The Preparation and Characterization Of Al_2O_3/ Water Nano Fluid

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Abstract : Enhancement in heat transfer in case of the heat exchanger and be obtained by using nanofluid, it is considered as a new type of heat transfer medium. Nanofluid consists of nanoparticles of size (1–100 nm) which are homogeneously and stably dispersed in a base fluid. These distributed nanoparticles, generally a metal or metal oxide greatly enhance the thermal conductivity of the nanofluid, increases conduction and convection coefficients, allowing for more heat transfer Nanofluid have been considered for applications as advanced heat transfer fluids for almost two decades. However, due to the wide variety and the complexity of the nanofluid systems, no agreement has been achieved on the magnitude of potential benefits of using nanofluid for heat transfer applications. The above potentials provided the thrust necessary to begin research in nanofluid, with the expectation that these fluids will play an important role in developing the next generation of cooling technology. The result can be a highly conducting and stable nanofluid with exciting newer applications in the future.

***IndexTerms* – Nano fluids, Heat transfer , Al_2O_3.**

I. Introduction

The research on enhancement of heat transfer has gained significant momentum during recent years. Because of expanded requirements by industry for heat exchange equipment which is less expensive to build and operate, than the traditional heat exchangers. Various methods of heat transfer enhancement are being used to develop more capable heat exchangers that result in savings in materials, space required and energy.

Enhancement in heat transfer can be achieved by adding of solid particles into heat transfer media. This technique has been identified as one of the helpful techniques for enhancing heat transfer, although a major consideration when using suspended millimeter- or micrometer-sized particles are that they have the potential to cause some severe problems, such as abrasion, clogging, high pressure drop, and sedimentation of particles. Compared to heat transfer enhancement through the use of suspended large particles, the use of nano particles in the fluids exhibited better properties relating to the heat transfer of fluid. This is because nanoparticles are usually used at very low concentrations and nanometer sizes. These properties prevent the sedimentation in the flow that may clog the channel. There have been some previous studies conducted on the heat transfer of nanoparticles in suspension. Since Choi and Eastman (1995) wrote the first review article on nanofluid, Nguyen et al. (2007) investigated the heat transfer coefficient and fluid flow characteristic of nanoparticles dispersed in water flowing through a liquid cooling system of microprocessors under turbulent flow condition. The results revealed that the nanofluid gave a higher heat transfer coefficient than the base liquid and the nanofluid with a 36 nm particle diameter gave higher heat transfer coefficient compared to the nanofluid with a 47 nm particle diameter. He et al. (2007) reported an experimental study that investigated the heat transfer performance and flows characteristic of TiO_2-distilled water nanofluids flowing through a vertical pipe in an upward direction under a constant heat flux boundary condition in both a laminar and a turbulent flow regime. Their results showed that at a given Reynolds number and particle size, the heat transfer coefficient is raised with increasing nanoparticle concentration in both laminar and turbulent flow regimes. Similarly, heat transfer coefficient was not sensitive to nanoparticle size at a given Reynolds number and particle size. Moreover, the results indicated that the pressure drop of the nanofluids was very close to that of the base fluid.

A number of papers and handbooks are available onthese researches. Recent reviews for hydrodynamic and heat transfer and CFD portion done by Aslam et al.(2012), Patel and Patel (2014)and Hamidreza et al.(2015).

II. Methods of Nanofluid preparation

The dispersed nano-sized particles in the range of 1-100nm into base fluid are known as nanofluid. The desirable requirements for the preparation of nanofluids reported by Xuan and Li (2000)are the even suspension, stable suspension, durable suspension, no chemical changes and low agglomeration. The existing literature reveals that the nanofluid preparation method plays avital role in determining the effective thermal conductivity and viscosity of nanofluid. There are many concerns on preparing nanofluid, mainly dispersion method, the type of mixture, a dispersion medium, dispersed phase, thermal stability, chemical compatibility, and preparation techniques. However, care should be taken to apply enough surfactant for making the stability of nanofluid. Jiang et al. (2003) concluded the role of the surfactant is to create a sufficient electrostatic repulsion and compensate the Vander Waals attractions. Rea et al. (2009) suggested that very small solid particles in the base fluid can be treated as single phase though nanofluid two component. Therefore, it is reasonable to consider nanofluids with low volume fractions of nanoparticles as a single phase fluid. In general, there are two important methods to prepare the nanofluids

