Asian Review of Mechanical Engineering
ISSN: 2249-6289 (P) Vol.12 No.1, 2023, pp.44-49

DOI: https://doi.org/10.51983/arme-2023.12.1.3669

Rheometric Analysis of Impact of Temperature, Volume Fraction and Mass of Nanoparticle on the Viscosity of Water Based Nanofluids

S. Ramesh Krishnan
Assistant Professor, Department of Mechanical Engineering,
Rajiv Gandhi Institute of Technology, Government Engineering College, Kottayam, Kerala, India
E-mail: rameshs.krishnan@gmail.com
(Received 2 April 2023; Accepted 8 May 2023; Available online 15 May 2023)

Abstract **- Nanoparticle volume fraction, temperature and molecular mass of nanoparticle impact viscosity of nanofluids. Among them, temperature has an intrinsic influence on viscosity and is recommended to be the most crucial and dominant parameter. There are several theory based models for finding viscosity of nanofluids. Even a small addition of nanoparticles to the base liquid greatly increases the viscosity of nanofluid. The viscosity of the nanofluid varies with the particle size even if the nanoparticle does not change. In this work, theoretical viscosity of nanofluid is compared with experimental viscosity at different temperatures and volume fraction. The analysis is done for nanofluids having nanoparticles of different molecular masses.**
Keywords: **Nanofluids, Nanoparticle, Temperature, Viscosity, Volume Fraction**

I. INTRODUCTION

The advantages achieved in using a fluid as a heat transfer medium in cooling systems regardless of its size is widely acknowledged. However conventional heat transfer fluids have their own property restrictions. With increasing heat flux densities and reducing size, particularly in electronic applications which we call to be the miniaturized systems, developing alternate heat transfer media with superior heat transfer characteristics has become indispensable. Nanofluids with nanoparticles comprising of metals, oxides etc. suspended in base fluids like water, ethylene glycol etc. have unique properties that make them very much effective in numerous applications of heat transfer. They can serve as effective coolants in micro and nano electronics, fuel cells, engines, refrigerators, heat exchangers and so on. They possess higher thermal conductivity and heat transfer coefficient than the base fluid which is attributed to the smaller size and larger surface to volume ratio of nanoparticles.

As a result, nanofluids have become a preferred heat transfer medium. Clear information on the rheological behavior of nanofluids is very much essential in deciding the appropriateness of nanofluids in heat transfer applications particularly in convective dominated applications. In such cases, the analysis of viscosity is very much essential for assessing the thermo-fluidic behavior of nanofluids. Nanofluids which have the solid nanoparticles suspended in the base fluid to form a colloidal solution have a higher viscosity than the other common fluids used as heat transfer media. Hence viscosity assessment is essential in the design of thermal systems and selection of heat transfer medium. As the temperature of nanofluid increases viscosity shows a decrease. As volume fraction increases, viscosity increases.

II. IMPACT OF VOLUME FRACTION, TEMPERATURE AND MASS OF NANOPARTICLE ON VISCOSITY

Almost all the research shows that whenever the nanoparticle is added to the base fluid, even if it is a low volume fraction, there is an abrupt increase in viscosity [1]. For instance, if we consider alumina-water nanofluid which is used in the present analysis, it is experimentally ascertained that its viscosity increases with an increase in nanoparticle volume fraction [2]. Alumina-water nanofluids exhibit Newtonian behavior between 1 and 4 % particle volume fraction which shows that as volume fraction increases, viscosity also increases [3,4]. Thus, as the volume fraction increases, even though thermal conductivity increases, convective heat transfer in the medium is adversely affected and the impact on viscosity turns out to be unfavourable to the overall heat transfer rate within the system. Even for the same nanoparticle used, the viscosity of the nanofluid is found to vary with the size of the particle. As the volume fraction is increased, nanofluids with bigger sized nanoparticles exhibit a higher viscosity than the samples that are prepared using nanoparticles of smaller size.

