Thermodynamic Study of Alpha- Alumina (α-Al_2O_3) Nanofluids

P. D. Bageshwar[1], N. R. Pawar [2]
[1, 2] Dept of Physics
[1]M. M. College, Darwha – 445 202, India
[2]Arts, Commerce & Science College, Maregaon – 445 303, India

Abstract- *Nanoparticles are expected to have a surface to volume ratio given as large surface to volume ratio proportional to the inverse of particle size of nanomaterials changes the role played by the surface atoms in determining their thermodynamic properties. Tremendous increase in the surface energy leads to diffusion at relatively low temperature reduced coordination number of the surface atoms. Physical properties such as electrical conductivity, magnetic property, melting point, thermal conductivity, reflectivity, etc., can be affected. Thermodynamics tells us that any material or system is stable only when it is in its lowest Gibbs free energy state. Therefore, there is a strong tendency for a solid or liquid to minimize the total surface energy when the size is reduced. The surface energy can be reduced through surface relaxation, wherein the surface atoms or ions can shift inward. It occurs through combining surface dangling bonds into strained new chemical bonds. This leads to a large surface to volume ratio, which can influence their reactivity, hardness, electrical, magnetic, catalytic, and optoelectronic properties [1-4].*

α-A l_2O_3 is one of the most widely used oxide ceramic material. α-A l_2O_3 nanoparticles were synthesized via sol-gel method. Aluminum isopropoxide Al $(OC_3H_7)_3$, and aluminum nitrate nanohydrate Al $(NO_3)_3$ 9 H_2O were used for preparing alumina solution. Sodium dodecylbenzene sulfonate (SDBS) was used as the surfactant stabilizing agent. The prepared sample was characterized by X- ray diffraction (XRD) [5-7]. Average particle size has been estimated by using Debye-Scherrer formula. It was found to be 20-30 nm. Nanofluids of α-A l_2O_3 nanoparticles were prepared by two step method in methanol base fluid and did their thermodynamic study like thermal conductivity, Gibbs free energy, etc related to the surface of nanoparticles and nanoparticle surfactant interactions.

Keywords- Thermal conductivity; Gibbs free energy; XRD; Thermo acoustic parameters

Highlights

- The thermal conductivity and Gibbs free energy of nanofluids are highly dependent on specific surface area to volume ratio of the nanoparticles in nanofluids.
- α-A l_2O_3 nanoparticles were synthesized via sol-gel method.

I. INTRODUCTION

α-Al_2O_3 is one of the most widely used oxide ceramic material. It is used in a variety of plastics, rubber, ceramics, and refractory products. As the α-phase ultrafine Al_2O_3 is a high performance material of far infrared emission, it is used in fiber fabric products and high pressure sodium lamp as far-infrared emission and thermal insulation materials. In addition, α-phase nano-Al_2O_3 with high resistivity and good insulation property, it is widely used as the main components for YGA laser crystal and integrated circuit substrates. Recently, advances in manufacturing technology have permitted the production of particles in the 10 nm to 100 nm range.

In the present investigation the synthesis of α-Al_2O_3 nanoparticles by sol-gel method is discussed. Ultrasonic velocity measurement helps in finding Gibb's free energy and thermal conductivity these are related to the surface of nanoparticle and nanoparticles surfactant interactions. α-Al_2O_3 nanoparticles with surface areas 30 nm have been prepared, their thermal conductivities and characterization have been investigated.

II. EXPERIMENTAL

Preparation of Samples:

Nanoparticles of alpha alumina (α-Al_2O_3) was prepared by sol-gel method [4-9] from Aluminum isopropoxide [Al $(OC_3H_7)_3$] and aluminum nitrate. Starting solution was prepared by adding aluminum isopropoxide [Al $(OC_3H_7)_3$] gradually in aluminum nitrate and solution continuously stirred for 48 hours. Later, Sodium dodecylbenzen sulfonate (SDBS) were added and stirred for one hour. The obtained solution were heated up to 60°C and stirred constantly for evaporation process. Now the paste so obtained was heated at

90°C for 8 hours, we get nanoparticles of alpha alumina (α-Al_2O_3) in powder form [8-16].