1) Single-step method

2) Two-step method or dispersion method

III. PREPARATION OF Al_2O_3 / WATER NANOFLUID FOR INVESTIGATION

In this investigation, Al_2O_3metal oxide nanoparticles are taken as nonmaterial and distilled water is taken as the base fluid. The two-step method is taken for preparing Al_2O_3 /water nanofluid. This is because the two-step method is better for oxide particles and this method gives higher stability and less agglomeration as proposed Das et al (2003), and Ghadimi et al (2011). The reasons for the use of water-based Al_2O_3Nanofluids are:

i. Al_2O_3 is generally regarded as a safe material for humans although it is recognized that this may change in the future with more fundamental research on nano-toxicology.
ii. Al_2O_3Nanoparticles are produced on large industrial scales, relatively cheaper and moderate thermal conductivity.
iii. Al_2O_3nanoparticles are chemically more stable than their metallic counterparts;
iv. Distilled water can be used over a fairly moderate range of temperature.

The Al_2O_3nanopowder was purchased from Reinste nano Ventures Pvt. Ltd., New Delhi.The specification of Al_2O_3 purchased nanoparticles and water are given in Tables 3.1 and 3.2. Figure 3.1 shows the agglomerated dry nanoparticles purchased for this investigation. It is seen the dry nanoparticles easily agglomerates even at room temperature.

Table 3.1: The specification of Al_2O_3nanoparticles

Aluminum Oxide nanopowder	
Molecular Formula	Al_2O_3
Molecular weight	101.96
CAS Number	1344-28-1
Lot Number	N06H417
Properties	
Form	Solid
Diameter	40-50nm
Specific Surface Area	32-40 m2/g
Purity	99.5%
Supplier	Reinste nano Ventures Pvt. Ltd., New Delhi.

Table 3.2: Properties of water and Al_2O_3nanoparticles

Materials	Density, ρ, Kg/m^3	Specific heat capacity, C_p, $J/kg\ K$	Thermal conductivity W/mK	Dynamic viscosity, μ, cP	Molecular weight, M kg/k mole
Water	997	4170	0.613	0.8 cP	18
Al_2O_3 solid nanoparticles	3880	729	40	--	101

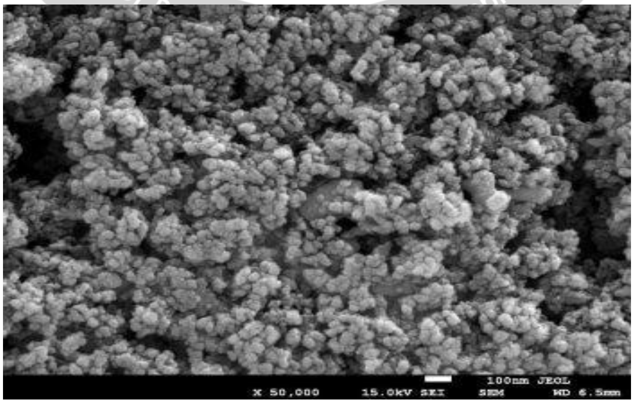

Figure 3.1: Image of dry and agglomerated Al_2O_3nanoparticles (Image courtesy: US research nanomaterials,Inc).

IV. CHARACTERIZATION OF NANOPARTICLES AND Al_2O_3 /WATER NANOFLUIDS

It is important to understand the behavior of nanoparticles and nanofluid prepared from fundamental point of view in order to apply nanofluid in practical situations. Therefore, the purchased Al_2O_3 dry Nano powder and the prepared nanofluid have been characterized by using the following methods.

X- Ray Diffraction (XRD) to determine the particle grain size, Scanning Electron Microscope (SEM) to determine the particle shape, suspension uniformity, and Particle agglomeration, KD2 Pro thermal property meter to measure the thermal conductivity of nanofluid, Schott rotational viscometer is used to measure the viscosity of nanofluid.

1. Determination of nanoparticle grain size using XRD

The simplest and most widely used method is (X-Ray Diffraction) XRD for estimating the average nanoparticle grain size. The Al_2O_3nanopowder was characterized by (X Ray Diffraction) XRD with a Rigaku Xray Differatometer and Cu-ka1 radiation in the range of 20–80^0. All the reflections in the XRD pattern (Fig. 4.1) can be indexed to the tetragonal phase of Al_2O_3 using JCPDS (Joint Committee on Powder Diffraction Standards). The X-ray diffraction test was carried out with a scan speed of 3^0/minute. The average grain size is estimated by using Debye-Scherrer formula (Equation 4.1). The full width at half maximum (FWHM) is taken from the XRD pattern (Fig.4.2).

$$d = \frac{0.9\lambda}{(FWHM)cos\theta} \quad (4.1)$$

*w*here *d*, λ, and θ*'* are the average particle grain size, the wavelength of the Cu-ka1 X- rays (1.5418A^0) and Braggs anglerespectively. The average grain size is found to be between 45 to 50nm by using the Scherrer formula (the error is within the limit of ±5 nm).

