Enhancement Heat Transfer of Cu-Water Nanofluids with Thermophysical Properties Modeling by Artificial Neural Network

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Abstract

Suspends Cu nanoparticles size in base fluids were adjusted for a formation of nanofluid using the ultrasonic homogenizing. A KD2 PRO was calibrated to measure the thermal conductivities while the dynamic viscosity with measured using the rotating viscometer. Thermal conductivity and dynamic viscosity effects on the other parameters such as volume fractions, base fluids type and the base fluids temperature, which applied an input to the Artificial Neural Network for modeling the nanofluids mathematical expressions and Thermophysical features. The equations of the properties later used in calculating the improvement in heat transfer by ANSYS FLUENT 16.1 to model a fluid flow through the pipe heated by uniform heat flux for laminar Reynolds number 250-2000. Results showed that the temperature and the volume fractions of the nanoparticles had great influences on the thermal conductivity and dynamic viscosity. Thermal conductivities ratio and Nusselt number for Cu-Water nanofluid were depicted with several correlations for previous works. The effect of the nanoparticles diameter on the thermal conductivity ratio was concluded and decided that the thermal conductivity ratio decreased with the increase of the nanoparticles diameter, so the effect of the volume fraction within small particle sizes approximately nil. Results reveal good enhancement in thermal transfers and the maximum heat transfer coefficient enhancement was obtained at 1% Cu nanofluid.

Keyword: Enhancement heat transfer, Cu nanofluid, ANN, ANSYS Fluent, Thermal Properties

الخلاصة

ان حساب تحسين المواصفات الحرارية له علاقة بالعديد من التحديات. تم تعليق الجزيئات النانوية للرصاص في السائل الاساسي الماء كتحضير لسائل نانوي باستخدام جهاز الموجات فوق الصوتية. لقد تم معايرة جهاز قياس الموصلية الحرارية *KD2 PRO* والذي استخدم لقياس الموصلية الحرارية للسائل النانوي بينما استخدم جهاز قياس الزوجة الدوار لقياس اللزوجة. ان العوامل المؤثرة على مقدار الموصلية الحرارية واللزوجة المقاسة هي مقدار حجم الجزيئات النانوية، درجة حرارة الماء ونوع السائل الاساس والتي استخدمت كمدخلات لبرنامج الشبكة العصبية الصناعية وذلك لنمذجة موديل رياضي للمواصفات الحرارية للسوائل النانوية. ان معادلة المواصفات المحسوبة تم استخدامها خلال حسابات مقدار التحسن بانتقال الحرارة باستخدام برنامج الموديل الرياضي أنسيز فلونت*16.1* لسائل نانوي يمر في انبوب دائري مع كمية حرارة ثابتة على الجدار ضمن جريان طباقي وعدد رينولد يتراوح 250−2000. لقد بينت النتائج ان مقدار الموصلية الحرارية واللزوجة للسوائل النانوي تعتمد كثيراً على مقدار درجة الحرارة وحجم الجزيئات النانوية الموجوده في السائل. تم مقارنة مقدار الموصلية الحرارية وعدد نسلت لسائل النحاس النانوي مع عدد من المعادلات التجريبية. تم استنتاج تاثير مقدار الاقطار النانوية على نسب الموصلية الحرارية وقد تم ملاحظة ان مقدار الموصلية الحرارية يقل مع زيادة الاقطار وان تاثير حجم الجزيئات خلال الاقطار الصغيرة يكون مهمل. لقد وجد تطابق كبير في النتائج وان هنالك تحسن ملحوظ في الاداء الحراري وان اعلى نسبة تحسن وجدت عند قيمة للحجم النانوي1%.

كلمات المفتاحية:− تحسين انتقال الحرارة، مائع نحاس نانوي، الشبكة العصبية الصناعية، أنسيز، الخواص الحرارية

Abbreviations		**Greek letters**	
K	Thermal Conductivity (W/m K)	ρ	Density (kg/m^3)
h	Coefficient of Heat Transfer (W/ m^2 K)	*μ*	Dynamic Viscosity (Pa.s)
p	Pressure (Pa)	*Φ*	Volume Fraction
q	Heat Flux (W)	**Subscripts**	
Re	Reynolds Number	*nf*	Nanofluid
Nu	Average Nusselt Number	*p*	Nanoparticles
C_p	Specific Heat Capacity (J/kg k)	*f*	Base Fluids
V	Velocity Vector (m/s)	*z*	Local location along the pipe
X/L	Ratio of axial position to the pipe length		
T	Temperature (^{0}C)		

Introduction

There are many types to augment the heat transfer, the first called "active techniques" which need an external power like vibration the surface or the fluid, the second type called "passive techniques" which do not need external power like use external surface to remove the heat from hot surface or using vortex generators. The third types called " compound techniques" which can use both the previous types in the same time (Web and Kim *et.al.,* 2006; Smaisim *et.al,*2016). Solid additive in liquids is one method of the passive techniques, which can augment the heat transfer. Nanofluids are fluids including suspensions of particles of Nano size, which had higher thermal characteristics related to the base fluids. As the solid nanoparticles have high thermal conductivity so, the mixture will have thermal conductivity higher than those liquids. Because of the Nano size of the suspended particles, the mixture can be appropriate heat transfer fluids in different devices automotive and electronic industries (Bejan *et.al.,* 2003).

(Choi *et.al.,* 2001) measured early the nanofluid heat conductivities for many types of nanofluids, while (Eastman *et.al.,* 2001) determined the effect of the variation of volume fractions of the nanoparticles on the augmentation of the thermal conductivity for the metallic fluid and compared the results with Hamilton-Crosser model. (Yimin and Qiang,2003) suspended Cu nanophase powders and compared with the base fluid, they produced that the nanophase effects on the overall heat transfer and enhance of the thermal performance.

