Study the Effect of Two Base Fluids Distilled Water and Ethylene glycol on the Physical Properties of Nanofluids Containing Cu, Al and Zr_2O_3 Nanoparticles

Khalid Faisal Sultan
Lecture
Department of Electromechanical Engineering
University of Technology
E– mail: ksultan.61@yahoo.com

Received 25 September 2013 Accepted 19 January 2014

Abstract

In this investigation the thermal properties of nanofluids and three types of nanoparticles which are ((Cu 25 nm)+ E G), (Al(30nm)) + E G) and (Zr_2O_3 (50nm) + EG) was studied using two types of base fluids (ethylene glycol and distilled water). Ethylene Glycol was proven to be better than distilled water – based fluid in the nanofluids for having two properties which are thermal conductivity and specific heat, while distilled water was better than ethylene glycol for having two properties which are density and viscosity. The rates of increase in thermal conductivity in this research are 45%, 22 % and 7.25 % to each of the Cu/ DW, Al / DW and Zr_2O_3 / DW respectively, while these percentages are 30 %, 17 %, 4.5 % and to all of the Cu / EG, Al/EG and Zr_2O_3 / EG respectively at 2.5% vol a concentration and that the cause of this increase for Cu / EG is that the small size of the particles Cu (25nm), while the viscosity of Zr_2O_3 / EG is larger than Cu / EG and Al/ EG due to the large size of the particles Zr_2O_3 (50nm). The specific heat capacity of nanofluid made by ethylene glycol and Cu (25nm), Al (30nm) and Zr_2O_3 (50nm) nanoparticle inclusions measured at room temperature were compared with two kinds of models for determination of the specific heat capacity of nanofluid. The result indicates that the specific heat capacity of Cu (25nm), Al (30nm), Zr_2O_3 (50nm) nanofluid decreases gradually with increasing volume concentration of nanoparticles. It can be found that there is almost linear relation between shear stress and shear rate for all concentrations of nanofluids which confirm a Newtonian behavior for Cu / EG, Al/EG and Zr_2O_3/ EG in volume fraction 0.25 and 2.5 % vol as well as Cu / DW, Al/ DW and Zr_2O_3/ DW.

دراسة تأثير تغير مائع الاساس(ماء نقي و اثيلين كلايكول) على الخواص الفيزيائية للموائع النانوية التي تحتوي على جزئيات النحاس, الالمنيوم و اوكسيد الزركونيوم

د. خالد فيصل سلطان
مدرس
قسم الهندسة الكهروميكانيكية
الجامعة التكنلوجية

الخلاصة

تم التحقق في هذا البحث من الخواص الحرارية للموائع الفائقة الدقة والى ثلاثة أنواع من الجزئيات الفائقة الدقة

وهي
Zr_2O_3 (50nm) +EG) , (AL (30nm) + EG) , (Cu (25nm) + EG)
وباستخدام نوعين من مائع الأساس هما اثيلين الكلايكول وماء نقي وبيان أيهما أفضل في الموائع الفائقة الدقة حيث ثبت أن أثيلين الكلايكول يكون أفضل من الماء النقي كمائع أساس في الموائع الفاقة الدقة وللخاصيتين هما الكثافة, واللزوجة . بينما يكون الماء النقي أفضل كمائع أساس من أثيلين الكلايكول وللخاصيتين هما الموصلية الحرارية والحراة النوعية. أن نسب الزيادة في الموصلية الحرارية في هذا البحث هي 45% , 22% , 7.25% والى كل من Zr_2O_3 / DW , Cu /DW , Al/DW بينما وان 2.5vol% وعند تركيز Zr_2O_3 /EG, Al/EG, Cu /EG والى كل من 4.5% , 17 %, 30 % كانت هذه النسب هي Zr_2O_3 /EG الصغيرة في حين كانت اللزوجة Cu (25nm) هو أن حجم جزئيات Cu /EG سبب هذه الزيادة بالنسبة إلى الكبيرة. كما بينت النتائج ان الحرارة النوعية إلى Zr_2O_3 (50nm) بسب حجم جزئيات Cu/EG, AL /EG الأكبر من لزوجة تتناقص تدريجيا مع زيادة تركيز الجزيئات كذلك الحال الى (Zr_2O_3/EG, Al/EG, Cu /EG) الموائع الفائقة الدقة,
وبينت الدراسة أيضا أن الموائع الفائقة الدقة هي موائع نيوتينية من خلال العلاقة الخطية (Zr_2O_3/DW, Al/DW, Cu /DW) بين أجهاد القص ومعدل القص.

Keywords: **Nano fluid, Ethylene glycol, Distilled Water, Newtonian**

NUMENCLATURE

E	Heat loss	Watt
I	Current	A
V	Voltage	V
D	Thickness of the discs	mm
R	The radius of the disc	mm
Ds	Thickness of the sample	mm
T1, T_2, T3	The temperatures of the through discs.	k
DW	Distilled Water	__
EG	Ethylene Glycol	__
K	Thermal conductivity of Nanofluid	$W/m^2.k$
Φ	Volume fraction	%