The prepared sample was characterized for their phase purity and crystallinity by X-ray powder diffraction (XRD), FTIR and SEM. Formation of the compound confirmed by XRD pattern matched with the standard data available in JCPDS file. Average particle size of α-Al_2O_3 nanoparticles has been estimated by using Debye-Scherrer formula.

$$D = \frac{0.9\lambda}{W \cos\theta} \quad (1)$$

Where 'λ' is the wavelength of X-ray (0.15460 nm), 'W' is FWHM (full width at half maximum), 'θ' is the diffraction angle and 'D' is particle diameter (size). The estimate size of α-Al_2O_3 nano particles is found to be about 20-30 nm. Nanofluids of α-A l_2O_3 nanoparticles were prepared by two step method in methanol base fluid.

III. RESULT AND DISCUSSION

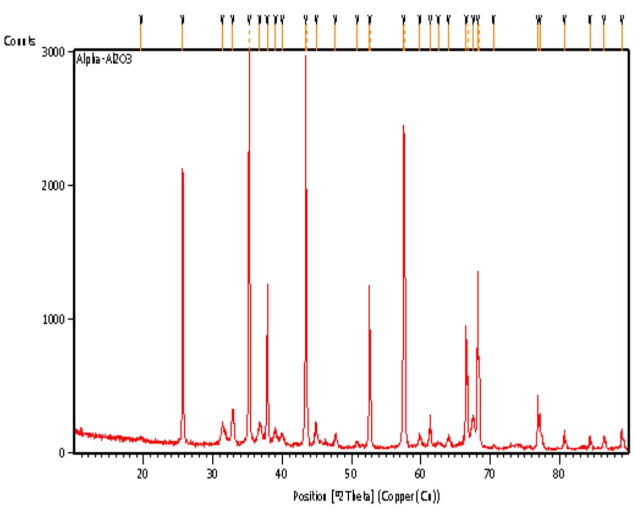

Fig.1 XRD pattern of α-Al_2O_3 nanoparticles

Fig.1 shows the XRD pattern of α-Al_2O_3 nanoparticles. The XRD measurement carried out by using "PAN analytical" X-ray diffractometer keeping the parameter constant at Start Position [°2Th.]: 10.0154 End Position [°2Th.]: 89.9834, Step Size [°2Th.]: 0.0170, Scan Step Time [s]: 5.7150, Scan Type: Continuous, Measurement Temperature [°C]: 25.00 Anode Material: Cu, K-Alpha1 [Å]: 1.54060. It is seen that the materials is well crystalline in nature and well agreed with standard JCPDS file no. 71-1127.
Ultrasonic velocity gets increases with increasing the molar concentration of the α-Al_2O_3 nanoparticles in methanol this shows that the physical parameters of the sample changes by increasing the molar concentration. For α-Al_2O_3 nanoparticle the ultrasonic velocity of the nanofluids is higher than methanol and also by increasing the molar concentration of the ultrasonic velocity of α-Al_2O_3 nanoparticles gets optimum at 0.2 and then decreases it is represented in the figure 2. Small dip at 0.8 indicates the weaking of interactions between α-Al_2O_3 nanoparticles and nanofluids. The cause behind this decrease of ultrasonic velocity may due to weak interaction between nanosize particle and micro sized fluid molecule. Ultrasonic velocity can be interpreted as the nanosize α-Al_2O_3 particles have more surface area to volume ratio and which can absorb more methanol molecules on its surface, which enhances the ultrasonic velocity at 0.2. The decrease of ultrasonic velocity with increase in concentration is due weakening of interaction between nano sized α-Al_2O_3 particles and micro sized fluid molecules of methanol. Non linear variation of ultrasonic velocity may due to the Brownian motion of nanoparticles. Aggegation of nanoparticles in nanofluids may occurs due to the interstitial accommodation or due to lack of perfect symmetry and decrease in available space between the constituents of the nanofluids [17].