(Yang *et.al.,* 2005) illustrated a numerical investigation to calculate the thermal conductivity, particle shapes, density and viscosity for several types of nanofluid. Their results confirmed with the experimental work of (Anoop *et.al.,*2009) to augment the heat transfer and compared with their correlation equation of error less than 3.2%. (Akbarinia *et.al.,* 2007) investigated experimentally the nanofluid flows through horizontally and inclined pipe and they had a maximum augmentation was 15%. (Namburu *et.al.,* 2009) calculated numerically the enhancement of thermal coefficient for CuO-Water, Al_2O_3-water and SiO_2-EG nanofluid through circular tube. They concluded that the heat transfer enhanced with increase of volume faction and Reynolds number, they notices that the nanoparticles size effects on the pressure drop.

(Papari *et.al.,* 2011) simulated an Artificial Neural Network model to predict the nanofluid heat conductivity for many type of nanofluids for laminar flow and wide range of volume fractions. The results compared with other experimental and mathematical models. (Hojjat *et.al.*2011) investigated experimentally 0.5% volume fraction of Cu-Water and Al_2O_3 nanofluids with the effects of the nanofluid temperature. They developed an Artificial Neural Network model to represent the dynamic viscosity and thermal conductivity as function of volume fraction and confirmed with the experimental data. Another Artificial Neural Network model presented by (Longo *et.al.,* 2012) to predict the oxide heat conductivity with 3 with 4 inputs. They studied the effects of temperatures, heat conductivities and volume fraction to specify as 3 input models then they enter the effect of clustering of the nanoparticles in the model as four input parameter. They concluded that the heat conductivities at 3 input are less resolution compared to 4 input model.

(Balla *et.al.,* 2013) presented the ANFIS model to form the thermal conductivities of the measured thermal conductivities by the transient hot wire method for the Zn-Cu. The author concluded that the ANFIS modelling is well to model the thermal conductivities compared with the other models. Later (Balla *et.al.,* 2015) used the ANFIS results to determine the heat transfer coefficient of multi-metallic nanofluids. The results of heat transfer coefficient obtained with ANFIS modelling for thermal conductivity gives a good agreement with the experimental results. (Akilu *et.al.*,2016) presented many models to describe the behaviours of the properties and estimate the performance of the thermal conductivity, specific heat density and viscosity for various individual nanofluids and compare it with the experimental early works. They found a good agreement with the previous works. (Esfahani *et.al.*, 2017) investigate experimentally the viscosities and heat conductivities of many nanofluids types such as Ag, TiO2 and Cu as nanoparticles while the water and mineral oil as base fluids. They obtained that the least error in prediction of dynamic viscosities and thermal conductivities of mineral oil based nanofluids was obtained by using ANFIS modelling 2.5%. (Alirezaie *et.al.*, 2017) experimentally prepare and investigate of the dynamic viscosities of the MWCNT and MgO with percentages of 10–90% in engine oil. Then experimental data were modelled by using a multi layer perception neural network and obtained a good agreement with the experimental results.

In this study, an experimental work was presented to measure the thermal conductivity and dynamic viscosity of Cu-Water nanofluid. Then an Artificial Neural Network model developed to predict the viscosity dynamics and thermal conductivities of nanofluids in ranges out of the experimental analysis followed by enter the results to the ANSYS FLUENT 16.1 to calculate the Nusselt number and the thermal performance of the nanofluids.

Nanofluid Preparation

The first step of this work is preparation of the nanofluid with the same steps described by (Hameed and Qusay,2017) with volume fraction equals to (0.2, 0.4, 0.6, 0.8 and 1)% with nanoparticles diameter 50nm. The characteristics of pure water and Cu nanoparticles at 300 K are illustrated in Table 1 and TEM photograph for the Cu-H_2O nanofluids shown in Figure 1. The 1200W ultrasonic Processor was used for homogenizing, dispersing and mixing nanofluid and Figure 2 shows it. Nanoparticles mass compared with the base fluids defined:

$$\phi = V_p / V_t \tag{1}$$

In addition, nanoparticles mass defined as:

$$m_p = 1\times 10^{-3} \phi \rho_p \tag{2}$$

Nanofluid density is:

$$\rho_{nf} = (1-\phi)\rho_f + \phi \rho_p \tag{3}$$

and nanofluid heat capacity is:

$$C_{pnf} = \frac{\phi \rho_p C_{pp} + (1-\phi)\rho_f C_{pf}}{\rho_{nf}} \tag{4}$$

Table 1: The characteristics of pure water and Cu nanoparticles at 300 K (Kamyat *et.al.*,2012), (Holman,2010)

Fluid at 300K	Size in nm	Thermal conductivity W/kg k	Thermal diffusivityx10^{-6} m^2/s	Density kg/m^3	Heat capacity J/kg k
Cu	50	401	0.107	8940	385
Pure water	----	0.6103	0.1465	996.5	4181

Thermophysical Properties Measurement of Nanofluid

KD2 PRO was utilized to determine the heat conductivities of Cu Nano-fluid. The distilled water was used to calibrate and verification of the KD2 PRO. Figure 3 shows the KD2 PRO used in the thermal conductivities measurement in this investigation. Cu-Water heated from 10 to 60 °C for the pure water and volume fraction (0.2,0.4,0.6,0.8,1)%.

Same experiments were applied to determine the dynamic viscosity of the pure water and Cu-Water nanofluids using the rotary-viscometer. The process of the measuring requires at least 3 minutes before recording the data to reach the steady state conditions. Figure 4 shows the rotary-viscometer device.

Validation for Distilled Water

Figure 5 illustrated a comparison between the measured thermal conductivities of the distilled water in this work and the thermal conductivities that measured by (Godson et al.2010) for the temperature range from 30 to 60°C. The results show a maximum deviation obtained is 3% for the available temperature values.

Figure 6 shows the validation of the dynamic viscosities for distilled water of this work with the measured by (Mclindon et al. 1998) from the temperature range 30 to 60°C with maximum deviation 1.75%.