Subscripts

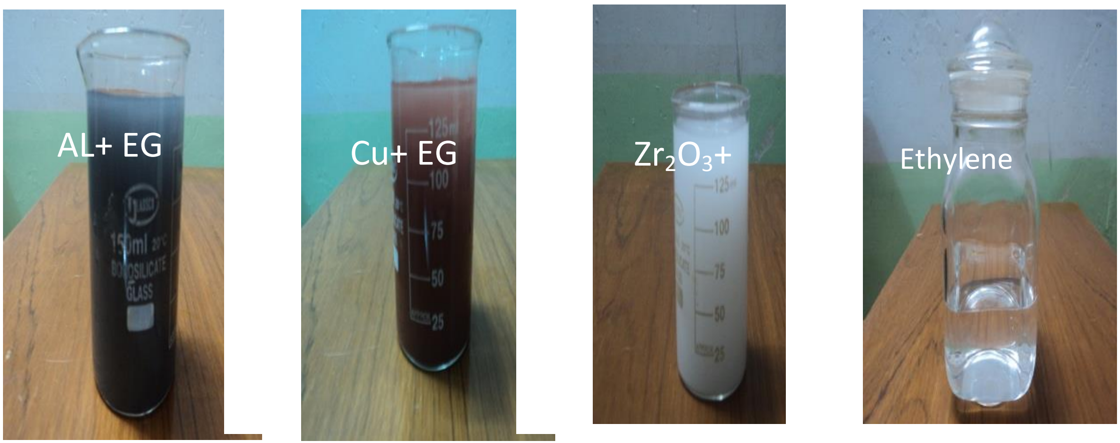
Nf	Nanofluid	__
b	Base	__

1. Introduction

Nanofluids, produced by dispersing nanoparticles into conventional heat transfer fluids, are proposed as the next generation heat transfer fluids due to the fact that their thermal conductivities are significantly higher than those of the base liquids [1]. Subsequently more than 16 laboratories worldwide have published experimental data on the thermal conductivity of nanofluids. The colloidal fluidic systems show unusually high thermal conductivity provided they are prepared in a suitable stable manner. At present the thermal conductivity data measured by different groups are scattered. Even for the same nanofluids, different groups reported different enhancements [2]. For instance, Lee et al. [3] reported an increase in thermal conductivity ratio of 14% compared to pure water with 3.5 vol. % CuO particles, while Eastman et al. [4] obtained a 40% increase at the same volume fraction. Masuda et al. [5] published results on the thermal conductivity of Al_2O_3–water nanofluid as early as 1993. The average size of their Al_2O_3 Nano particles used is about 13 nm. Their measurements gave a 30% increase at the particle loading of 4.3 vol.%, which was more than 20% higher than that reported by Lee et al. [3]. Some researchers' results [6, 7] showed that the thermal conductivities of Nano fluids were strongly dependent on the size of the suspended particles, with the conductivities decreasing with Nano particle sizes. While Xie's results [8] showed that the 60 nm particles gave about twice the enhancement as compared to the 15 nm particles, which was contrary to the former stated influence of the particle size. Hong's conclusion [9] was similar to that of Xie's[8]. In Hong's opinion suspensions containing small Nano particle clusters are more effective in improving thermal conductivity than that of individual dispersed Nano particles because the clustered Nano particles may provide a long path for heat transfer. Similar scattered phenomena occur in the study of the mechanisms of the thermal conductivity enhancements in nanofluids. The above facts demonstrate that several factors affect the measured thermal conductivity values, such as the temperature of fluid, particle size, the settlement time after nanofluid preparation and the stability of nanofluid. It should be noted that the stability of nanofluid is vital, because it not only affects the accuracy of measurement for the thermal conductivity of Nano fluid, but also affects its application in heat transfer systems when nanofluid is used as the substitute for conventional thermal fluid. Choi [10] reported that the Cu/ethylene glycol Nano fluid with 0.3% volume of Cu nanoparticles can enhance thermal conductivity up to 40%. In the present paper, we prepared stable nanofluids containing Cu, AL, and Zr_2O_3 nanoparticles through a two – step method. The thermal transport properties including thermal conductivity, viscosity, density and specific heat were measured experimentally and compared with that obtained using empirical correlation for many researchers in this field and were studied the effects of the concentration, size and type nanoparticles on enhancement of heat transfer.

2. Sample Preparation

Nanofluid samples were prepared by dispersing pre – weighed quantities of dry particles in both deionized water and ethylene glycol. The pH of each nanofluids mixture was measured. The mixtures were then subjected to ultrasonic mixing [60 kHz, 150 w at 25 – 30 ^{o} C, Toshiba, England] for several minutes to break up any particle aggregates. The acidic pH is much less than the iso electric point of these particles, thus ensuring positive surface charges on the particles. The surface enhanced repulsion between the particles, resulted in uniform dispersions for the duration of the experiments. An images of nanofluids containing Cu (25nm), Al (30nm) and Zr_2O_3 (50nm) are displayed in Fig.(1). In this study (1gm) of nanoparticles was mixed with (250 mL) pure water and ethylene glycol.



Figure(1): Image for Ethylene Glycol – Based NanoFluids Containing Al, Cu and Zr_2O_3 Nanoparticles

3. Experimental properties of the Nanofluids

Thermal properties of nanofluids with the three types of nanoparticles Al, Cu and Zr_2O_3 using two types of base fluids (distilled water and ethylene glycol) have been measured using the laboratory apparatus. The conductivity thermal, dynamic viscosity, specific heat, density have been compared with these obtained from correlation equations developed by many researchers in this field and measurement of these properties was as follows.

A. Measurement of the Viscosity

In this study, measurement of viscosity in practice where found that there is a very little difference between the practical and empirical relations used by researchers such as Einstain model [11], Brinkman model [12] ,Wang et al. model[13] , Batchel model[14]. The Wang et al. model is the closest to practical by a difference not exceeding 1.72%. Where the measured viscosity for three types of nanofluids (Cu (25nm) +EG), (Al (30nm)+EG) and Zr_2O_3 (50nm)+EG) with by different volume fraction and found the viscosity increase with concentration increasing. As well as to measure the viscosity ,measuring of the shear stress and the strain rate and the accuracy be ± 1% and the device which used to measure these variables BROOK FIELD DIGITAL VISCOMETER MODEL DV - E as shown in Fig (2). The principle of operation of the DV – E is to rotate a spindle (which is immersed in the test fluid) through a calibrated spring. The viscous drag of the fluid against the spindle is measured by the spring deflection. Spring deflection is measured with a rotary transducer which provides a torque signal. The measurement range of a DV – E (in cent poise or milli Pascal seconds) is determined by the rotational speed of the spindle. The viscosity of the Ethylene glycol and distilled water (60:40% by weight was measured before the addition any of types the three of nanoparticles. The obtained readings were compared with data from the American Society of Heating, Refrigerating and Air – conditioning Engineers (ASHRAE) hand book [15], see Fig. 3. The ASHRAE data and the experimental values match nicely (maximum difference of ± 2%) with temperature ranging from 20^0C to 55^0C.

Measurement of the Specific Heat

The specific heat of the nanofluid was measured using colorimeter as shown in Fig (4).The comparison between two models of specific heat is used in all researches by this field [16, 17], where the second model is the closest to the practical and a difference of 2.65%.

