Experimental Investigation on the Multi-metallic Cu-Zn Nanofluids Heat Transfer Enhancement and Pressure Losses

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Abstract

Metallic nanofluids are suspensions of metallic particles of nanometre size in base fluids. The combination of two kinds of metallic particles mixed at the same volume ratio is known as multi-metallic nanoparticles. These multiple metallic particles of nanometre size were suspended in deionized H_2O via the use of ultrasonic vibrators at varying volume fractions as well as variations in the ratios of metallic/metallic particles of nanometre size. In our study the dynamic viscosity, the nanofluid's heat conductivities were determined for varying temperatures and volume fractions. The coefficient of thermal transmission of the flowing nanofluid in the constant wall heat flux tube were determined experimentally in laminar condition. The results revealed huge thermal transmission enhancement comparison to the base fluids. The pressure loses were illustrated for all nanofluids. The comparisons of the different metallic and multi-metallic types of the nanofluids were showed that Cu nanofluids have a greater coefficient of thermal transmission compared with the Cu-Zn, Zn at equal volume fractions.

Keywords: Nanofluid, Thermal transmission, Thermal transmission enhancement, Multi-metallic nanofluids

الخلاصة

النانوفلود المعدنية هي تعليق من الجسيمات المعدنية من حجم نانومتر في السوائل الاساسية. الجمع بين نوعين من الجسيمات النانوية المعدنية بنفس النسب يسمى النانوفلود متعدد الجسيمات النانوويه المعدنية. تم تعليق هذه الجزيئات متعددة المعدن في الماء منزوع الايونات عن طريق استخدام الموجات فوق الصوتية لاحجام جزيئية مختلفة وكذلك الاختلاف في نسبة الجزيئات المعدنية. في هذه الدراسة تم حساب اللزوجة الديناميكية والموصلية الحرارية للموائع النانوية مع اختلاف درجات الحرارة والحجم الجزيئي. تم احتساب معامل انتقال الحرارة للنانوفلوود متدفق في انبوب مع تسليط مصدر حراري ثابت على جدار الانبوب في ظروف الجريان الطباقي. كشفت النتائج عن تحسن كبير في معامل انتقال الحرارة للنانووفلود مقارنة مع الماء وقد تم توضيحه لجميع انواع النانوفلود. وكذلك فقدان الضغط قد تم توضيحه.واظهرت المقارنات بين مختلف انواع النانوفلود ان النحاس لديه معامل انتقال حراري اعلى من باقي انواع النانوفلود.

الكلمات المفتاحية :-سوائل نانوية ، تحسين انتقال الحرارة ، سوائل نانوية متعددة .

Introduction

Enhancements in the thermal transmission of working fluid play vital roles in the heat transfer equipments improvements. Nanofluids are suspensions of particles of nanometre size into working fluids to improve its thermal properties. In general, metal particles of nanometre size have greater heat conductivities compared to other forms of nanoparticles. The thermal transmission coefficient of Cu– water nanofluids in tubes within the Reynolds number ranges 10000 to 25000, for volume fraction (0.3–2.0) % has been previously determined (Xuan *et. al.*, 2003). In a similar vein, the correlations for the Nusselt numbers were proposed. The results showed increase in coefficient of convective thermal transmission with an increase in Reynolds numbers as well as volume fraction. On the other hand, the researchers found that pumping power penalty can be neglected. The same research group (Xuan *et.al.*, 2004) investigated in an experimental setting, the convective thermal transmission of Cu–water nanofluid for laminar flow in a flat tube. The data generated revealed that for 20% increase in the volume fraction, the Nusselt numbers of the nanofluids will increase by over 39% in comparison with those of H_2O that are pure.

Enhancements in thermal transmission in one phase flow of Cu–acetone particles with mean particle sizes g ranging from 80 to 100 nm range and ranges in weight fractions from 0.0 to 4.0 g/l has been previously investigated (Zhou *et. al.*, 2004). The coefficient of forced convective thermal transfer of Cu–(deionised) DI water at the size g = 26 nm and weight fractions range w = 0.5–2% has also been documented (Li *et.al.*, 2005). These scholars discovered that the increase in Nusselt numbers was proportional with the Reynolds numbers. However, the ratios of the Nusselt numbers of the nanofluids to base fluids ranged from 1.06 to 1.39 while the volume fractions of Cu particles of nanometre size rise from 0.5 to 2.0% of similar Reynolds numbers. The coefficient of thermal transmission of Carbon nanotube (CNT) suspended in water in a micro-channel with diameter of 355 mm and Reynolds numbers ranging from 2 to 17 and w = 1.10, 2.20 and 4.40% were experimentally investigated by (Faulkner *et.al.*,2004).The scholars demonstrated enhancements in the convective thermal transmission nanofluid at highest concentration. The coefficient of convective thermal transmission of graphite suspended in water nanofluid on the laminar flows in heat exchanger was previously investigated [6]. The data generated revealed that enhancements in the coefficient of thermal transmission of nanofluid at 2% by weight is 15% greater compared to base fluids. Multi-wall carbon nanotube MCNT at 0.1- 1% by weight nanofluid in a horizontal pipe has also been experimentally investigated (Ding *et.al.*, 2006). The data generated revealed that enhancements in thermal transmission was 350% at a Reynolds numbers 800. The researchers found that enhancement in the coefficient of thermal transmission highly exceeded the base fluid's thermal transmission coefficients for the aqueous-based Ti, carbon and Ti nano-tube nanofluid. While, the main reasons for this enhancement are the effective heat conductivities and the effect of the migration of particles on the thickness of the thermal boundary layers. (Maiga *et.al.*,2005) reported that the experimental data for the thermophysical characteristics of the nanofluids available from various groups in the literatures still not quite enough to clarify the physical explanations for the greater enhancements in the enhancements in thermal characteristics. Alongside, the coefficient of forced convective thermal transmission inside a circular pipe at laminar conditions in the literatures are still small and not enough to predict the enhancement for nanofluids. Therefore, more researches on thermal transmission coefficients of nanofluids are necessary. Additionally, mixing the different types of the nanoparticles will change the properties of the nanoparticles materials. The rig used in this experiment was constructed to measure the coefficient of convective thermal transmission of the multi-metallic Cu-Zn, Cu, as well as Zn suspensions in H_2O nanofluids for varying volume fractions at the laminar flow. The pressure losses for the different volume fractions were illustrated.