Then Figure 7 shows the relationship of Nu of water that calculated compared with the Nu determined by Shah and London (Shah and London,1978) as:

$$\mathrm{Nu} = \begin{cases} 1.953(\mathrm{Re\,Pr\,D/L})^{1/3}; & (\mathrm{Re\,Pr\,D/L}) \geq 33.3 \\ 4.364 + 0.0722\mathrm{Re\,Pr}\frac{\mathrm{D}}{\mathrm{L}}; & (\mathrm{Re\,Pr\,D/L}) \leq 33.3 \end{cases} \quad (5)$$

Artificial Neural Network (ANN) Model

Heat conductivity and viscosity dynamics of nanofluid results from the experimental work were employed as the input/output to the ANN Model to predict inside the scope of the experiments. ANN model applied the 4 inputs with 2 outputs besides 5 layers with 3 hidden layers, the structure of the model described in Figure 8. 30 neurons used for the first, 40 neurons for the second layers and 30 neurons for the third layers. The choice of the neurons numbers was depend on the optimization of the error, which is satisfied the results of (Longo *et.al.,* 2012), (Zhao *et.al.,* 2015), (Esfe *et.al.,* 2015) and (Naeini *et.al.,* 2016).

Governing Equations and Procedure for the Solution

Continuity, Navier-Stokes and energy equations were applied on the fluid with laminar flow, steady state and 3-Dimensions are:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (6)$$

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \quad (7)$$

$$\rho\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) = -\frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) \quad (8)$$

$$\rho\left(u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = -\frac{\partial p}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) \quad (9)$$

$$\rho c_p\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z}\right) = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) \quad (10)$$

The pipe had a diameter of 10cm and length of 1m with Reynolds number from 250 to 2000 and temperature of (10,20,30,40,50 and 60)^{0}C. The tube headed by Uniform heat flux equals 4500W/m^2 with volume fractions (0.2, 0.4, 0.6, 0.8 and 1) % and diameter of nanoparticles (20,30,40,50,60,70 and 80) nm for. The boundary conditions illustrated in Table 2.

Table 2 Boundary conditions Summarized.

	Velocity Components			Pressure	Temperature
	U	**V**	**W**	**P**	**T**
Inlet	u_∞	0	0	$\partial P/\partial n$=0	Tin
Outlet	$\partial U/\partial n$=0	$\partial V/\partial n$=0	$\partial W/\partial n$=0	0	$\partial T/\partial n$=0
Tube wall	0	0	0	$\partial P/\partial n$=0	$\partial T/\partial n = -q''/k$

ANSYS FLUENT 16.1 used to solve governing equations by SIMPLE algorithm by coupling the pressure and velocity. Refine meshes used by ANSYS

MESHING ICEM CFD 16.1 for the pipe with Tetrahedral element in 3-Dim and grid density limits were 2568746–2624543 tetrahedral cells. Procedure steps for each iteration are illustrated by the flow chart shown in Figure 9. Nusselt number was calculated as:

$$\mathrm{Nu}(z) = \frac{h(z) \cdot D}{K_0} \tag{11}$$

where h(z) is defined by:

$$h(z) = \frac{q}{T(z)_w - T(z)_b} \tag{12}$$

and the average h_{avg} computed as:

$$h_{\mathrm{avg}} = \frac{1}{L}\int_0^L H(z)dz \tag{13}$$

so the Nu_{avg} is defined by:

$$\mathrm{Nu}_{\mathrm{avg}} = \frac{h_{\mathrm{avg}} \cdot D}{k_0} \tag{14}$$

Result and Discussion

Figure 10 represented the effect of the temperature on the thermal conductivity ratios. It can be noted that the thermal conductivity increases with the temperature for the same volume fraction, this can be explained as the increase of the temperature causes an increase in the thermal energy in the nanofluid which causing an increase in its movements. Another motivation can be reported for this enhancement, which generates a nanolayer around the particles that had greater heat conductivities when it related with base fluid. Figure 10 also declared that at the higher volume fractions, thermal conductivity increases too for the same temperature. This is because of the nanoparticles suspended within the base fluid, which raise the metallic composite and thermal conductivity.

Figure 11 showed the effect of the temperature on the dynamic viscosities. It noted that the viscosity dynamics of the nanofluid increase with temperature levels. Similar behaviour concluded for the dynamic viscosities with the change in values of the temperature modify.

Figure 12 illustrated the values of thermal conductivities for the ANN model compared with the Vasu, Corcione, Patel and Garg correlation equations that compare with the earlier model of Hamilton Crosser equation in equation 15 (Akilu et al,2016). The figure showed the finest models to estimate the thermal conductivities is ANN model with error 3.5%,

$$k_{nf} = \frac{k_p + (z-1)k_{bf} - \varphi(z-1)(k_{bf} - k_p)}{k_p + (z-1)k_{bf} - \varphi(k_{bf} - k_p)} k_{bf} \tag{15}$$

Table 2 and 3 illustrate the empirical equations that presented to calculate the thermal conductivity and Nusselt number related with Cu nanofluids.