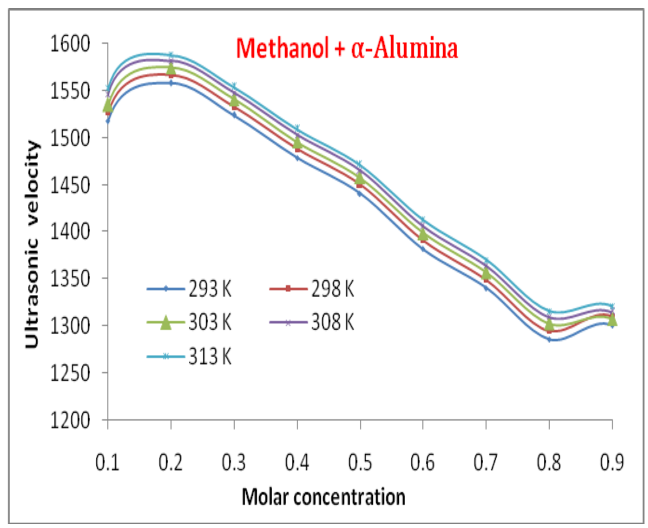

Fig.2 Ultrasonic velocity of α-Al_2O_3 nanoparticles in methanol base fluids

Fig.3 shows the variation of Gibbs free energy with molar concentration of α-Al_2O_3 nanoparticles in methanol base fluid. Gibbs free energy of α-Al_2O_3 nano suspension increases with increase in molar concentration of α-Al_2O_3 nanoparticles in methanol. This indicates the stability of α-Al_2O_3 nanoparticles in methanol base fluid. Stability decreases with increase in molar concentration.

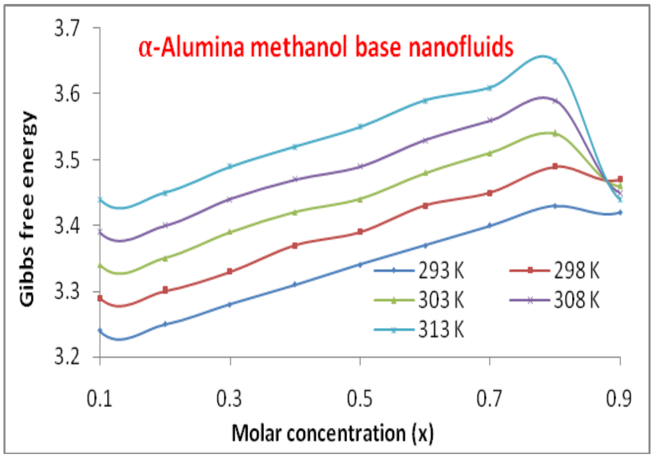

Fig. 3 Gibbs free energy of α-Al_2O_3 nanoparticles in methanol base nanofluid

Fig.4 shows the variation of thermal conductivity with molar concentration of α-Al_2O_3 nanoparticles in methanol base nanofluids. The results clearly show that the effective thermal conductivity of α-Al_2O_3 increases with temperature. It has substantially higher value at molar concentration 0.1 of α-Al_2O_3 in methanol base nanofluids. The thermal conductivity enhancements are highly dependent on specific surface area of nanoparticle, with an optimal surface area for the highest thermal conductivity. The results of Kumar *et al.* and Koo and Kleinstreuer show the strong relationship between Brownian motion and temperature of nanoparticles. Furthermore, the effect of temperature on thermal conductivity is not very well understood and documented.

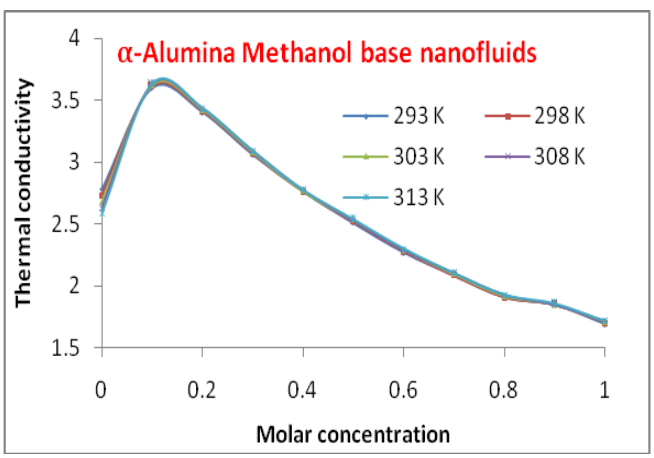

Fig. 4 Thermal conductivity of α-Al_2O_3 nanoparticles in methanol base nanofluid