Preparation of the nanofluid

The first step in this research is to prepare the multi-metallic nanofluid using the two step procedure, then measuring the thermophysical properties for nanofluids. The multi-metallic Cu-Zn (by mixing Cu and Zn), nanoparticles were suspended in distilled H_2O at varying volume fractions using ultrasonic bath. The average size of the nanoparticles Cu and Zn was 50 nm. The volume fraction of the nanoparticles determine as below

$$\varnothing = \frac{V_p}{V_t} \tag{1}$$

Where V_p is the volume of the nanoparticles, while the V_t is the total volume for both the water and the nanoparticles. The four volume fraction were prepared (0.2, 0.4, 0.6 and 1) %. The 1.5 L were prepared for each volume fractions and used in the experiment measurements of the heat transfer coefficient after measuring the heat conductivities as well as the viscosity dynamics.

Thermophysical properties of the nanofluids

The heat conductivities of multi-metallic nanofluids and metallic nanofluids were determined with the use of galvanised transitory hot wire technique in the same method as earlier reported in a previous study (Balla et. al. , 2013). Heat conductivities at varying volume fractions with ranges of temperatures (30-50)° C were determined. The sine-wave Vibro Viscometer SV-10 was employed for the determination of the viscosity dynamics at price temperatures for Cu and Zn nanofluid suspended in water and measured using the water bath. The results for the viscosity dynamics as well as the heat conductivities were presented as reported previously (Balla *et.al.*, 2013) (While the thermal capacities and the densities of the nanofluids were determined as follow

$$\mu_{nf} = \mu_f + \varphi\mu_{np} \tag{2}$$

$$Cp_{nf} = Cp_f + \varphi Cp_{np} \tag{3}$$

Experimental set up

The experimental setup was built to evaluate thermal transmission of nanofluid flowing in a constant heated pipe at the wall with laminar flow and adiabatic conditions. The adiabatic conditions were achieved by insulating the pipe using three types of insulated, first type is a flexible rubber pipe insulation with measured thermal conductivity 0.033w/m.k. The second type insulation is, fiberglass wrap protects were its help to prevent heat loss through the copper pipe. Finally, Aluminum faced foam pipe wrap reflect heat from copper pipe. Also the Asbestos material was used to prevent the electricity effect. The schematic diagram of the experiment was illustrated in Figure 1. The experimental rig consist Cu pipe having an inner diameter of 10 mm and 2 mm thick, heater with constant heat flux 1500 W/m^2. The tube and heater were thermally isolated to prevent the heat loss to the environment. The temperatures at the wall of the tube were measured by eight T type thermocouples at the steady state conditions where the thermocouples were fixed in the hole of the wall to reduce the effect of the conductivity of the tube and obtain a good stick. The bulk temperature at the entrance and exit were determined using the thermal properties. The control valve was used to obtain the required Reynold numbers by capturing the flow rate required and changing the velocity. The National instrument was used to collect the all data.

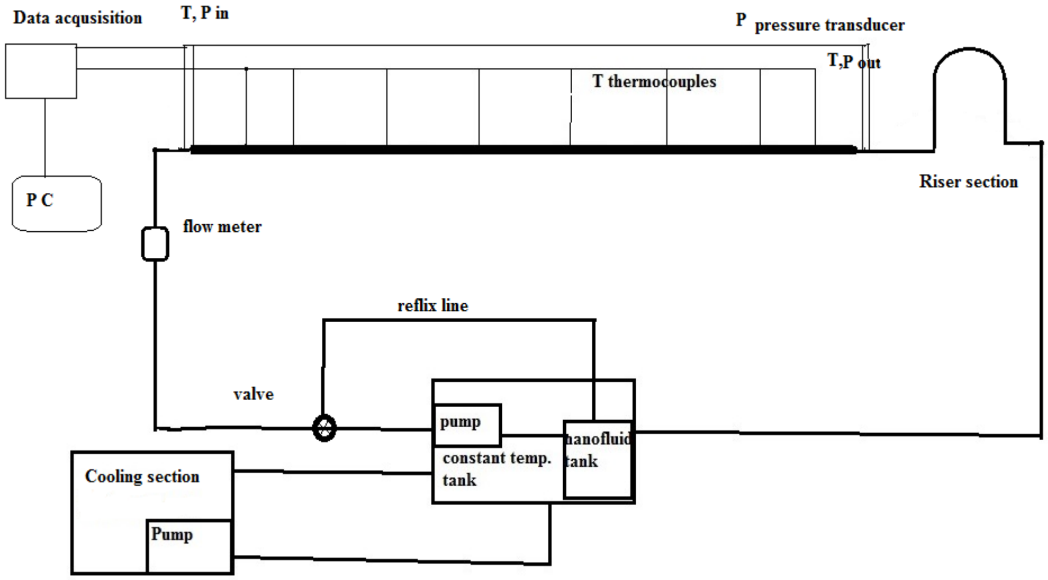

Fig. 1 Schematic diagram illustrating the experimental settings.

Coefficient of thermal transmission post process

For the purpose of determining the coefficient of thermal transmission, the conventional wall temperatures along the pipe wall, the entrance as well as the exit temperature were determined and record. So, to measure the coefficient of the conventional thermal transmission, the energy balance was writing as follows:

$$h_x = \frac{q_x}{T_w - T_{bnf}} \tag{4}$$

Where T_w is a wall temperature at x position and T_{bnf} the bulk temperature of the nanofluid at x position. While the

$$T_{nf(x)} = T_{nf(in)} + \frac{qP\,x}{\dot{m}\,c_p} \tag{5}$$

Where P is the Perimeter of the tube, C_{pnf} is a constant specific heat of the nanofluids. And the thermal flux is:

$$q_x = \frac{Q}{A_x} \tag{6}$$

Employing the coefficient of the conventional thermal transmission to calculate the conventional Nusselt number;

$$\mathrm{Nu}_x = \frac{h_x D}{k_{nf}} \tag{7}$$

The total coefficient of thermal transmission is:

$$h_{av} = \frac{\int_0^L h_x dx}{x} \tag{8}$$

Whereas the mean Nusselt number is:

$$\mathrm{Nu}_{av} = \frac{h_{av} D}{k_{nf}} \tag{9}$$

Reliability of the experiment

The parameters that were measured to determine the coefficient of convective thermal transmission and friction factors during experimental measurements were exposed to probabilities as a result of errors in the quantification. The Coleman and Steele (Coleman *et. al.*, 1995) method were used during the uncertainty estimation for the measurements in this study. The uncertainties in the experimental results were estimated at 95% confidence level for different measured variables which affect the Nusselt number correlation.