Table 2 Empirical equations that calculate the thermal conductivity

Authors	Empirical Equation	Nanofluid	Eq. No.
Vasu *et.al.*, 2007	$k_{nf} = 0.74k_f \text{ Re}_m \phi^{0.05}\left(\frac{k_p}{k_f}\right)^{0.2624}$	Cu–Water	16
Garg *et.al.*,2008	$k_{nf} = (1+6\varphi_p)k_{nf}$	Cu-EG	17
Patel *et.al.*,2010	$k_{nf} = \left(1+0.135\left(\frac{k_b}{k_b}\right)^{0.273}\varphi^{0.467}\left(\frac{T}{20}\right)^{0.547}\left(\frac{100}{d_p}\right)^{0.234}\right)k_{bf}$	Cu-Water Cu-EG	18
Corcione,2011	$k_{nf} = \left(1+4.4(\text{Re}^{0.4}\text{ Pr}^{0.66})\varphi^{0.66}\left(\frac{T}{T_{bf}}\right)^{10}\left(\frac{k_b}{k_{bf}}\right)^{0.234}\right)k_{bf}$	Cu-Water Cu-EG	19

Table 2 Empirical equations that calculate the Nusselt number

Authors	Empirical Equation	Nanofluid	Eq. No.
Vasu *et.al.*,2007	$Nu = 0.027(\text{Re}_{nf})^{0.8}(\text{Pr}_{nf})^{0.4}$	Cu–Water	20
Pak & Cho,1998	$Nu = 0.021(\text{Re}_{nf})^{0.8}(\text{Pr}_{nf})^{0.5}$	Cu-Water Cu-EG	21
Xuan & Li,2003	$Nu = 0.059\left(1+7.628\varphi^{0.6886}\left(\text{Re}_f \text{ Pr}_f \frac{d_p}{D}\right)^{0.001}\right)\text{Re}_{nf}^{0.9238}$	Cu-Water Cu-EG	22
Maïga *et.al.*, 2006	$Nu = 0.085(\text{Re}_{nf})^{0.71}(\text{Pr}_{nf})^{0.35}$	Cu-Water Cu-EG	23

As a result, the ANN model is used to predicting the values of thermal conductivities and dynamics viscosities for the ranges out of the present work of experiments. Then the ANN simulation produced in the ANSYS FLUENT 16.1 to determine the Nusselt number and the coefficient of heat transfer.

Figure 13 showed the relationship of the heat transfer coefficient along the tube at Re=1000 for various values of the volume fractions. It is clear that the heat transfer coefficient greater at the pipe entrance and reduces gradually during the pipe until the boundary layer fully developed through the pipe. That means a maximum enhancement heat transfer during the entrance region of the pipe because of the lower temperature of the liquid at the entrance compared with the rest of the heating pipe beside the thermal effects of the nanoparticles appears with the heat transfer.

It has been noticed that the values of the Nusselt number rise with Reynolds number and volume fraction increasing. This is due to two reasons, first when the volume concentrations increased, the thermal conductivity of nanofluid increased, the number of nanoparticles increased and hence their total contact area was simply higher, which, in turn, would provide a more effective heat exchange between the nanoparticles and base fluid. and secondly that, by increased flow rates, the Reynolds number and the amount of heat transfer increases as nanofluid flow rates increase.

Figure 14-17 showed the results of the ANSYS FLUENT 16.1 and compare with the other works. Figure 14 showed Nusselt number gradient along the pipe with different amount of the volume fractions. It can be notice that the profile curves of the Nusselt number in Figure 14 are approximately similar to the profile of thermal conductivities of Figure 13. This is because of the Nu depends on the convective heat transfer and thermal conductivity who both effect with the temperature gradient and volume fraction. Figure 15 showed the effect of the temperature on the Nusselt number gradient with variation of volume fractions. Again, the figure had a similar profile with Figure 10 for the same reasons mention above. Figure 16 illustrated comparisons between Numerical work with empirical correlation equations setup on Cu-Water nanofluid experiments at temperature 40 ^{0}C and volume fractions of 0.8%. Even there are differences in the assumptions between the empirical equations with this work; the results showed a good agreement with most correlations and that gives a confidence to get more results of the range of the experiments. It can be noted clearly that Nu Increases with increase Re. Figure 17 showed the effects of the diameter of nanoparticles on the thermal conductivity ratio of nanofluid. It can be noted that the thermal conductivity ratio decreased with the increase of the diameter of the nanoparticles, and the effect of the volume fraction throughout the small particle sizes was approximately nil. For that reason, it could be deduced that it's better to select the small particle sizes to improve the thermal conductivity, and that conform to the results produced by (Vasu *et.al.,* 2007) and (Akilu *et.al.,*2016).

Conclusion

This work measured experimentally the dynamic viscosity and thermal conductivity for pure water and Cu-Water nanofluid for various volume fractions, temperature and Reynolds number. Then ANN model achieved to model the Thermophysical properties which give a good results and could extent the results for more range of experiments. Thermal conductivity for the nanofluids had greater values compare with the pure water. Nusselt number increases with the volume fraction and Reynolds number while the thermal conductivity deceases with increase the diameter of nanoparticles.

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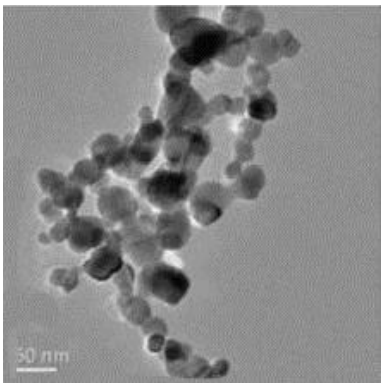

Figure 1 TEM photograph for the Cu-water nanofluids

Figure 2 1200W Ultrasonic processor for homogenizing nanofluid produced by MTI CORPORATION.

Figure 3 KD2PRO measuring device for thermal conductivity of nanofluid produced by DECAGON DEVICE INT.

Figure 4 NDJ-5S Viscometer measuring device for dynamic viscosity of nanofluid.

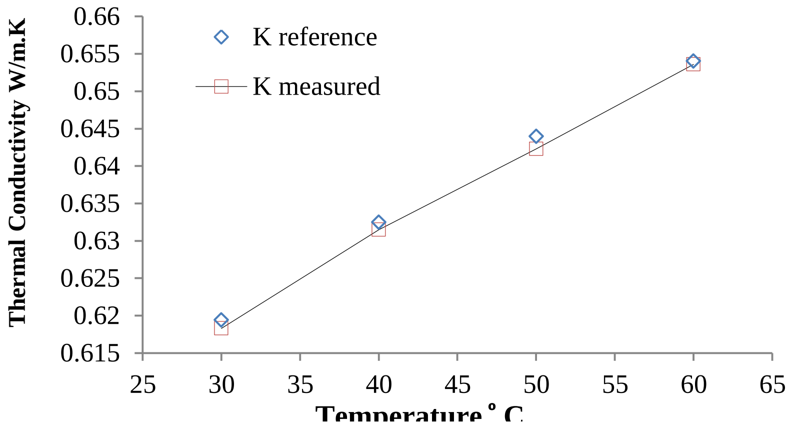

Figure 5 Thermal conductivity of distilled water validation with (Godson *et.al.*,2010).