Measurement of the Thermal conductivity

The used apparatus for measuring the thermal conductivity of a nanofluid is (THC – 101) type and shown in Fig(5). Where using Lee's disc method for measurement of the thermal conductivity for nanofluids. Where three types used nanofluids are revealed in Fig (6), and the disc that was used in the experiments is shown in Fig (7). This method can be used for a wide range of temperatures and summary this method putting the model which want measurement thermal conductivity between two discs of brass (1, 2) and be thermal conductivity by heater coil and connecter to the power apparatus, The heater is switch on from the power supply with (V = 6 V and I = 0.2 A) to heat the brass disks (2 and 3) and the temperatures of the all disks increases in nonlinear relationships and at different rates with the time according to its position from the heat source. The schematic diagram for this method is depicted in Fig (8). put the device in the place of tightly closed to constant the temperature of the environment and after period of time arrived two discs (2,3) to the equilibrium and that any irregularity in the sample disc result of not access to an equilibrium state and if you know the temperature of the discs (1,2,3) and the thermal energy which passing through the coil can be calculated the thermal conductivity in the following form.[17,18].

$$K\left[\frac{T_2-T_1}{ds}\right]=e\left[T_1+\frac{2}{r}\left(d_1+\frac{1}{2}ds\right)T_1+\frac{1}{2}ds\,T_2\right] \tag{1}$$

And can calculate the value of **e** as follows:

$$IV=\pi r^2 e\left(T_1+T_3\right)+2\pi r e\left[d_1T_1+\frac{1}{2}ds\left(T_1+T_2\right)+d_2T_2+d_3T_3\right] \tag{2}$$

The experimental results for the thermal conductivity comparison with the equations or models of thermal conductivity developed by researchers such as Hamilton and Crosser model [19], Timo Feeva et al model[20], Wesley Charles – Williams' model[21], Yu and Choi model[22]. The Hamilton and Crosser is the closest to practical by difference does not exceed 3. 27%.

4. Results and discussion

The measured values of the density agrees well with the figures from mixing theory [14] as shown in Figs.(9 and 10). Also show at the density of Ethylene glycol – based Cu ,Al and Zr_2O_3 are increased with increasing concentration . The density of Cu/EG is greater than Zr_2O_3/EG and Al/EG due to the high density and small particle size for Cu. Figs.(11, 12 and 13) show that the dynamic viscosity of Ethylene glycol – based Cu ,AL and Zr_2O_3 are increased about 2.3 % for 0.25vol% at $25C^0$ compared with that of EG. The viscosity for EG/ Zr_2O_3 is greater than EG/Al and EG/Al_2O_3 due to large particle size for Zr_2O_3 (50nm) as show in Fig.(14).

Figs.(15, 16 and 17) reveal the small difference between the experimental results and two models may arouse from the surface and size effects on the specific heat capacity of nanoparticle [13], and hence, decreased with increasing,due to agglomeration of nanofluid (clustering).

We adopt model I and II respectively to show the nanoparticle size effect on the specific heat capacity of nanofluid, as shown in Fig.18. The specific heat capacities of nanoparticles correspond to the bulk Cu (25 nm), Al(30nm) and Zr_2O_3 (50nm) respectively [13]. As shown the specific heat capacity of nanofluid is underestimated using the specific heat capacity of bulk Cu, Al and Zr_2O_3. While the prediction can be improved with the specific heat capacity of Cu (25 nm), Al (30 nm) and Zr_2O_3 (50nm) nanoparticle obtained from either theoretical analysis or experiments. The results from our previous calculation show that the discrepancy between nanoparticles with different sizes is small when increasing the nanoparticle volume concentration due to the large specific heat capacity of base fluid. Qualitatively the solid – liquid interface may change the phonon vibration mode near the surface area of a nanoparticle and thus change the specific heat capacity of nanofluid. The high specific interfacial area of nanoparticle can adsorb liquid molecules to its surface and form liquid layers which will reversely constrain nanoparticle and turns its free – boundary surface atoms to be non – free interior atoms [13]. The varied Gibbs free energy of nanoparticle and liquid layers will further change the specific heat capacity of nanofluid. Fig.18. shows that the specific heat capacity for Al/EG is greater than Zr_2O_3 and Cu due to nanoparticle size. The results indicates that the specific heat capacity of Cu (25 nm), Al (30 nm) and Zr_2O_3 (50nm) nanofluid decreases gradually with increasing volume concentration of nanoparticles. Figs.(19–22) shows the dependence of thermal conductivity enhancement on the particle volume fraction for Cu/ EG, Al/EG and Zr_2O_3/EG nanofluids. The thermal conductivity enhancement is calculated from the following formula:

$$\text{Thermal Conductivity Enhancement (\%)} = \left(\frac{k_{nf}}{k_b} - 1\right)x100$$

Results show that the thermal conductivity enhancement increases with the volume fraction of Cu (25 nm), Al (30nm) and Zr_2O_3 (50nm) nanoparticles (see Figs 19,20, 21 and 22) and the Hamilton and Crosser is the closest to practical difference does not exceed 3.27 %. The highest thermal conductivity enhancement observed in the current experiment is 30 %, 17 % and 4.5% at a particle volume fraction of 2.5% for Cu / EG, Al/EG and Zr_2O_3/ EG nanofluids respectively. The thermal conductivity enhancement for Cu /EG is greater than Al/ EG and Zr_2O_3/EG Nano fluids due to small nanoparticle size for Cu as shown in Fig .22. The Figs (23, 24, and 25) represent shear stress versus shear rate for three series of nanofluid in various concentrations. It can be found that there is almost linear relation between shear stress and shear rate for all concentrations of nanofluids which confirm a Newtonian behavior for Cu / EG, Al/EG and Zr_2O_3 / EG in volume fraction 0.25 and 2.5 vol %. It is found that the addition of nano particles increase the wall shear stress.

Figs (26, 27, 28 and 29) represent the ratios of density, viscosity, specific heat and thermal conductivity to the base fluid ethylene glycol – based Cu / EG, Al/EG and Zr_2O_3 / EG. The results show that the Cu /DW, Al/DW and Zr_2O_3/DW nanofluids gives higher thermal properties, heat transfer enhancement and shear stress rise than the Cu / EG, Al/EG and Zr_2O_3 / EG nanofluid **.**

5. Conclusion

1. It was found that the addition of nanoparticles increases both the thermal conductivity and wall shear stress.
2. The shear stress and shear rate of Cu, Al and Zr_2O_3 nanofluid have shown a linear relationship and the nanofluid exhibited Newtonian behavior.
3. The nanoparticle volume concentration has considerable influence on the viscosity of Cu, Al and Zr_2O_3 nanofluid. The Nano fluid with higher particle concentrations exhibited more viscosity.
4. The viscosity of nanofluid for the base of Ethylene glycol or distilled water increases when the volume concentration of nanoparticles increases.
5. The effect of nanoparticle size and nanoparticle – liquid interface on the specifIc heat capacity of Nanofluid.
6. The effect of liquid adsorption on suspended nanoparticle's surface will also increase the specific heat capacity of nanofluid to some extent with increasing nanoparticle's volume concentration, which may be worthy be investigated further for nanofluid.
7. The results show that nanofluids EG based (Cu, Al and Zr_2O_3) gives better density and viscosity than distilled water ,while on reversal for thermal conductivity and specific heat be better for distilled water than Ethylene glycol

6. Reference

[1] Y.M. Xuan, Q. Li, W.F. Hu, Aggregation structure and thermal conductivity of Nanofluid, AIChE J. 49 (2003) 1038.