$$\left(\frac{\delta h}{h}\right) = \sqrt{\left[\left(\frac{\delta U}{U}\right)^2 + \left(\frac{\delta D}{D}\right)^2 + \left(\frac{\delta \emptyset}{\emptyset}\right)^2 + \left(\frac{\delta T}{T}\right)^2\right]} \tag{10}$$

Validation of the mathematical model

To validate the experimental results for the results Nu number of water compared with the Nu computed by Shah Correlation (Pak *et.al.*, 1998) were determined as illustrated in figure 2. The comparisons between the measured local Nusselt number and the theoretically calculated Nusselt number by Shah equation of water agreed well for the modelling with the Nu correlation with the Reynold number 1300. The comparisons of the experimental data generated with the theoretically generated results authenticated the numerical modelling for local fluid. The Darcy friction factor f as supplied by Blasius, could be derived from equations (11) and (12). The pressure losses measured from the experimental rig for water was compared with pressure losses obtained from Blasius equation [14]. Figure 3 depicts the comparisons of the determined pressure losses and the pressure loses determine by Blasis equation.

$$f = \frac{64}{Re} \tag{11}$$

$$\Delta p = f\left(\frac{1}{D}\right)\left(\frac{1}{2}\rho v^2\right) \tag{12}$$

Results and Discussion

The experimental local thermal transmission coefficients of Cu-Zn water in the thermally evolving regions are depicted as functions of the axial distance from the pipe inlet, at four volume fractions, as shown in Figures 5, 6 and 7 at Re 700, 1300 and 1900, respectively. All heat transfer coefficient data for the nanofluids are higher compared to those of pure DI- H_2O. Several trends were observed in Figures 5, 6 and 7. First of all, the convective thermal transmission coefficients decreases along the pipe. Secondly, the comparison of the figures 4, 5 and 6 show the coefficient of thermal transmission results of the Cu- Zn H_2O nanofluids showed that increase in the coefficients of thermal transmission leads to increase in Reynold numbers as well as the concentration of the particles. Additionally, the enhancements in the coefficient of thermal transmission at the entrance of the pipe are higher than the enhancements in thermal transmission coefficients at the fully develop regions. Lastly, the nanofluid demonstrated elongated inlet regions compared to the pure DI- H_2O. In the same manner, the coefficient of thermal transmission for the Cu-H_2O nanofluids were illustrated in Figures 8, 9 and 10 for the Reynold numbers 700, 1300 and 1900. The all observations obtained in the previous results were observed in the Cu water as well as it were obtained in the Zn water in the figures 11, 12 and 13 for the same Reynold numbers. The Interpretations for the first and second observations obtained for multi-metallic nanofluids in Figures 4, 5 and 6 are the same observations in Figures 7-12 with longer entrance region in all volume fractions. Some of the researchers as in [15, 16] gave two explanations for these

behaviours in nanofluid. The first reason is the agglomerate and the second is the attraction between nanoparticles such as a Van der waals attractive forces and exhaustion principles (Russel *et.al.*, 2012) While the first reasons could be reduced by decrease in the time for the experiments and increasing the ultrasonic time during the preparation of nanofluids. Then the attraction between the nanoparticles plays the vital role in this behavior in nanofluids. In addition, the use of multi-metallic nanofluids increasing these forces then as a result for that the entrance length were increased as shown in Figures 4, 5 and 6. Figure 13 shows the measured pressure change along the tube for Cu- Zn, Cu and Zn at 1% volume fractions at different Reynold number. The pressure loss increase with increase Reynold number as well as the rise in the volume fractions raise the pressure loss. The figure shows there is a penalty power loss due to using the nanofluids but still not far away from the pressure losses in water flowing. This increases in pressure loss for nanofluids due to effects of the nanofluid migration in the boundary layers. The average Nu number were determined for all nanofluid types using equation 9 and then put as an inputs to the minitab 6 statistical software to determine the average Nu number correlation as a function
for two factors Re and Prandtl number as follow,

$$Nu = 0.282\, Pe^{0.372} \qquad (13)$$

The 95% confidence was found between the experimental Nu and the Nu predicted by the correlated equation. The comparison of measured and correlated Nu change with Pe for all nanofluid was shown in figure 14. The figure demonstrated that increase in Nu with increase in Pe. The Pe is a dimensionless number used quantifying the ratios of the heat energy convicted to the fluids to the heat energy conducted within the fluids.

Conclusion

The heat transfer of the nanofluids such as multimetallic Cu-Zn, Cu and Zn water were measured in laminar flows in a fixed thermal flux at the wall. Based on the findings from the experimental measurements results, the nanofluids increase the coefficient of thermal transmission and the coefficient of the thermal transmission increases with an increase in the Reynold number. The 95% confidence was found between the experimental Nu and the Nu predicted by the correlated equation.

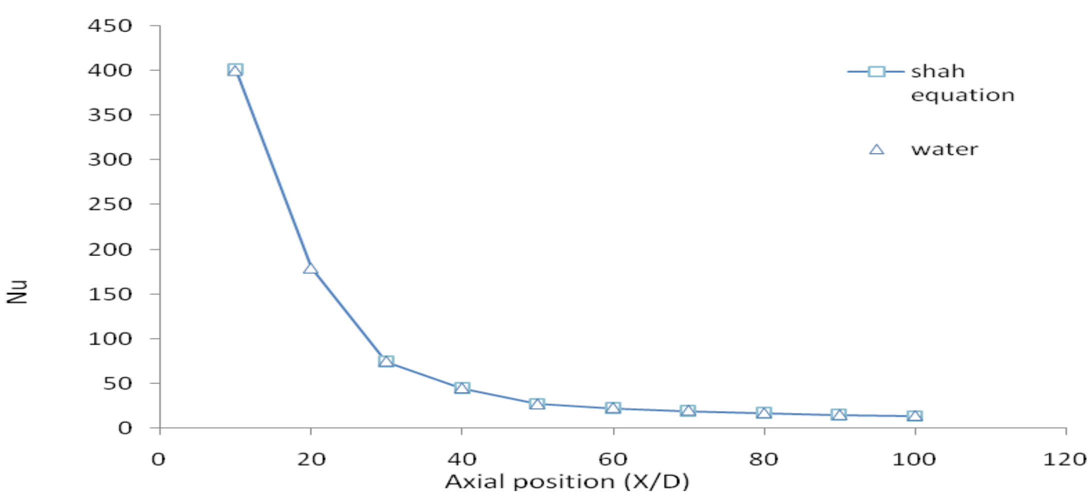

Figure 2 the comparison of the measured and theoretical Nusselt number for water along the tube at Reynold 1300.