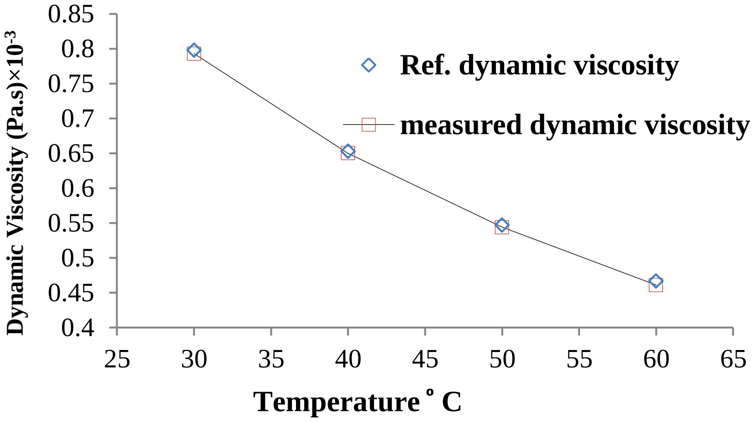

Figure 6 Comparison of measured distilled water dynamic viscosity and dynamic viscosity obtained by (Mclindon *et.al.*, 1998).

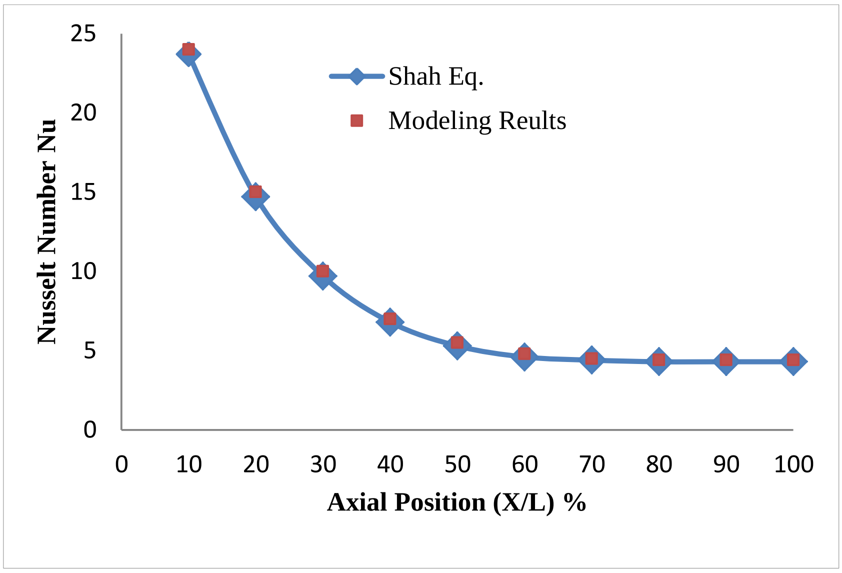

Figure 7 Comparison of the Nu of water with Shah equation

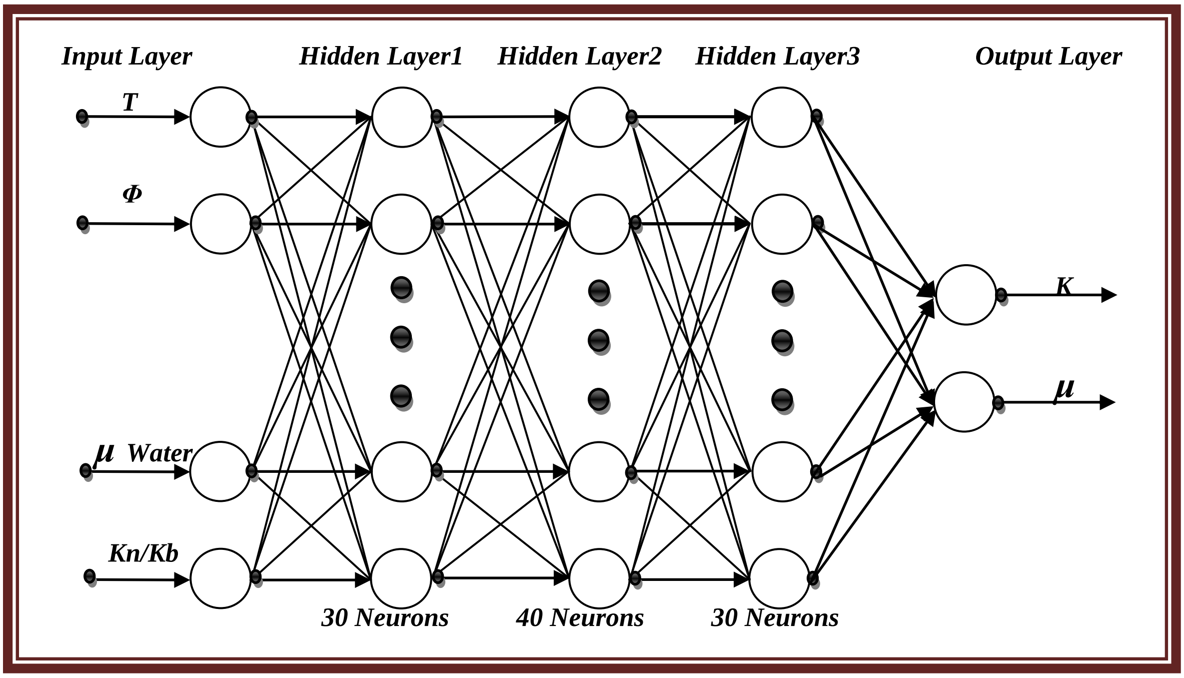

Figure 8 Structure of the Artificial Neural Network.