[2] S. Kabelac, J.F. Kuhnke, annals of the Assembly for International Heat Transfer Conference, 2006, p. 13, KN-11.

[3] S. Lee, S.U.S. Choi, S. Li, J.A. Eastman, Measuring thermal conductivity of fluids Containing oxide Nano particles, J. Heat Transfer 121 (1999) 280.

[4] J.A. Eastman, S.U.S. Choi, S. Li, L.J. Thompson, Proc. Symp. Nano phase Nano comp. Materials, 1997, pp. 3–11, II.

[5] H. Masuda, A. Ebata, K. Teramae, N. Hishinuma, Alteration of thermal Conductivity and viscosity of liquid by dispersing ultra-fine particles (dispersions of λ – Al_2O_3,SiO2 and TiO2 ultra-fine particles), Netsu Bussei 4 (1993) 227–233.

[6] S.H. Kim, S.R. Choi, D.S. Kim, Thermal conductivity of metal-oxide Nano fluids: particle size dependence and effect of laser irradiation. ASME J. Heat Transfer 129(2007) 298.

[7] C.H. Chon, K.D. Kihm, S.P. Lee, S.U.S. Choi, Empirical correlation finding the role of temperature and particle size for Nano fluid (Al_2O_3) thermal conductivity enhancement, Appl. Phys. Lett. 87 (2005) 153107.

[8] H.Q. Xie, J.C. Wang, T.G. Xi, Y. Liu, F. Ai, Q.R. Wu, Thermal conductivity enhancement of suspensions containing Nano sized alumina particles, J. Appl. Phys. 91 (2002) 4568.

[9] T.K. Hong, H.S. Yang, C.J. Choi, Study of the enhanced thermal conductivity of Fe Nano fluid, J. Appl. Phys. 97 (2005) 064311.

[10] Eastman JA, Choi SUS, Li S et al (2001) Anomalously increased effective thermal conductivities of ethylene glycol-based Nano fluids containing copper Nano particles. Appl Phys Lett 78:718–720

[11] A. Einstein, 1956. Investigation on the theory of Brownian motion", Dover, New York, .pp.1 – 18.

[12] H.C.Brinkman, 1952. The viscosity of concentrated suspensions and solution". Chem.Phys .20571.

[13] B.-X. Wang, L.-P. Zhou, and X.-F. Peng, “Surface and size effects on the specific heat capacity of nanoparticles,” International Journal of Thermophysics, vol. 27, no. 1, pp. 139–151, 2006

[14] G.K.Batchelor, 1977. The effect of Brownian motion on the bulk stress in a suspension of Spherical particles". J.Fluid mech.83 (1) 97.

[15] ASHRAE Handbook 1985 Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc., Atlanta, 1985.

[16] B. Pak, Y. Cho,1998. Hydrodynamic and heat transfer study of dispersed fluids with Submicron metallic oxide particles", Experimental Heat Transfer 11 (2) 151–170.

[17] Xuan, Y. and W. Roetzel, 2000**.** Conceptions for heat transfer correlation of nanofluids, International Journal of Heat and Mass Transfer, 43: 3701-3707.

[18] Murthy BSR, Dr.A.Ram Krisnna and Rama KrisnnaB.v.2004.Thermally analysis of Epoxy Based Fiber Reinforced" IE (I) Journal –Mc, vol.84.

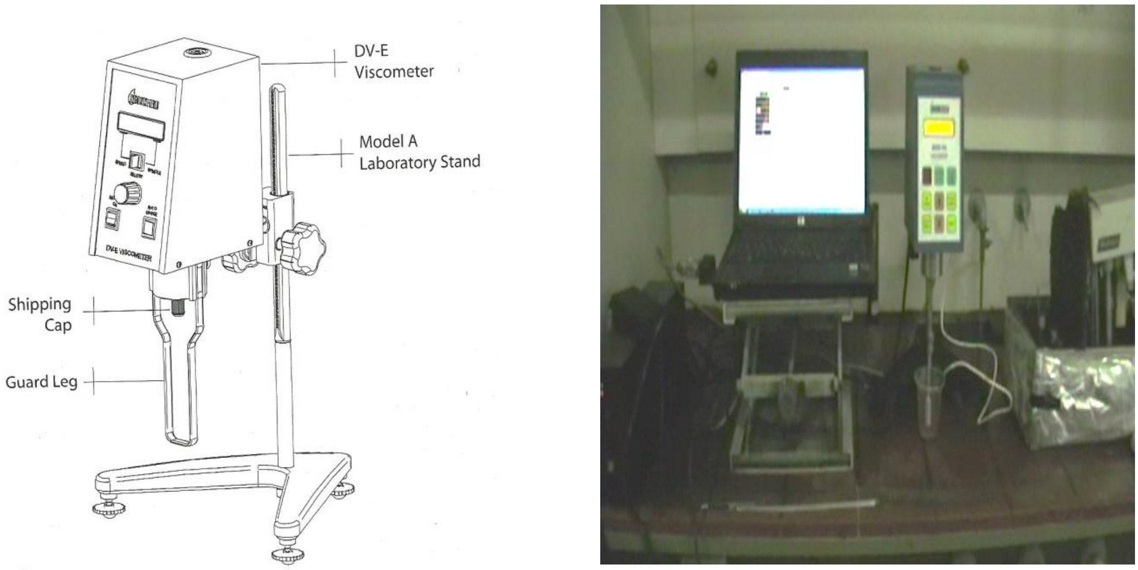
[19] Rondeauz F, Ph., Bready J.m.Rey.2001. Thermal conductivity measurement of Epoxy system at low Temperature" Cryogen tic engineering conference (CFC). USA.