Many models are suggested to determine the viscosity of nanofluids. For example, the first formula used to estimate viscosity of nanofluid is regarded to be the Einstein's formula [5] which assumes nanofluid to be a viscous fluid having spherical particles. The equation which is valid at too small volume fractions ($\phi < 0.02$) is given as

$$\mu_{nf} = \mu_f \, (1 + 2.5\varphi) \quad (1)$$

where μ_{nf} is the viscosity of the nanofluid and μ_f is the viscosity of the base fluid whereas ϕ is the volume fraction of the particle in suspension. This equation shows a linear increase in viscosity with particle fraction. But it considers neither the structure nor the interaction between the particles within the solution and is also not suitable for viscosity assessment of nanofluids with high volume fractions. Later on, many models were proposed for determining the viscosity such as the model suggested by Mooney [6], Nielsen's power law model [7], modified Einstein's viscosity equation by Batchelor [8] and so on. These models are to be selected based on different criteria such as diameter of the particle, its volume fraction in the nanofluid, density of the particle, impact of Brownian motion on heat transfer, inter particle spacing etc.

Apart from volume fraction that is discussed above, there is also an evident relationship of temperature with viscosity of nanofluid. There is almost a unique opinion in the research community that temperature is the most crucial and significant parameter impacting viscosity. In general, viscosity shows a downward trend with an increase in temperature. With an increase in temperature, the intermolecular force of attraction between the nanoparticles and the corresponding base fluid molecules weakens [9]. Hence a rise in temperature reduces the viscosity of nanofluids over a temperature range. This has been reported in many studies such as those done by Namburu [10], Ferrouillat [11] and Sundar [12]. As per the Andrade equation [13], the viscosity is related to temperature as

$$\ln \eta = A + \frac{B}{T} \quad (2)$$

where η is the viscosity, T is the temperature and A and B are constants. This equation was later revised by adding a constant C which is identified as the VTF equation [14] given by

$$\ln \eta = A + [\frac{B}{T+C}] \quad (3)$$

where C corresponds to the temperature at which viscosity turns out to be infinite.

Since temperature very much influences the viscosity of nanofluids apart from volume fraction, some correlations are also developed to consider the impact of temperature on viscosity of nanofluids. One among them is the Pak and Cho viscosity model [15] that considers room temperature as reference and gives how both temperature and volume fraction influence viscosity of nanofluid. The model also suggests a reduction in viscosity as the temperature is increased. By this correlation, the nanofluid viscosity is correlated as

$$\mu_{nf} = \mu_f \,(1 + 39.11\varphi + 533.9\,\varphi^2) \quad (4)$$

Another relevant study to assess temperature dependence on viscosity with particle volume fraction ranging from 1–4 % is by Nguyen et al. [16] who suggested the relation,

$$\mu_{nf} = \mu_f \,(2.1275 - 0.0215T + 0.00027\,T^2) \quad (5)$$

Viscosity of nanofluid is dependent on material of nanoparticle also. The viscosity of nanofluids as a function of size of nanoparticle and material of the nanoparticle is modeled and investigated by Rudyak *et al.,* for different volume fractions. They showed that as the nanoparticle size decreases, the viscosity of the nanofluid increases and is dependent on the material of the nanoparticle also [17].

There are still other correlations developed that assess the impact of both temperature and volume fraction on viscosity. For Al_2O_3 - water nanofluid, the viscosity relationship in terms of temperature and volume fraction is given by [18]

$$\mu_{nf}/\mu_f = (-0.155 - 19.582\,T^{-1} + 0.794\,\varphi + 209447\,T^{-2} - 0.192\,\varphi^2 - 8.11\,\varphi\,T^{-1} - 27463T^{-2} + 0.0127\,\varphi^3 + 1.6044\,\varphi^2\,T^{-1} + 2.175\,\varphi T^{-2}) \quad (6)$$

III. THEORETICAL AND EXPERIMENTAL ANALYSIS OF VISCOSITY AT DIFFERENT TEMPERATURES

In the present work, the viscosity of nanofluid is calculated for different temperatures and volume fractions. The nanoparticles considered are aluminium oxide and copper oxide with molecular masses 101.96 g/mol and 79.545 g/mol respectively. The theoretically assessed viscosity values for the different samples are tabulated in Table I.

TABLE I VARIATION IN VISCOSITY WITH TEMPERATURE AND MOLECULAR MASS OF NANOPARTICLE

Temperature (º C)	Viscosity of Al_2O_3 (cP)	Viscosity of CuO (cP)
30.1	0.91	0.9
36	0.7	0.8
39.9	0.65	0.7
50	0.6	0.5

Nanofluid samples are prepared as in Figure 1 by dispersing nanoparticles in the base fluid by a one-step process. Good dispersion is a prerequisite for the application of nanofluid. Hence surfactants are used to enhance the stability of nanofluids. In the one-step process for preparation of nanofluids, there is simultaneous formation and dispersion of nanoparticles. This method avoids agglomeration of nanoparticles and increases the stability of nanofluids.

