



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 SiO₂ / 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 Fe₃O₄ 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 Al₂O₃-water nanofluid on heat transfer enhancement in natural convection," *International Journal of Heat and Fluid Flow*, Vol. 30, No. 4, pp. 679-690, 2009.