[20] Hamilton, R.L. and O.K. Crosser, 1962. Thermal conductivity of heterogeneous 2 – component systems.& Engineering Chemistry Fundamentals, 1962.**1**(3): p. 187.124.

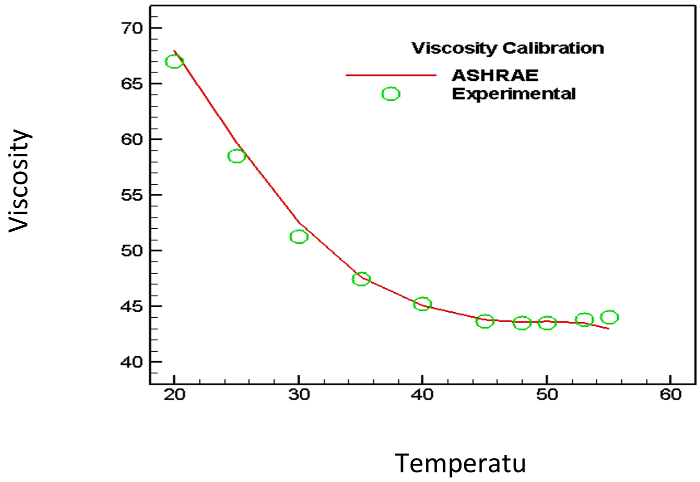
[21] Timo feeva, E.V., A.N. Gavrilov, J.M. et al**,.**2007**.**Thermal conductivity and particle agglomeration in alumina Nano fluids experimental and theory". Physical Review E,.76(6):p.16.

[22] Wesley Charles Williams, 2006.Experimental and theoretical investigation of transport phenomena in Nano particle Colloids (Nano fluids)", Department of Nuclear Science and Engineer at Massachusetts Institute of Technology.

[23] Yu, W. and S.U.S. Choi, 2003. The role of interfacial layers in the enhanced thermal conductivity of Nano fluids: A renovated Maxwell model". Journal of Nano particle Research, 5(1-2): p. 167 – 171.



Figure(2): Digital Viscometer Model DV – E



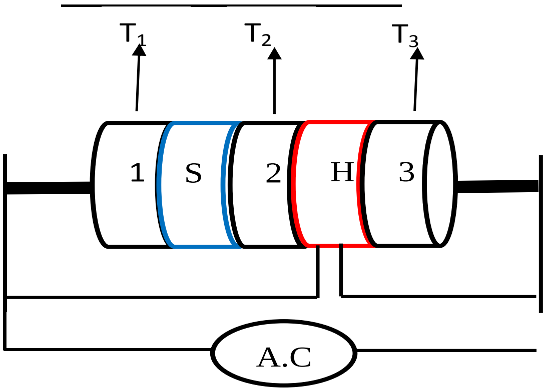
Figure(3): Comparison of ASHRAE Viscosity Values of 60:40 Ethylene Glycol And Water Mixture (by weight) and Experimental data, 1Cp (centipoises) =1mPas.

Figure(4): Specific Heat Apparatus (ESD 201)

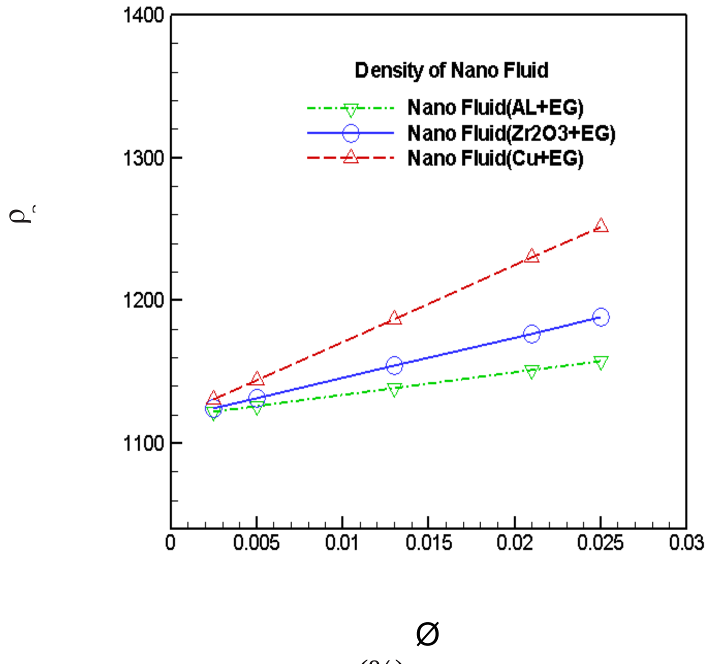
Figure(5): Thermal Conductivity Apparatus

Figure(6): nanofluid Dish Al / EG , Al_2O_3 / EG and CuO /EG

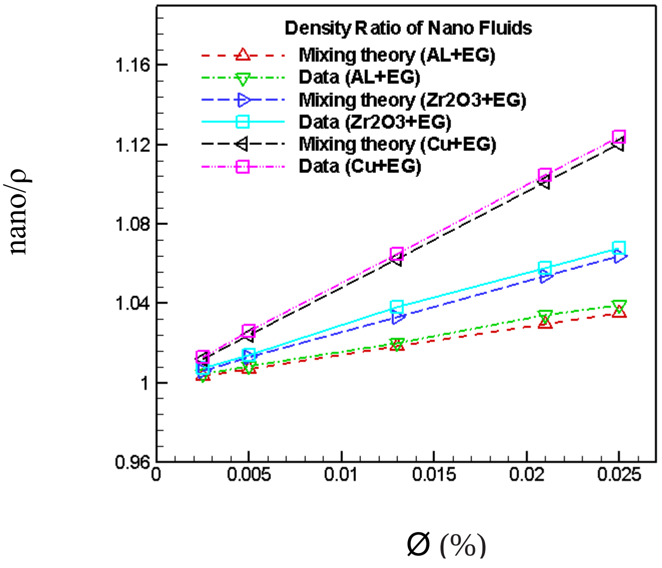
Figure (7): Sample disc used the experiments