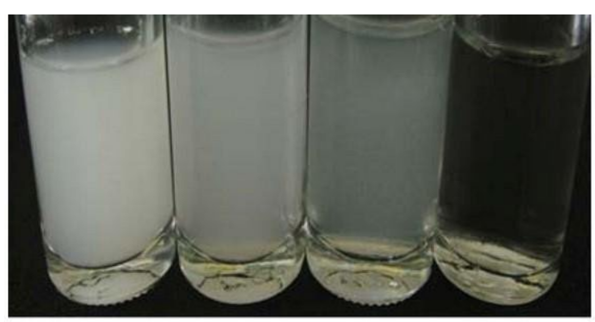

Fig. 1 Prepared Al_2O_3 Water Nanofluid

A rheometer as shown in Figure 2 is a laboratory device used to analyze and study how a dense fluid, which is in the form of a liquid, suspension or slurry, flows in response to an applied force. It is used to analyze those fluids for which a single value of viscosity cannot be defined. As a result, it is required to set more parameters than in the case of a viscometer. There are two specifically different classes of rheometers - rotational or shear rheometer that controls the applied shear stress or shear strain and extensional rheometer that applies extensional stress or extensional strain.

Fig. 2 Modular Compact Rheometer

Rheometer has three sections - the lower part, which is the temperature control chamber, the upper part consisting of the motor to rotate top plate and the software. The rheometer software offers a fairly broad range of predefined measurement templates and analysis procedures for a wide range of applications. After turning on the rheometer (Figure 3), the position of the cone is set to zero using the software interface. The cone tip keeps a 1mm gap with the bottom flat plate to avoid the contact. Once the temperature is fixed, the sample is poured into the base plate. The spillover of the liquid should be cleaned. The machine retracks the cone to the original position after the completion of the experiment. Results are obtained in the form of graphs from the instrument.

Fig. 3 Viscosity measurement of Al_2O_3 and CuO nanofluid samples

IV. RESULT FOR AL_2O_3 NANOFLUID

The variation in viscosity of nanofluids with Al_2O_3 as the nanoparticle at different temperatures and volume fractions is shown in Figure 4 to Figure 7.

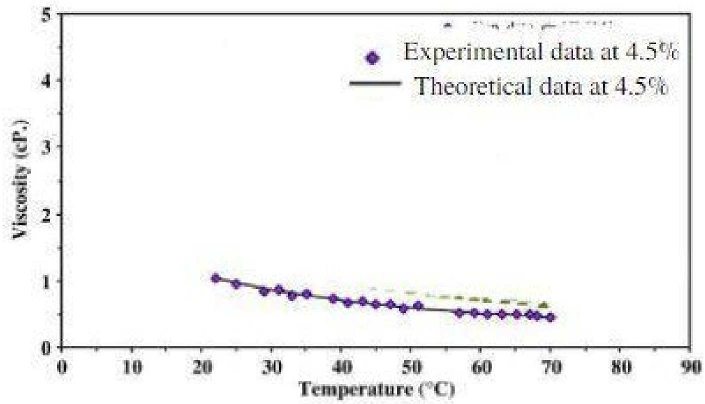

Fig. 4 Viscosity v/s temperature relationship of Al_2O_3 nanofluid at 1% volume fraction

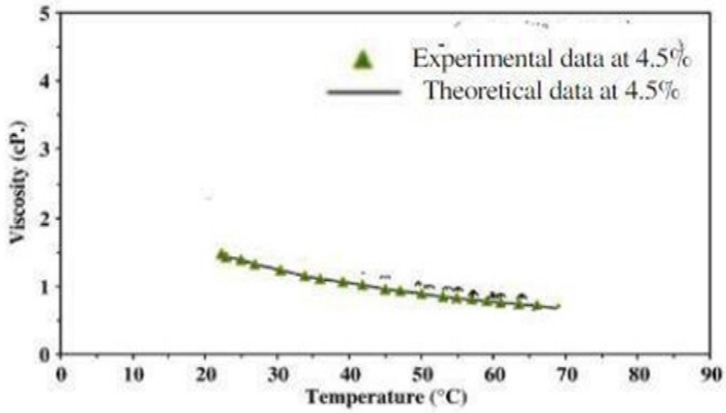

Fig. 5 Viscosity v/s temperature relationship of Al_2O_3 nanofluid at 4.5% volume fraction