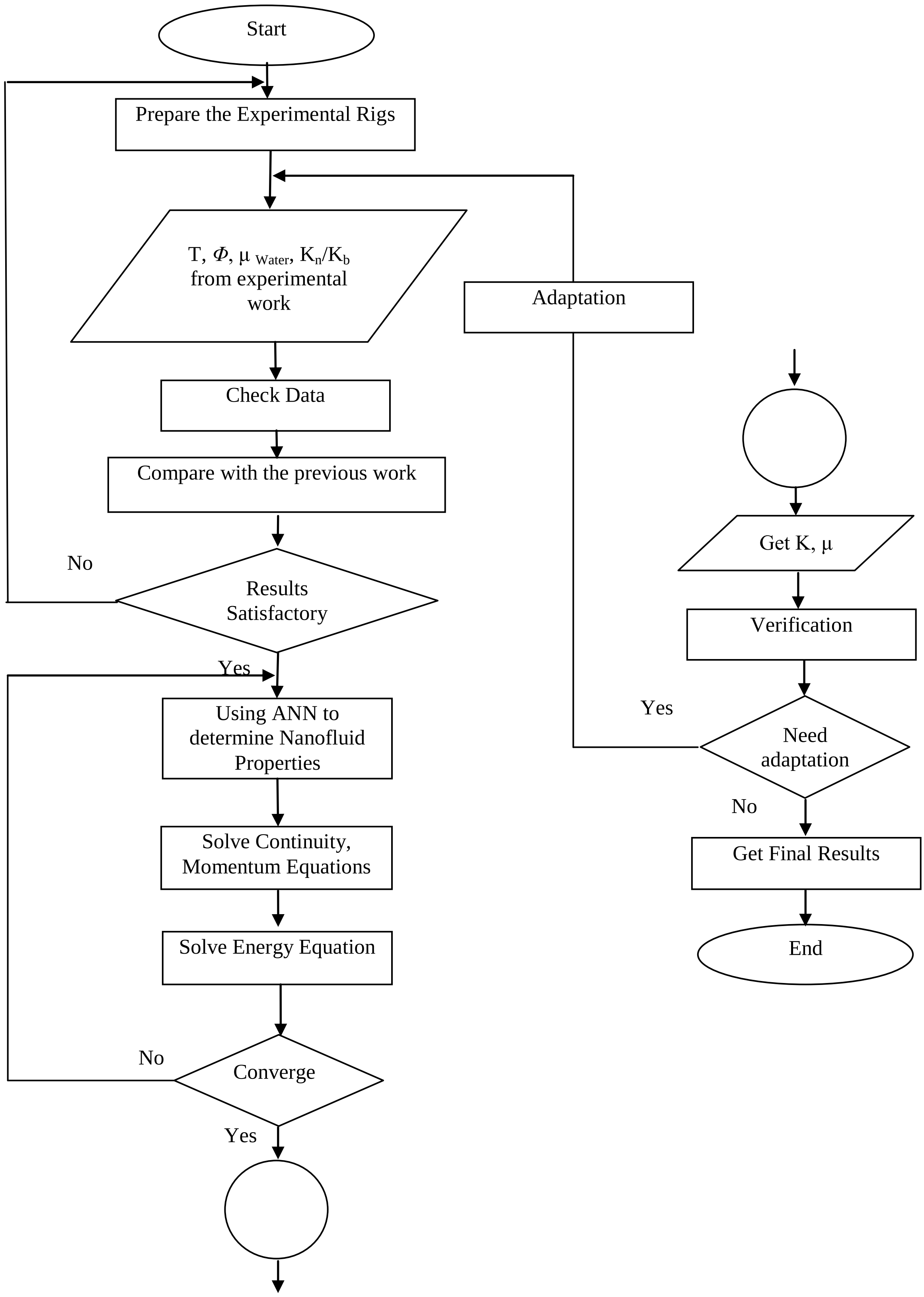

Figure 9 Flow chart for the solution procedure

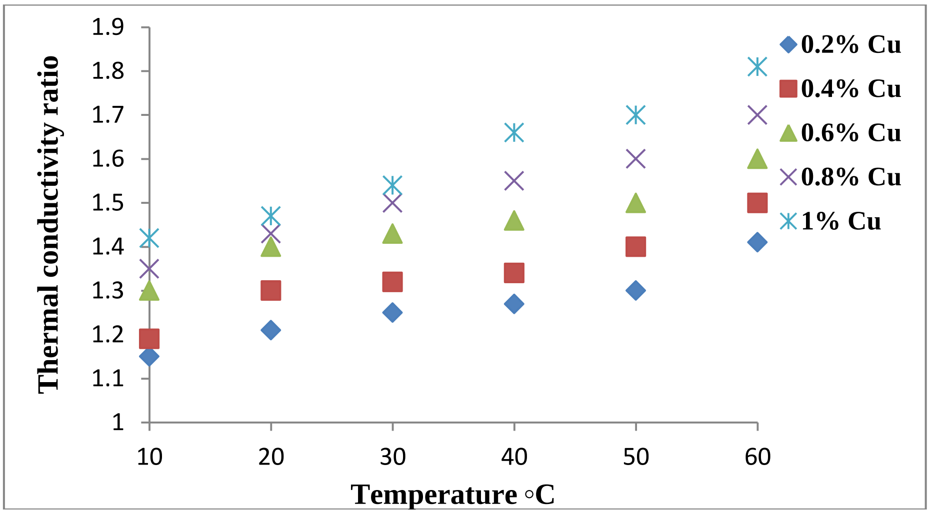

Figure 10 Thermal conductivities ratios of Cu nanofluid variations with temperature and volume fractions.