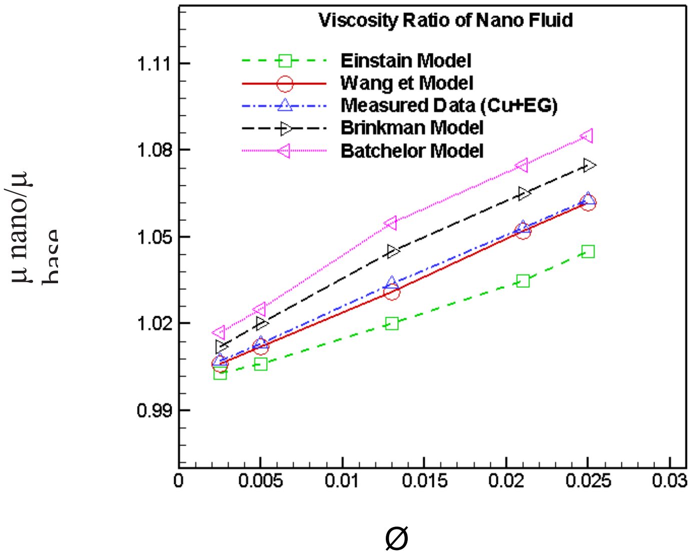
Figure(8): Schematic diagram for Lee's in disc method



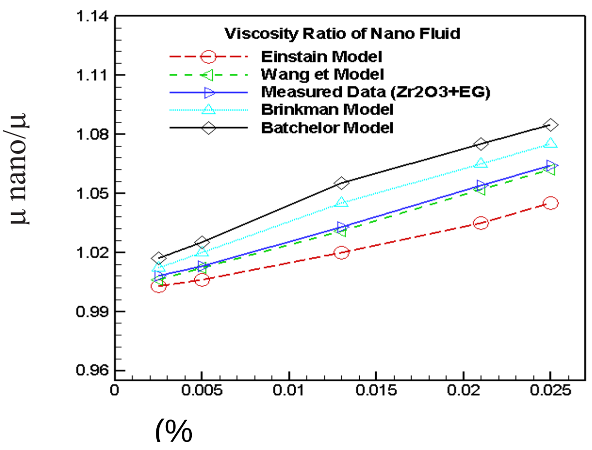
Figure(9): Density of EG + based Cu, Zr_2O_3 and Al



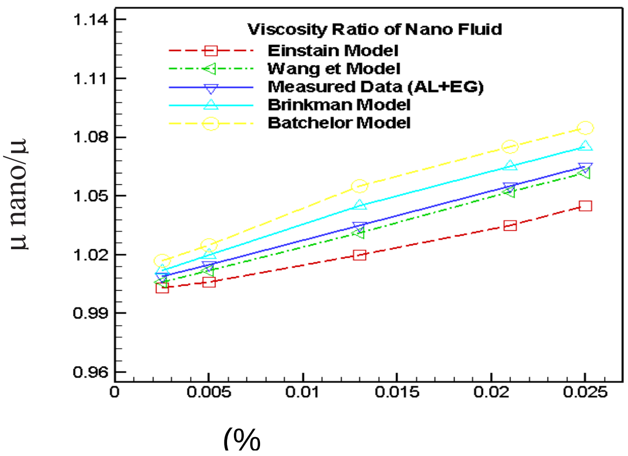
Figure(10): Density ratio of EG + based Cu, Zr_2O_3 and Al



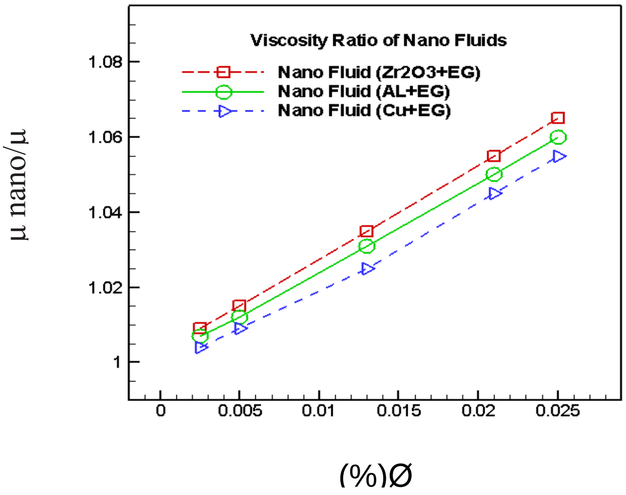
Figure(11): Viscosity ratio of EG + based Cu



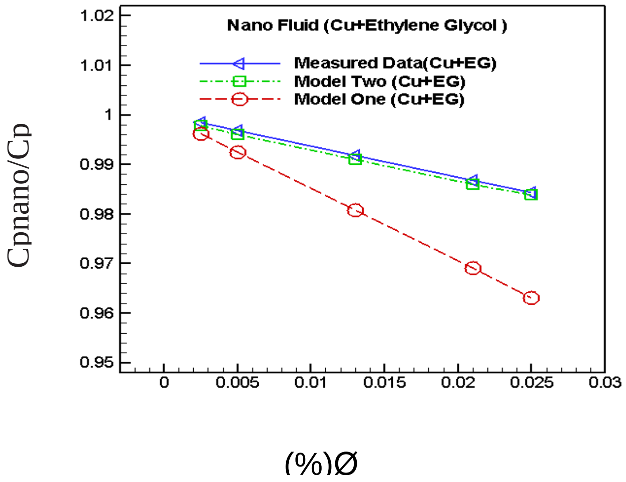
Figure(12): Viscosity ratio of EG + based Zr_2O_3



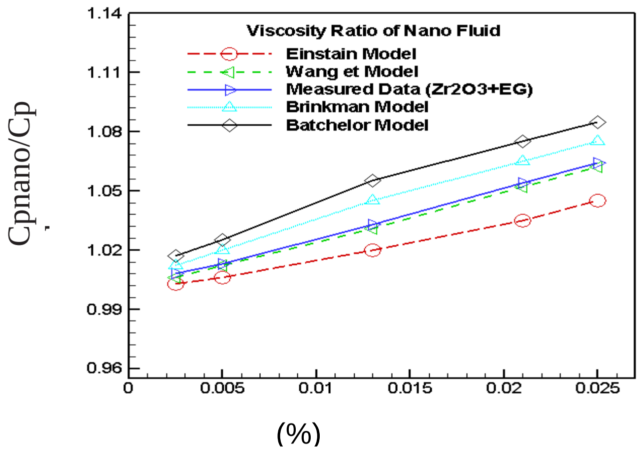
Figutr(13): Viscosity ratio of EG + based Al