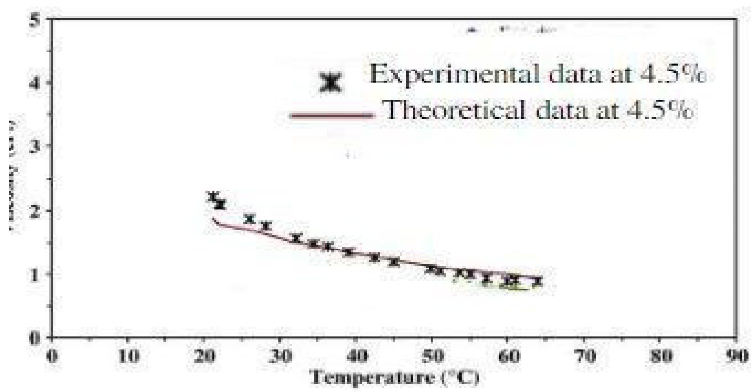

Fig. 6 Viscosity v/s temperature relationship of Al_2O_3 nanofluid at 7% volume fraction

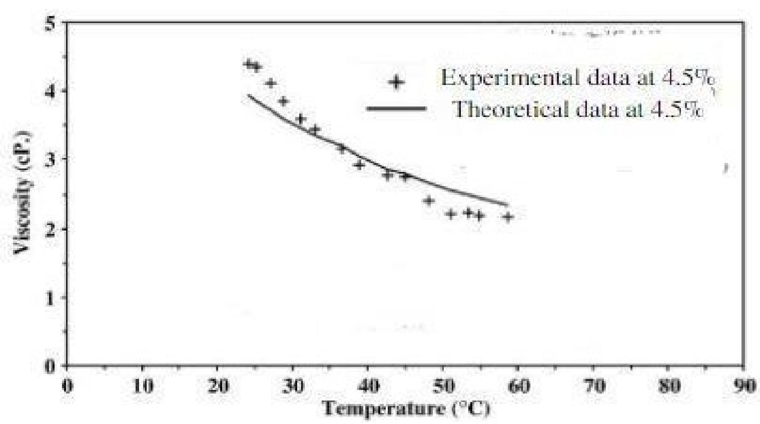

Fig. 7 Viscosity v/s temperature relationship of Al_2O_3 nanofluid at 9% volume fraction

V. RESULT FOR CUO NANOFLUID

Similar to the results plotted for Al_2O_3 nanofluid, the variation in viscosity of CuO nanofluid at different temperatures and volume fractions is obtained as shown in Figure 8 to Figure 11.

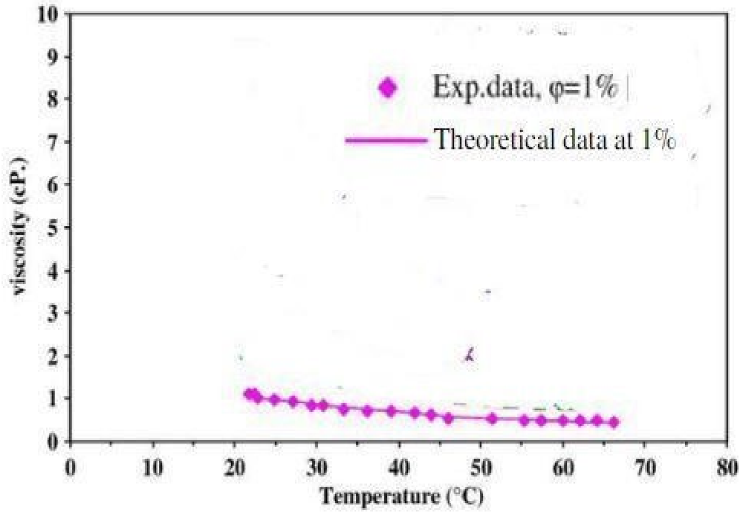

Fig. 8 Viscosity v/s temperature relationship of CuO nanofluid at 1% volume fraction