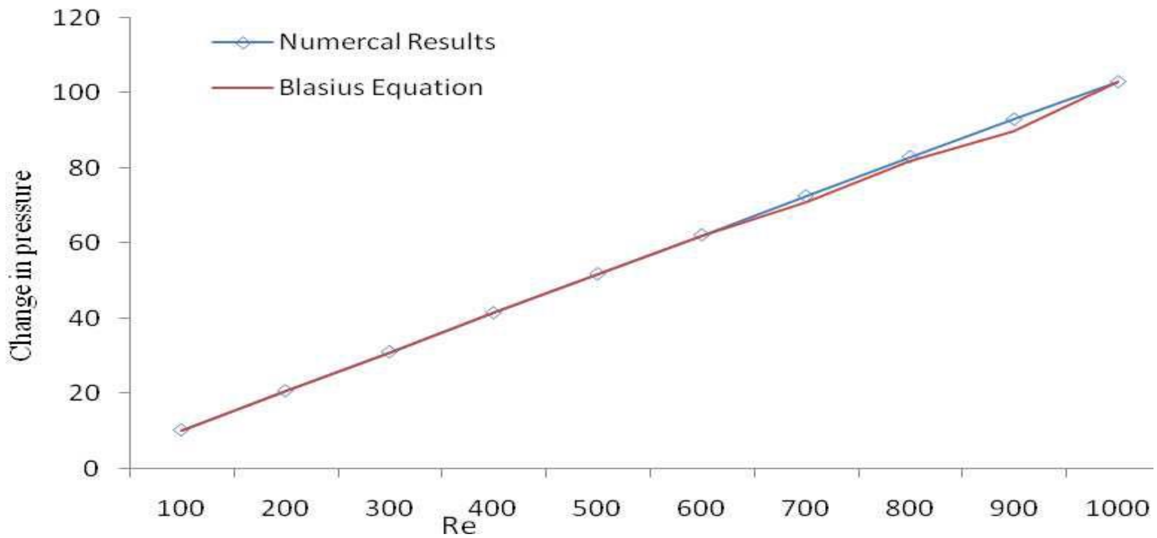

Figure 3 the comparison of the experimental and theoretical pressure losses of water along the tube.

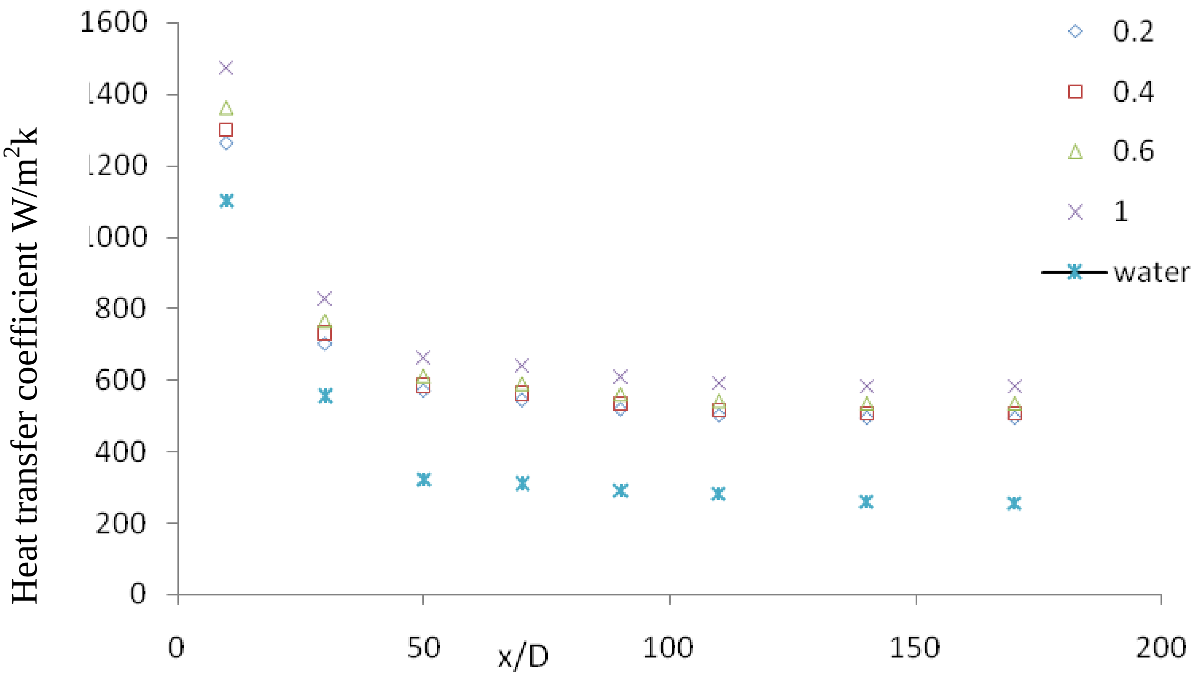

Figure 4 Coefficient of thermal transmission of multi-metallic Cu-Zn nanofluids along the pipe at Re 700.