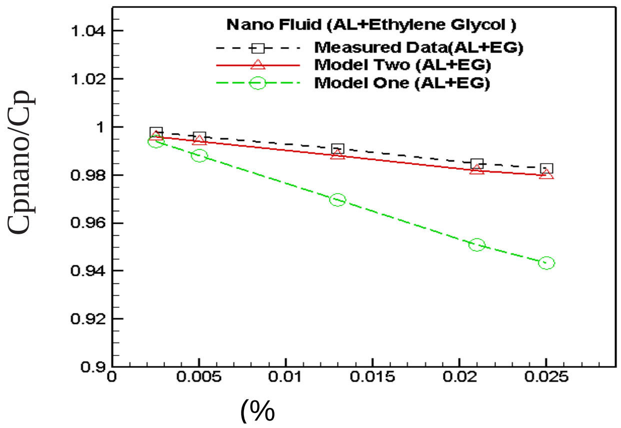
Figure(14): Viscosity ratio of E G + based Zr_2O_3, Al, Cu



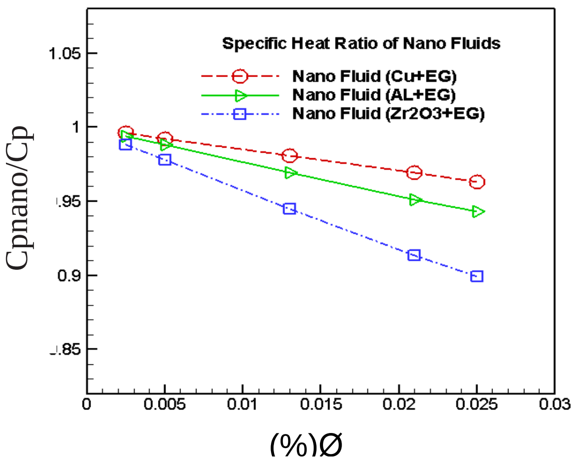
Figure(15): Comparison of specific heat correlation with two model for Cu+ E



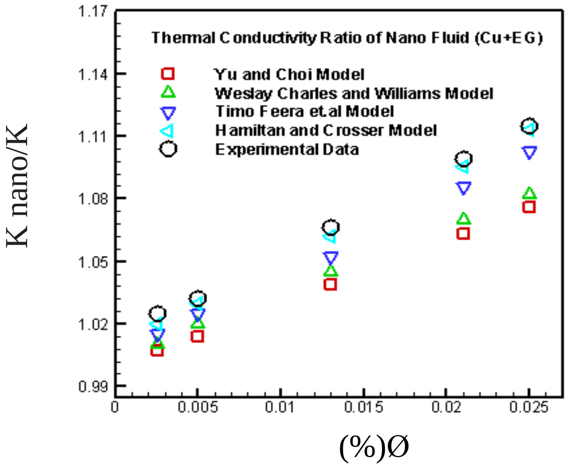
Figure(16): Comparison of specific heat correlation with two model for Zr_2O_3+ EG



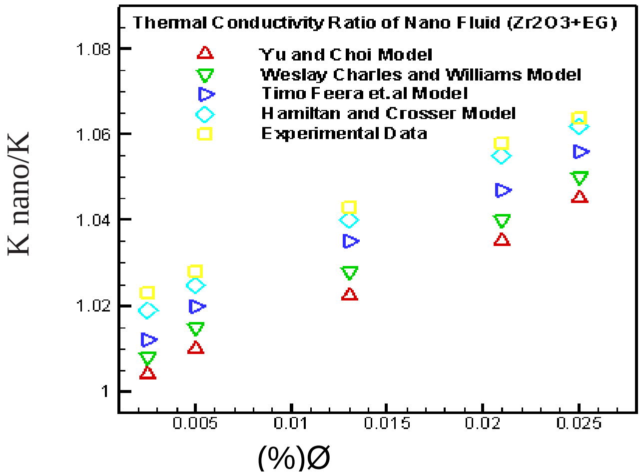
Figure(17): Comparison of specific heat correlation with two model for Al + EG



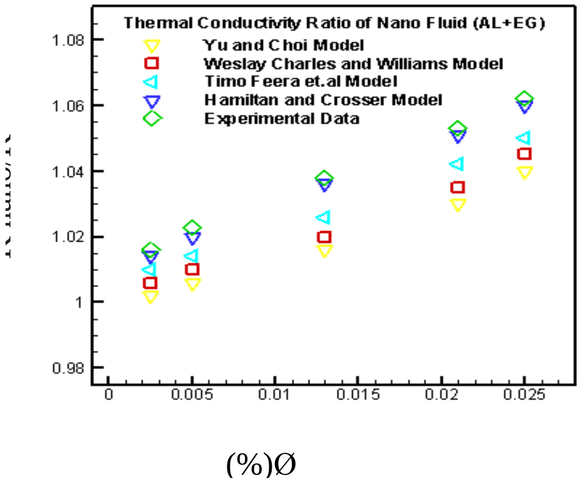
Figure(18): Specific heat ratio of EG + based Al, Cu and Zr_2O_3



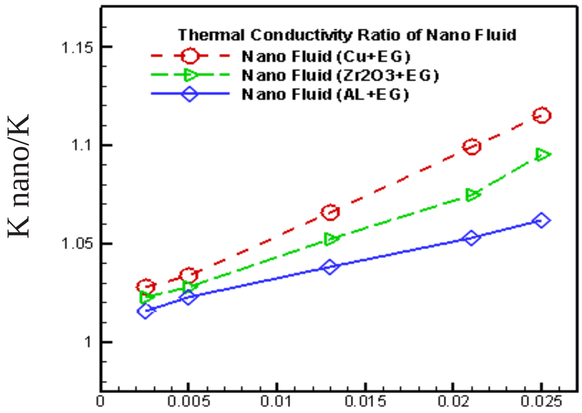
Figure(19): Thermal conductivity ratio of EG + based Cu



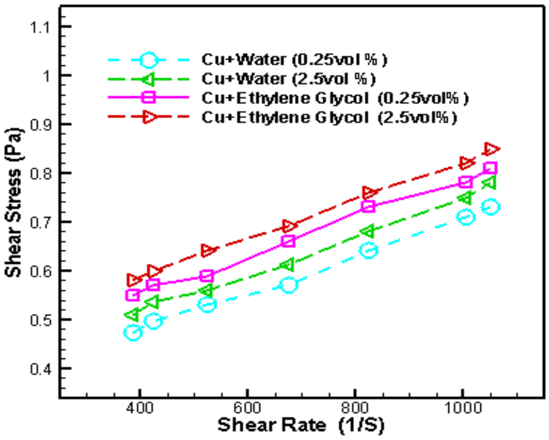
Figure(20): Thermal conductivity ratio of EG + based Zr_2O_3