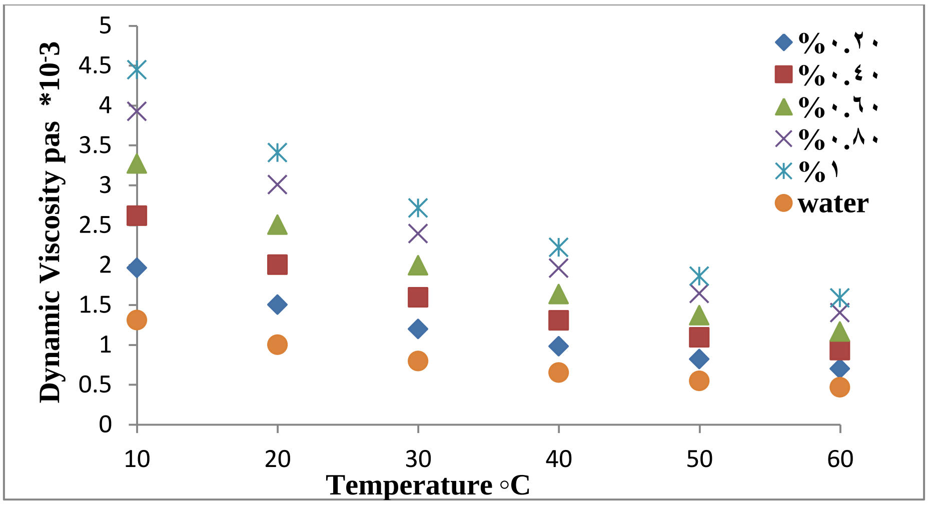

Figure 11 Dynamic viscosity Ratio of Cu nanofluids variation with temperatures and different volume fractions.

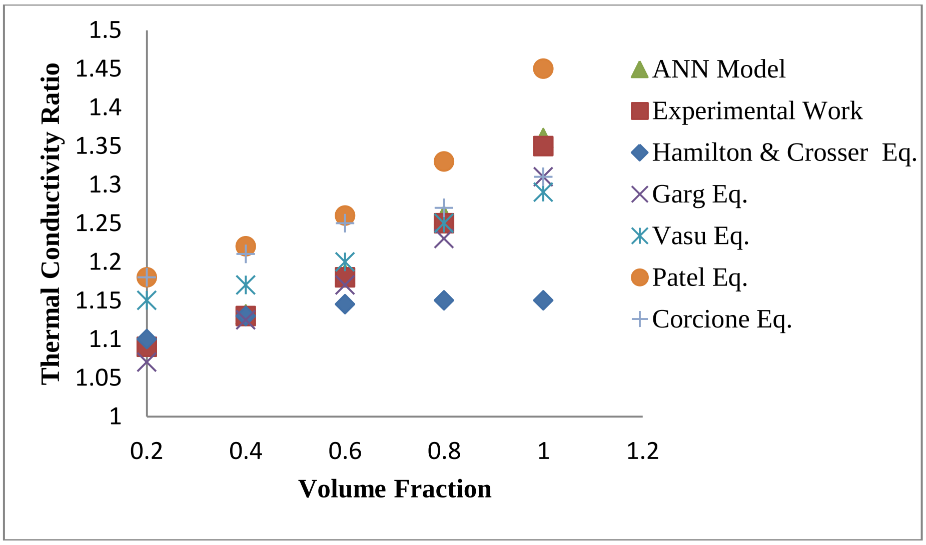

Figure 12 Comparison of the determined ratio of thermal conductivity and the predicted thermal conductivity by Artificial Neural Network Model (ANN).

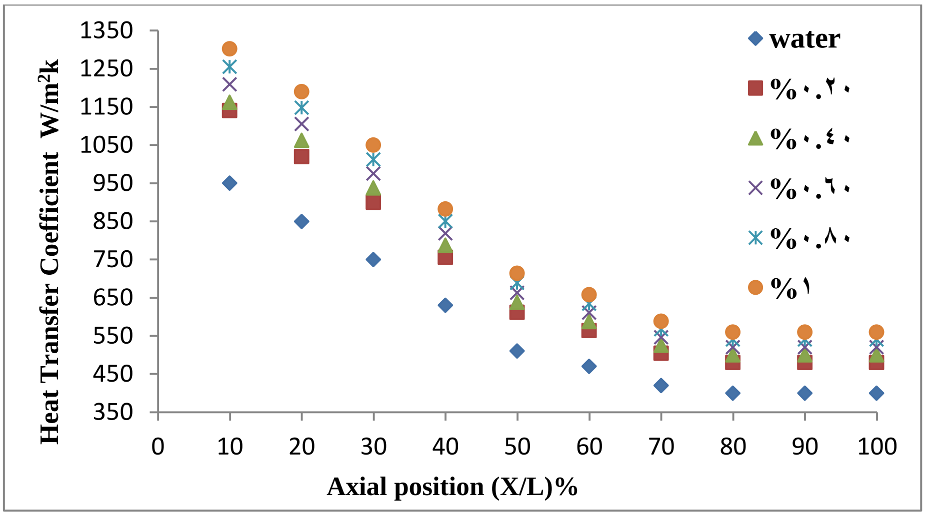

Figure 13 Heat transfer Coefficients for Cu nanofluid with axial position at Re= 1000.