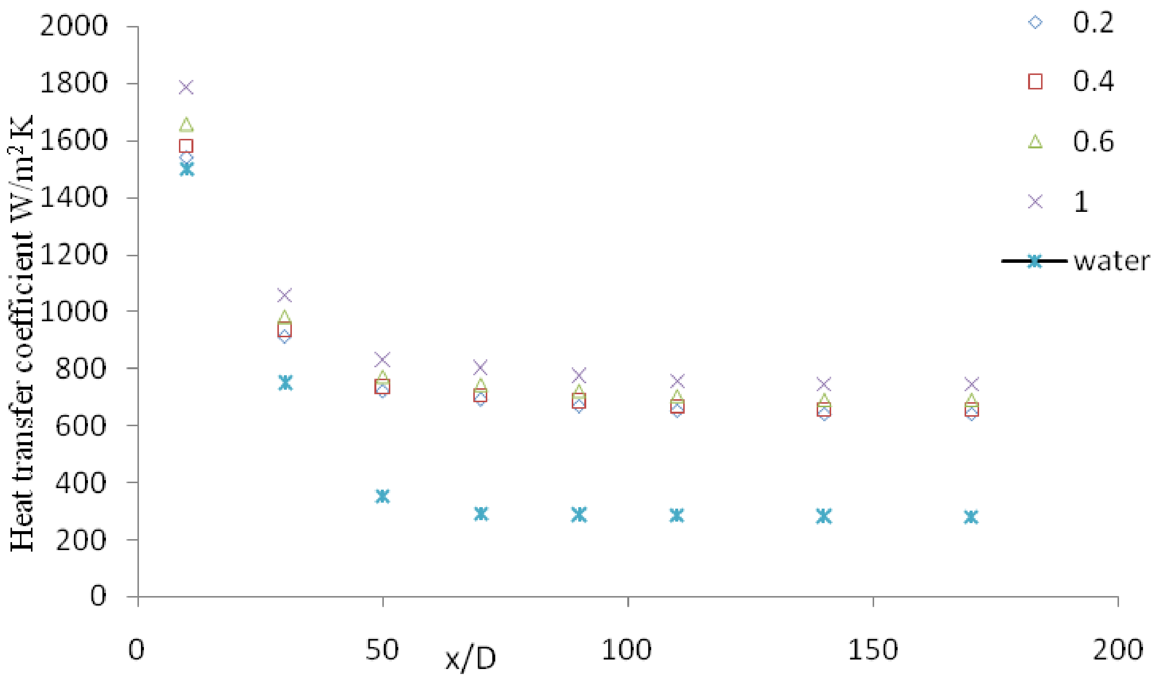

Figure 5: Coefficient of thermal transmission of multi-metallic Cu-Zn nanofluids along the pipe at Re 1300.

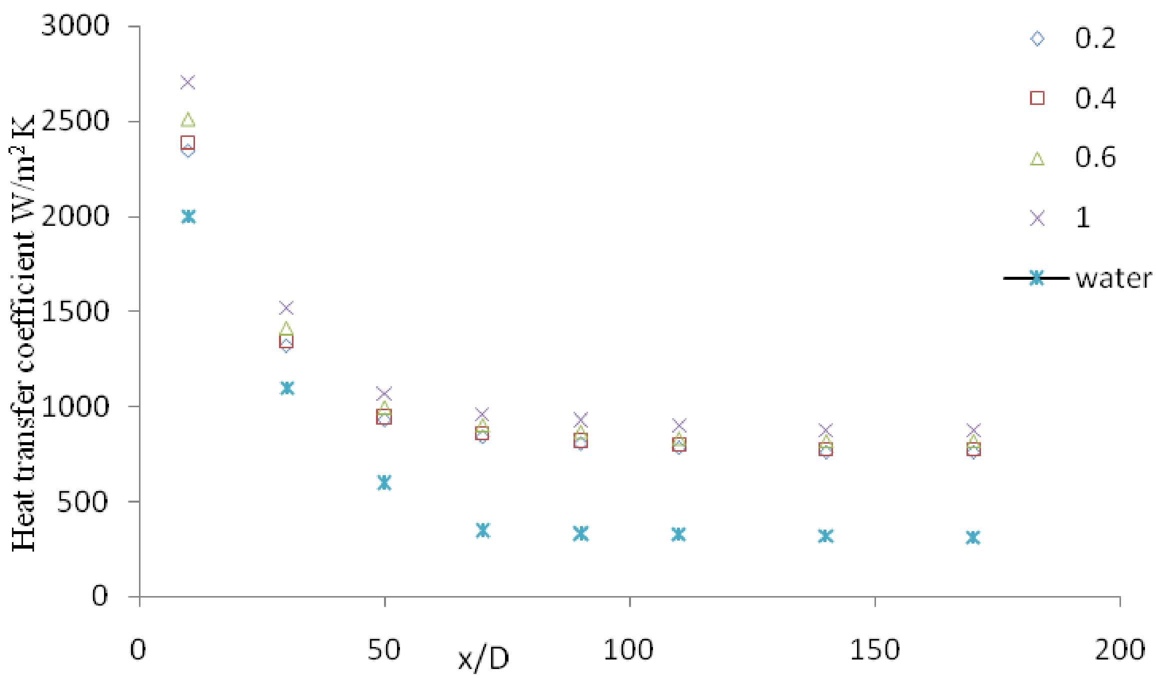

Figure 6: Coefficient of thermal transmission of multi-metallic Cu-Zn nanofluids along the pipe at Re 1900.