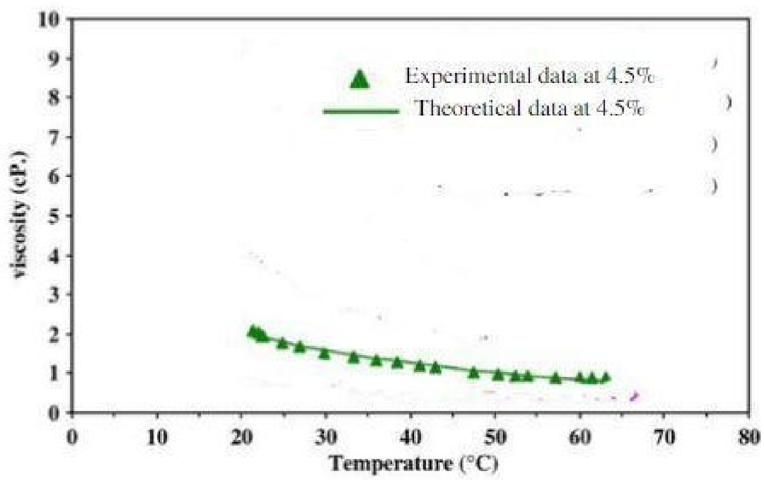

Fig. 9 Viscosity v/s temperature relationship of CuO nanofluid at 4.5% volume fraction

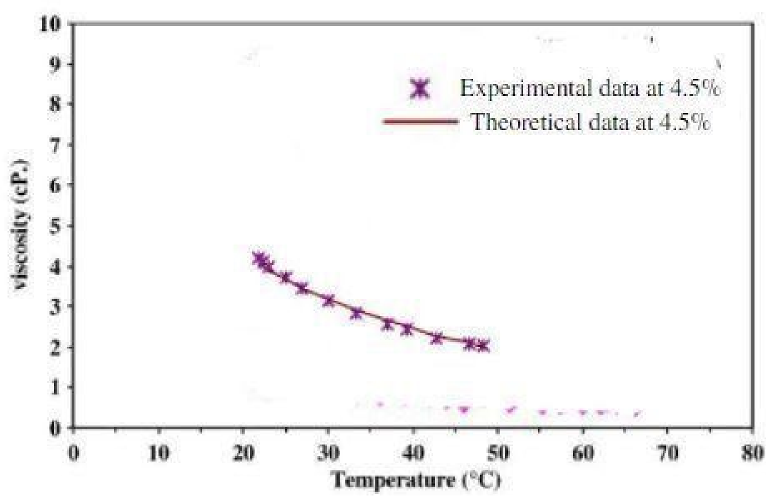

Fig. 10 Viscosity v/s temperature relationship of CuO nanofluid at 7% volume fraction

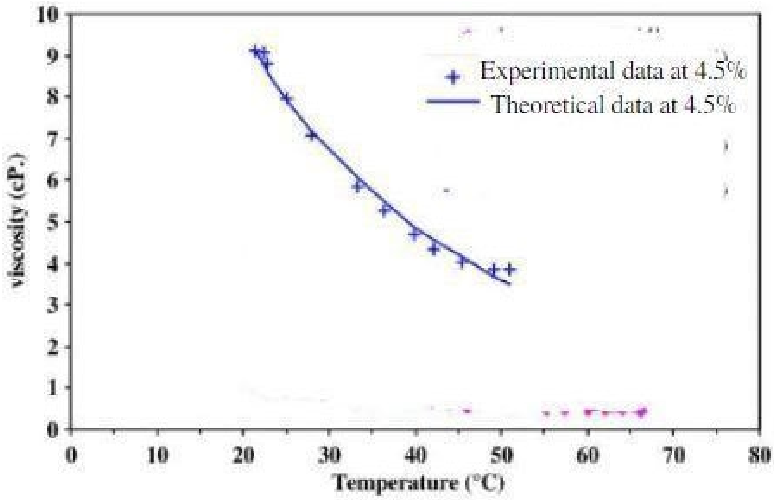

Fig. 11 Viscosity v/s temperature relationship of CuO nanofluid at 9% volume fraction

VI. CONCLUSION

Viscosity of nanofluids shows deviation from theoretical values with a change in volume fraction and mass of nanoparticle. The nanoparticles which are suspended in the base fluid are constantly moving and are undergoing collision. Since there are chances of agglomeration also, these can result in particle aggregate structure of nanofluids as a result of which there will be an enhancement in viscosity. As particle volume fraction increases, the deviation of theoretical values from experimental values increases. Viscosity increases with an increase in volume fraction and decreases as the temperature increases for the same volume fraction. These results are in conformance with the standard results. Nanofluid viscosity considerably increases with particle volume fraction and decreases with temperature. From the graph, it is clear that the experimental value deviates from theoretical values at higher volume fraction. The deviation also increases with increase in molecular mass.