IV. CONCLUSION

1. The structural, optical and thermal properties of the α-Al_2O_3 nanoparticles and methanol base nanofluids are characterized by XRD, ultrasonic velocity, Gibbs free energy and thermal conductivity.
2. The sound velocity increases with increase in the concentration of α-Al_2O_3 nanoparticles due to aggregation of α-Al_2O_3 nanoparticles in methanol based nanofluids.
3. Ultrasonic velocity decreases with increase in temperature due to Brownian motion of α-Al_2O_3 nanoparticles in methanol based nanofluids and thermal agitation.

REFERENCES

[1] M. S. Liu, M.C.C. Lin, I. T. Huang, C.C. Wang, *Chem. Eng. Technol*., 29 (2006) 72-77.

[2] Yi Jiang, Ruiyuan Tian, Haiqiang Liu, Jain Kun Chen, Xinghau Tan, Lina Zhang, Guangyao Liu, Hanfu Wang, *Nano Research*, 8 (2015) 1-12.

[3] Yu W. and Xie H., A review of nanofluids: preparation, stability mechanisms and applications, *J. Nanomaterials*, 2012 (2011) 1-17.

[4] Lee S., Choi S.U.S., Li S. and Eastman J.A., Measuring thermal conductivity of fluids Containing oxide nanoparticles, *J. Heat Transfer*, 121 (1999) 280-289.

[5] Kulkarni D.P., Das D.K. and Chukwu G.A., Temperature dependent rheological property of copper oxide nanoparticles suspensions, *J. Nanosci. Nanotechnol*, 6 (2006) 1150-1154.

[6] D.H. KUMAR, H.E. PATEL, V.R.R. KUMAR, T. SUNDARARAJAN, T. PRADEEP and S.K. DAS, 2004. Model for heat conduction of nanofluids, *Physical Review Letters*, **94**(14), 1-3.

[7] S. RAJAGOPALAN, S. J. SHARMA and V.Y. NANOTKAR, 2005. Ultrasonic Characterization of Silver Nanoparticles, *Journal of Metastable and Nanocrystalline Materials*, **23,** 271-274.

[8] Z. GAN, G. NING, Y. LIN and Y. CONG, 2007. Morphological control of mesoporous alumina nanostructures via template-free solvothermal synthesis. *Mater Lett*. **61**(31), 3758- 3761.

[9] X. ZHAN, M. HONKANEN and E. LEVA, 2008. Transition alumina nanoparticles and nanorods from boehmite nanoflakes. *J Crystal Growth*. **310**(30), 3674-3679.

[10] Y.K. PARK, E.H. TADD, M. ZUBRIS and R. TANNENBAUM, 2005. Size controlled synthesis of alumina nanoparticles from aluminum alkoxides, *Materials Reasearch Bulletin*, **40**(9), 1512.

[11] D.G. WANG, F. GUO, J.F. CHEN, H. LIU and Z. ZHAG, 2006. Preparation of nano aluminium trihydroxide by high gravity reactive precipitation, Chemical Engineering Journal, **121**(2-3), 109-114.

[12] R. AGHABABAZADEH, A.R. MIRHABIBI, J. POURASAD, A. BROWN, A. BRYDSON and N.

AMERI MAHABAD, 2007. Economical synthesis of Nanocrystalline alumina using an environmentally low-cost binder, *Journal of Surface Science*. **601**(13), 2864-2867.

[13] P. CHRISTIAN and M. BROMFIELD, 2010. Preparation of small silver, gold and copper nanoparticles which disperse in both polar and non-polar solvents, *J. Mater. Chem*. **20**, 1135-1139.

[14] R. ROGOJAN, E. ANDRONESCU, C. GHITULICA and B. STEFAN, 2011. Synthesis and characterization of alumina nano-powder by sol-gel method. *UPB Sci Bull Ser B.* **73**(2, 27), 67-76.

[15] V. Bhalla, R. Kumar, S. Tripathi and D. Sing, 2013. Mechanical and thermal properties of Praseodymium nanoparticles: an ultrasonic study, *Int. J. Mod. Phys. B*, **27**, 1350116.