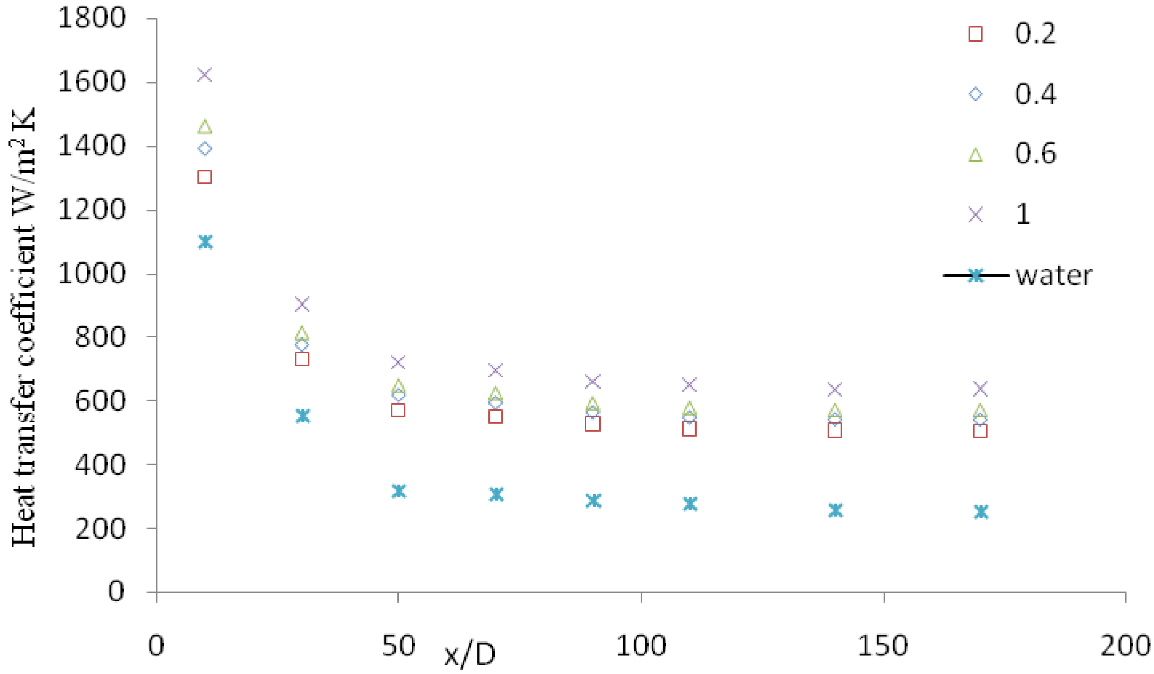

Figure 7: Coefficient of thermal transmission of metallic Cu nanofluids along the pipe at Re 700.

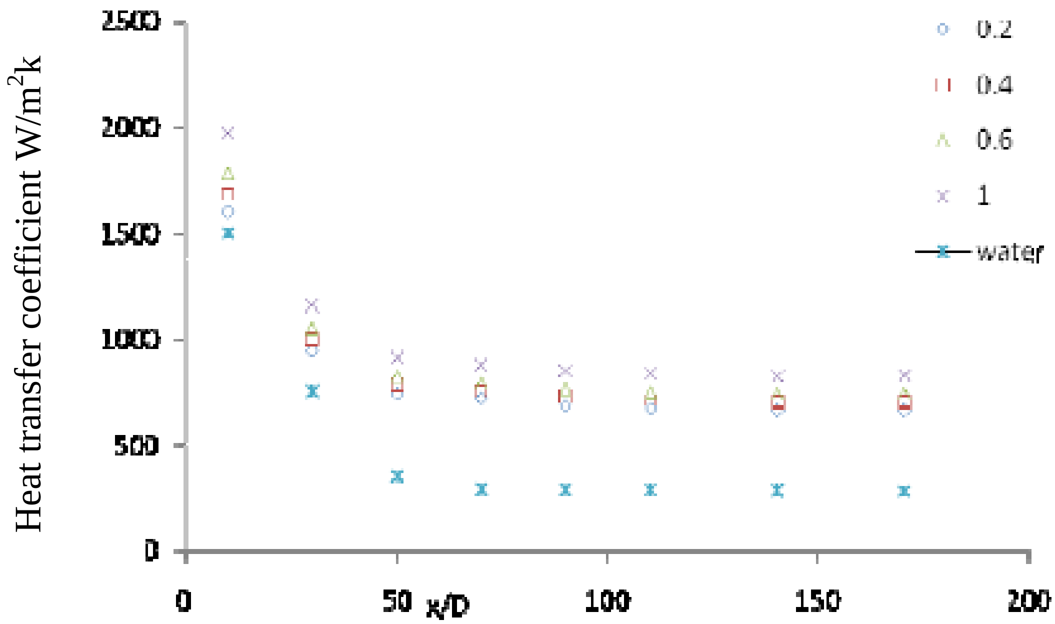

Figure 8: Coefficient of thermal transmission of metallic Cu nanofluids along the pipe at Re 1300.

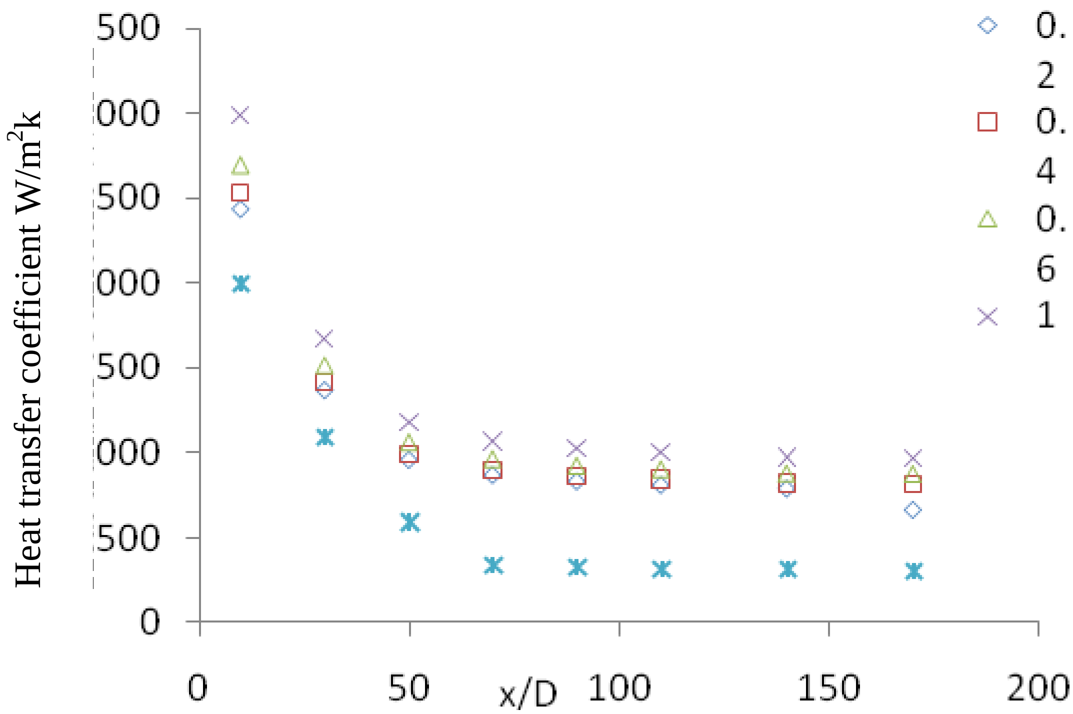

Figure 9: Coefficient of thermal transmission of metallic Cu nanofluids along the pipe at Re 1900.