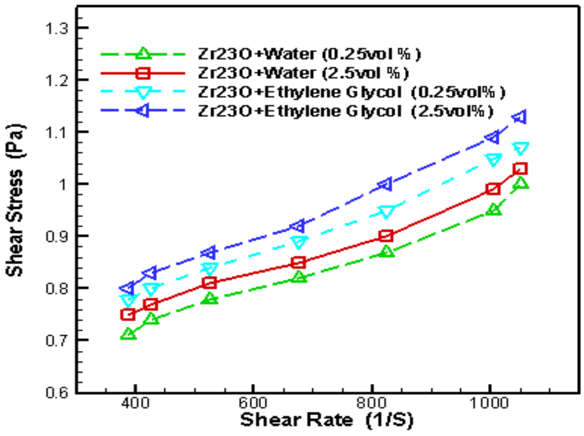
Figure(21): Thermal conductivity ratio of EG + based Al



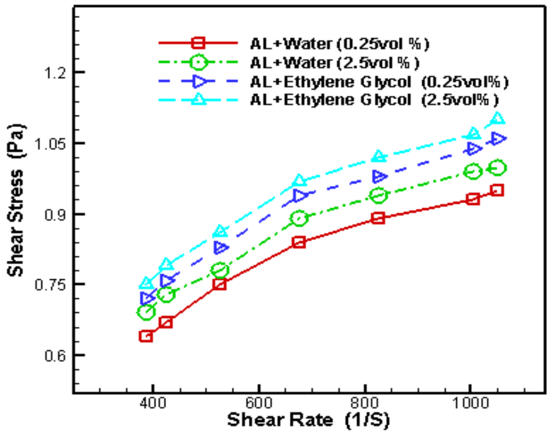
Figure(22): Thermal conductivity ratio of EG + based Cu, Zr_2O_3 and Al



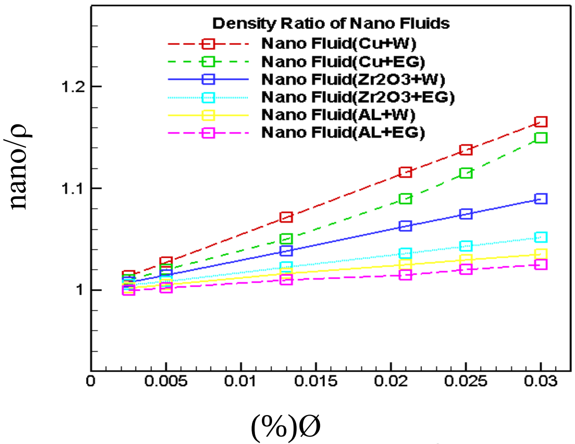
Figure(23): Shear stress versus shear rate for EG + based Cu



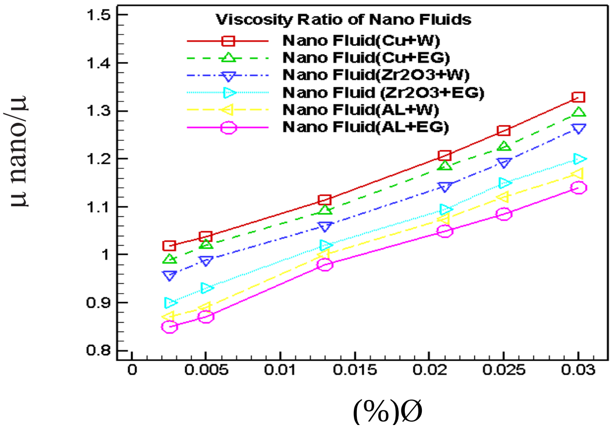
Figure(24): Shear stress versus shear rate for EG + based Zr_2O_3



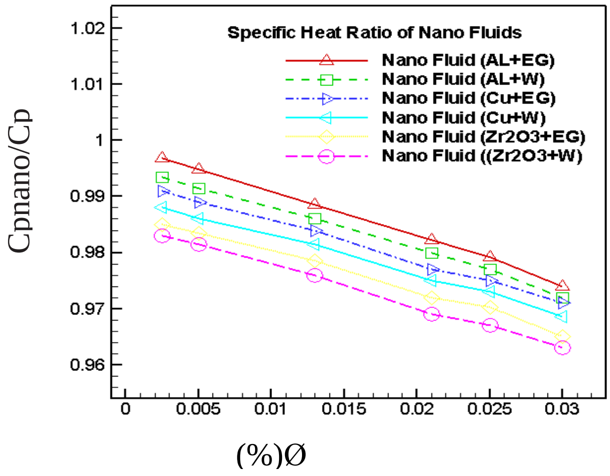
Figure(25): Shear stress versus shear rate for EG + based Al



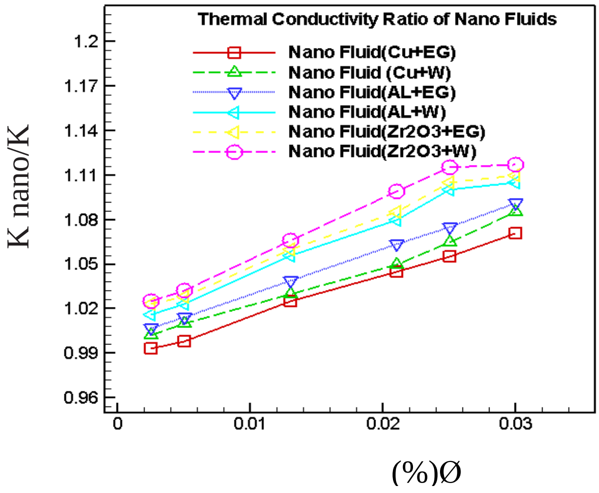
Figure(26): Density ratio of EG and DW + based Cu, Zr_2O_3 and Al



Figure(27): Viscosity ratio of E G and DW + based Cu, Zr_2O_3 and Al



Figure(28): Specific heat ratio of EG and DW + based Al Cu and Zr_2O_3



Figure(29): Thermal conductivity ratio of E G and DW+ based Cu ,Al and Zr_2O_3