the heat conductivities of fluids containing nanoparticles by altering the ratios of the metallic/metallic increase the possibility of utilising the bimetallic nanofluids in a number of industrially oriented applications.

The Sugeon-fuzzy interface system is primarily based on ANFIS. The determination of nanofluids heat conductivities was the motivation behind the building of such model. The effecting independent parameters such as temperature and volume fractions are shown to be affecting the dependent parameters like the heat conductivities ratios. Eventually, the ANFIS model was found to be dominate in term of prediction accuracy over various affordable prediction models.

Nomenclature

Symbol	Definition
ANFIS	Adaptive neuro fuzzy inference system
C_p	Specific heat
k	conductivity
MWCNT	Multiwall carbon nanotubes
Q	power supply
TEM	Transmission electron microscopy
THW	Transitory hot wire
Subscripts	
ϕ	Volume fraction
ρ	density
Greek letters	
f	Base fluid
Nf	Nanofluid
p	nanoparticle

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