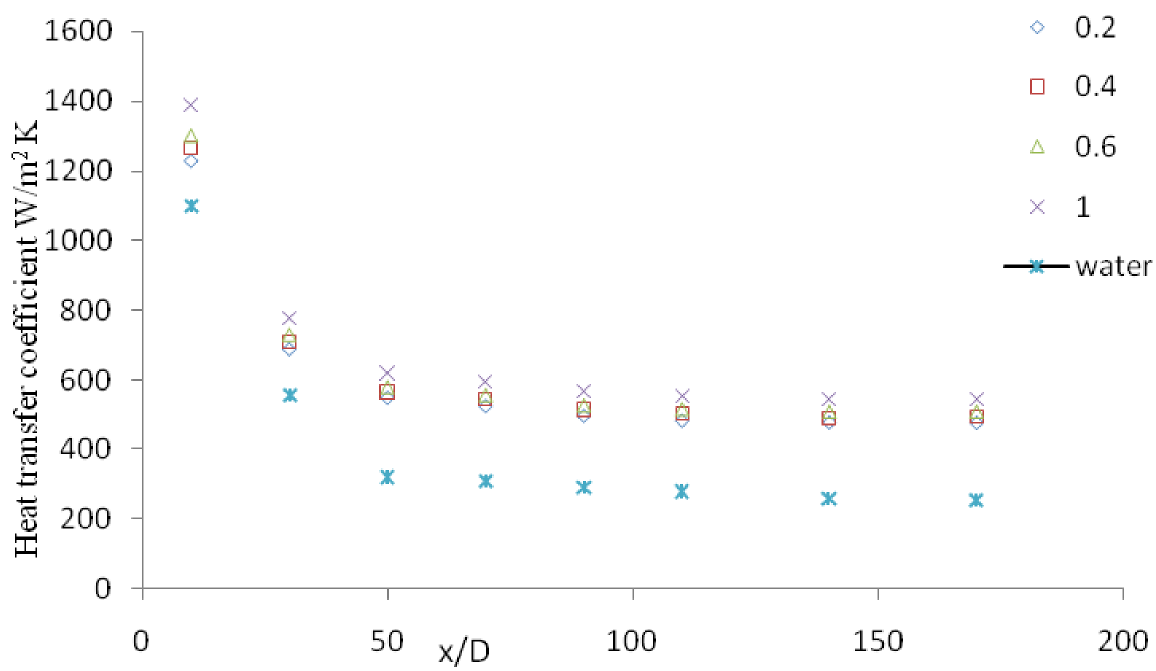

Figure 10: Coefficient of thermal transmission of metallic Zn nanofluids along the pipe at Re 700.

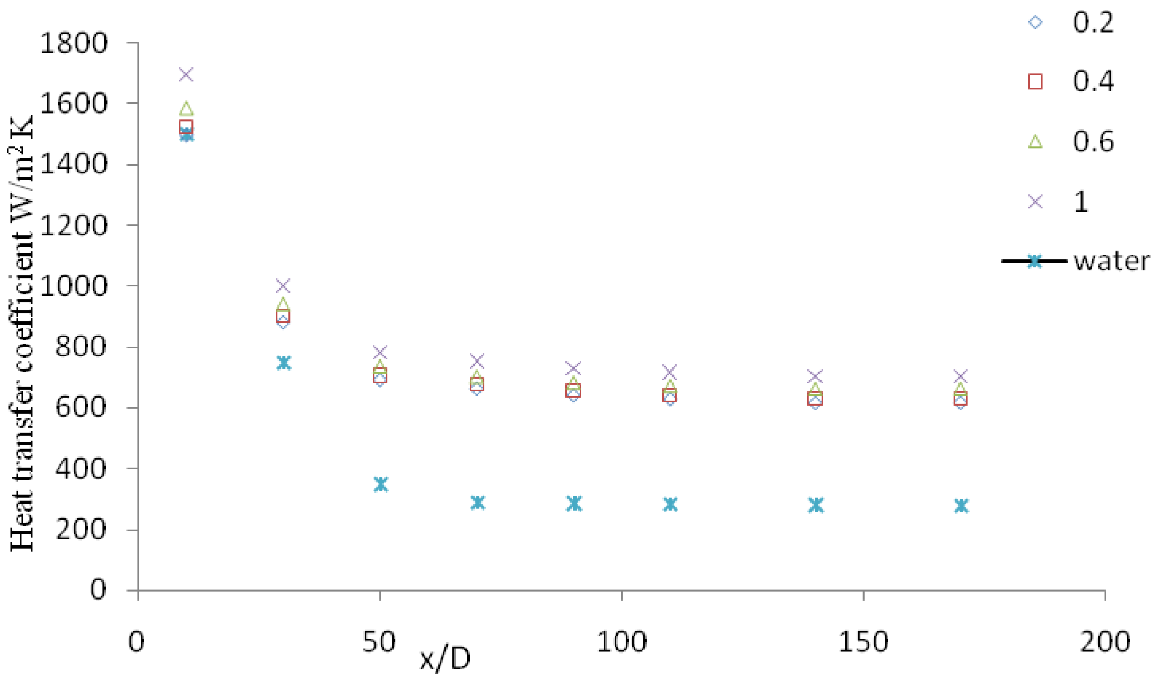

Figure 11: Coefficient of thermal transmission of metallic Zn nanofluids along the pipe at Re 1300.