REFERENCES

[1] P. C. Mishra, S. Mukherjee, S. K. Nayak *et al.,* "A brief review on viscosity of nanofluids," *Int Nano Lett,* Vol. 4, pp. 109-120, 2014.

[2] R. Prasher *et al.,* "Measurements of nanofluid viscosity and its implications for thermal applications," *Appl. Phys. Lett.,* Vol. 89, No. 13, pp. 133108, 2006.

[3] S. K. Das, N. Putra and R. Wilfried, "Pool boiling characteristics of nano-fluids," *Int. J. Heat Mass Transf.,* Vol. 46, No. 5, pp. 851-862, 2003.

[4] N. Putra, R. Wilfried and Sarit K. Das, "Natural convection of nanofluids," *Heat Mass Transf.,* Vol. 39, No. 8-9, pp. 775-784, 2003.

[5] A. Einstein, "A New Determination of Molecular Dimensions," *Annals. Phys.,* Vol. 324, No. 2, pp. 289-306, 1906.

[6] M. Mooney, "The viscosity of a concentrated suspension of spherical particles," *J. Colloid Sci.,* Vol. 6, No. 2, pp. 162-170, 1951.

[7] L. E. Nielsen, "Generalized equation for the elastic moduli of composite materials," *J. Appl. Phys.,* Vol. 41, No. 11, pp. 4626-4627, 1970.

[8] G. K. Batchelor, "The effect of Brownian motion on the bulk stress in a suspension of spherical particles," *J. Fluid Mech.,* Vol. 83, No. 01, pp. 97-117, 1977.

[9] S. Thomas and C. B. P. Sobhan, "A review of experimental investigations on thermal phenomena in nanofluids," *Nanoscale Res. Lett.,* Vol. 6, No. 1, pp. 1-21, 2011.

[10] P. K. Namburu, *et al.,* "Experimental investigation of viscosity and specific heat of silicon dioxide nanofluids," *Micro Nano Lett. IET,* Vol. 2, No. 3, pp. 67-71, 2007.

[11] S. Ferrouillat, *et al.,* "Influence of nanoparticle shape factor on convective heat transfer and energetic performance of water based SiO_2 / ZnO nanofluids," *Appl. Therm. Eng.,* Vol. 51, No. 1, pp. 839-885, 2013.

[12] L. Syam Sundar, K. S. Manoj and S. Antonio, "Investigation of thermal conductivity and viscosity of Fe_3O_4 nanofluid for heat transfer applications," *Int. Commun. Heat Mass Transf.,* Vol. 44, pp. 7-14, 2013.

[13] E. N. Da C. Andrade, "A theory of the viscosity of liquids - Part II," London, Edinburgh, and Dublin Philos, *Mag. J. Sci.,* Vol. 17, No. 113, pp. 698-732, 1934.

[14] D. Meschede and V. Helmut, *Gerthsenphysik,* 21st Edition, *Springer,* Berlin, pp. 1288., 2002.

[15] B. C. Pak and Y. I. Cho, "Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. Exp," *Heat Transf Int. J.,* Vol. 11, No. 2, pp. 151-170, 1998.

[16] C. T. Nguyen, *et al.,* "Temperature and particle-size dependent viscosity data for water-based nanofluids-hysteresis phenomenon," *Int. J. Heat Fluid Flow,* Vol. 28, No. 6, pp. 1492-1506, 2007.

[17] V. Ya, Rudyak S. L. Krasnolutskii, "Dependence of the viscosity of nanofluids on nanoparticle size and material," *Physics Letters A,* Vol. 378, No. 26-27, pp. 1845-1849, 2014.

[18] Eiyad Abu-Nada, "Effects of variable viscosity and thermal conductivity of Al_2O_3-water nanofluid on heat transfer enhancement in natural convection," *International Journal of Heat and Fluid Flow,* Vol. 30, No. 4, pp. 679-690, 2009.