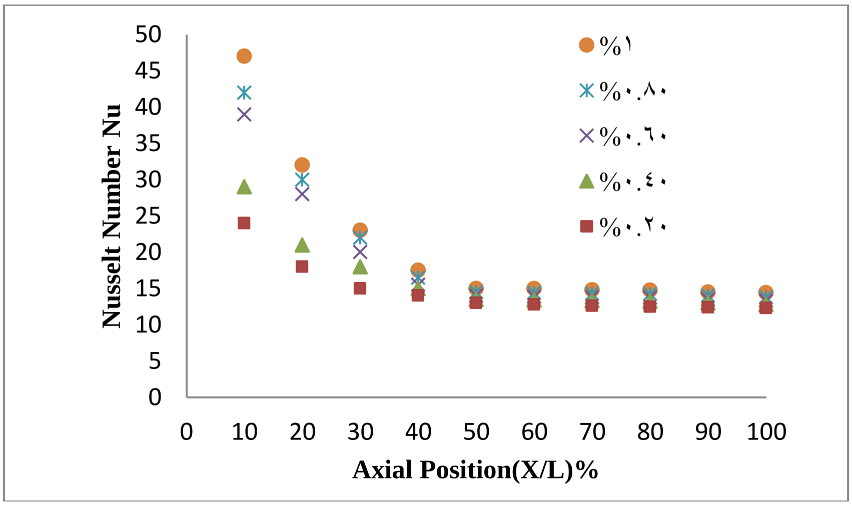

Figure 14 Nu along the axial position for various volume fractions

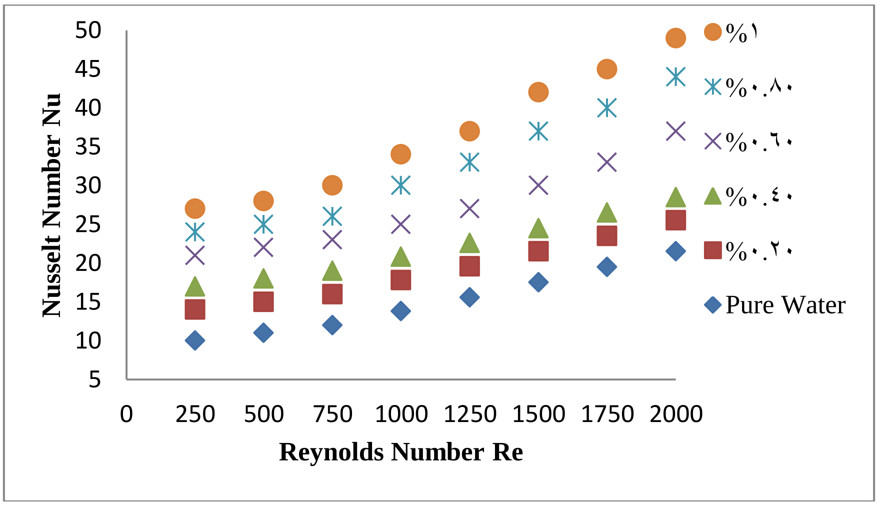

Figure 15 Effect of Re on Nu for various volume fractions

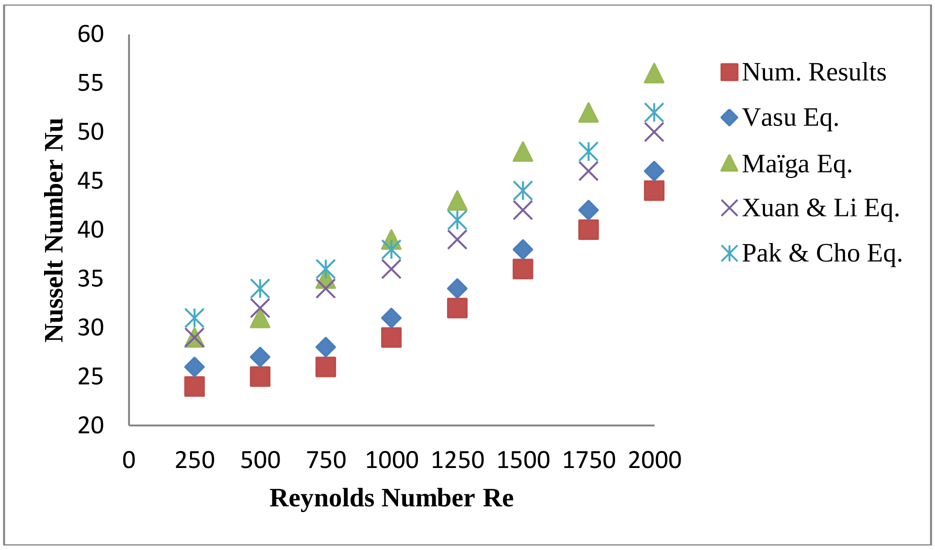

Figure 16 Comparisons for of Re on Nu of nanofluid at 40 ^{0}C and 0.8%

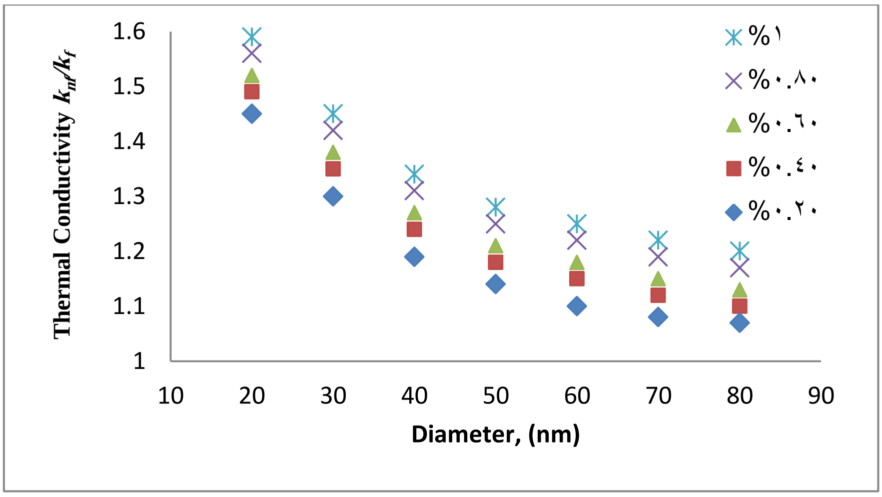

Figure 17 Diameter of nanoparticles effects on the thermal conductivity ratio of nanofluid