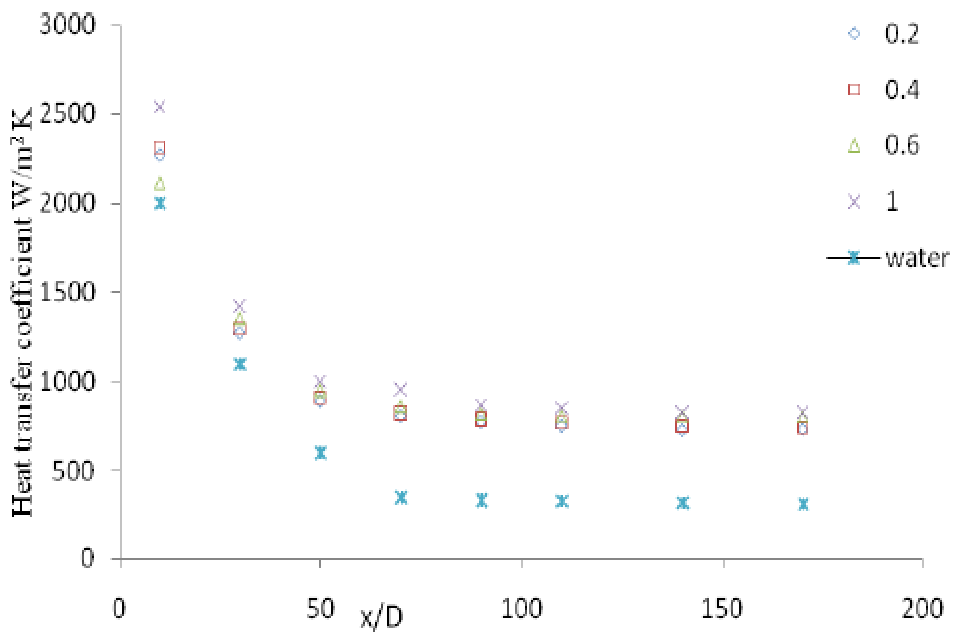

Figure 12: Coefficient of thermal transmission of metallic Zn nanofluids along the pipe at Re 1900.

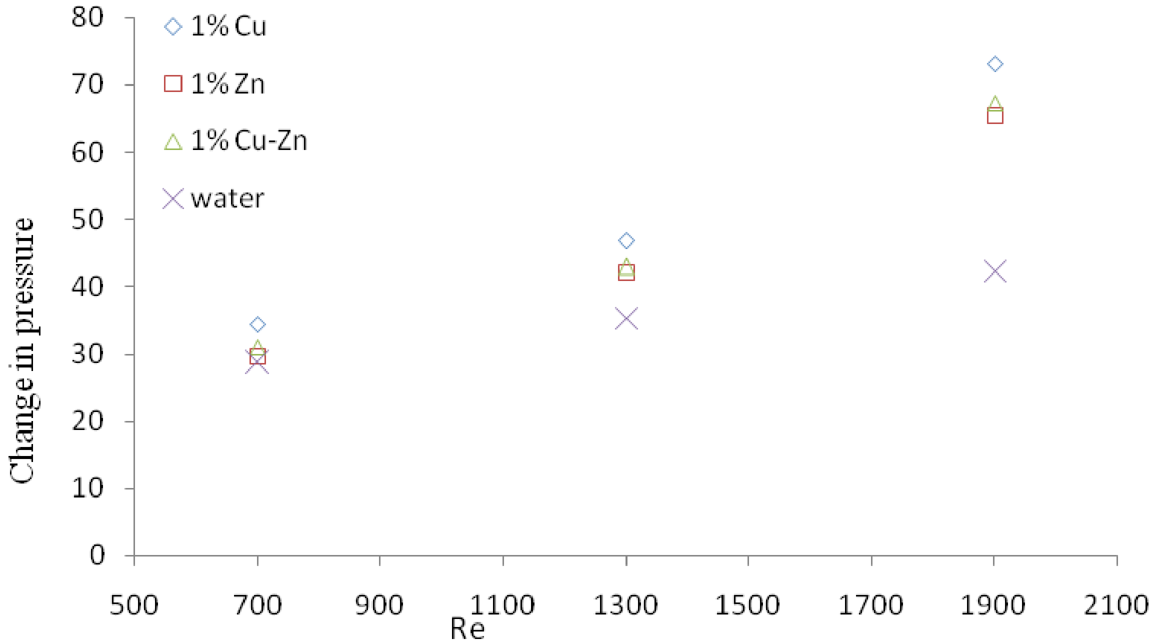

Figure 13: The comparison of the pressure change with Reynold number for different nanofluids at 1% volume fraction.

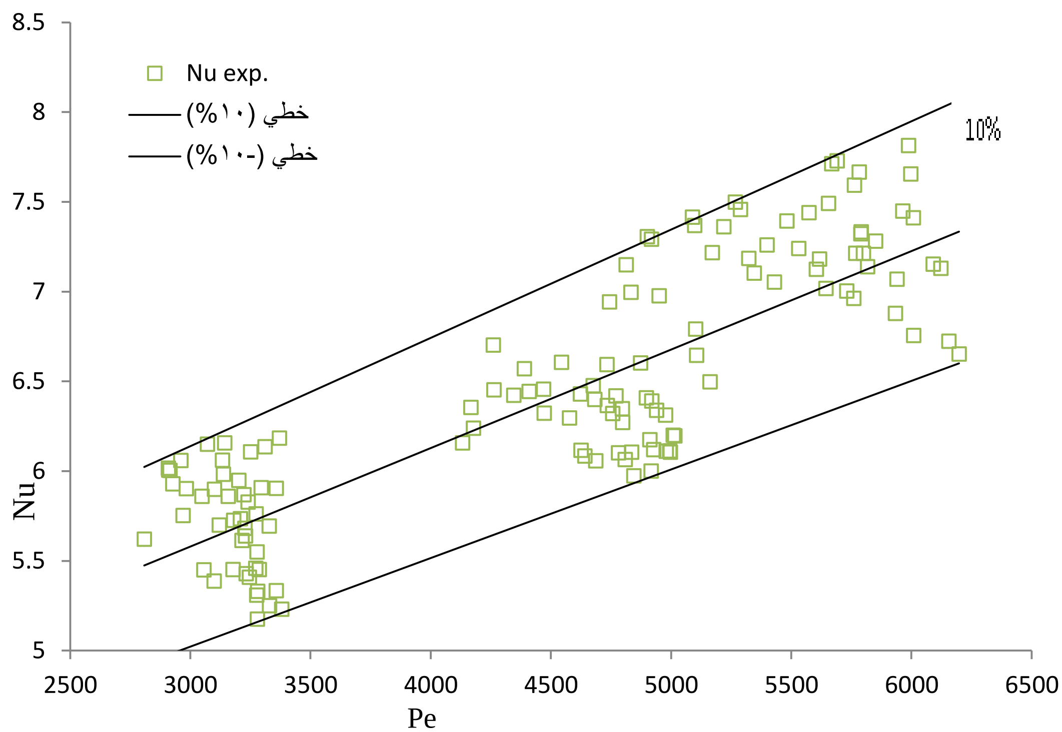

Figure 14 The comparison of measured and correlated Nu change with Pe for all nanofluids

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