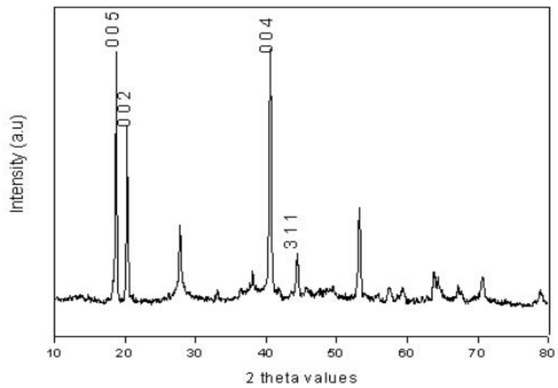

Figure 4.1: XRD patterns of Al_2O_3nanoparticles

2. Determination of particle shape, suspension uniformity of nanoparticles using SEM.

Tiwari et al (2015) reported the need to study the particles shape and suspension uniformity as spherical shape particles give higher thermal conductivity enhancement than cylindrical particles. Murshed et al (2008) suggested the Scanning Electron Microscope (SEM) is the powerful tool to study the shape and suspension uniformity.

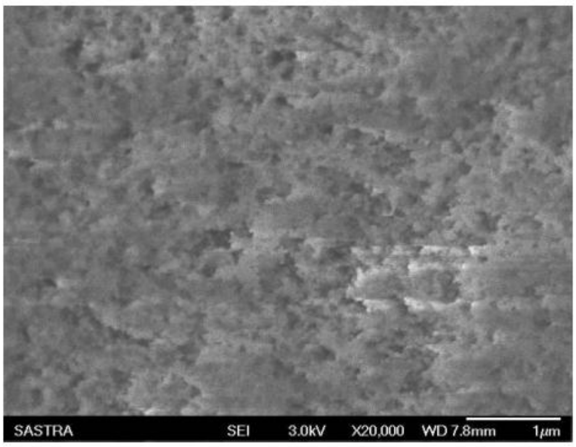

Figure 4.2: SEM images of dry Al_2O_3nanoparticles

The purchased Al_2O_3 dry nanoparticles and prepared nanofluid have been studied with SEM (Jeol JSM 6360 SEM). Figure 4.2 shows the SEM image of dry nanoparticles. It is seen that the highly agglomerated particles in the size X20.000 of micrometer under the atmospheric condition and most of the nanoparticles are spherical in shape. Apart from studying dry nanoparticles, the suspended nanoparticles in the basefluid have been studied with SEM. The sample nanofluid under consideration has been prepared to place in SEM the sample holder. The SEM image of suspended particles in the base fluid was obtained by sonicating, placing the sample on sample holder, by rapid drying for getting solid particles and making them conductive as suggested by Ghadimi et al (2011). Accordingly, the nanofluid sample is solidified into a gel (gelified). The nanofluid is sonicated, heated to $40^0 C$ and mixed with gelatin- de ionizedH_2O solution to create the jellified nanofluid. A thin layer of the mixture is poured into a clean dish and placed in a refrigerator for 20 minutes to allow the mixture to become gel and then it is transferred into a vacuum chamber to solidify for 5 hours to remove any excess liquid from the nanofluid film and prevent out gassing in the SEM. A 1 cm square section is cut from the film and attached to a pin stub specimen holder. The sample is sputtered with a thin layer of gold to create a conducting surface. Then the image of suspended and aggregated nanoparticles was obtained.

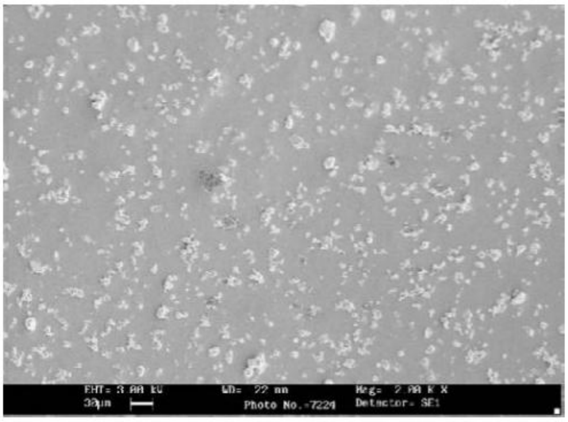

Figure 4.3: SEM images of dispersed Al_2O_3nanoparticles in water.

It is clear from the Fig.4.3 that the dispersed nanoparticles appear to be uniformly dispersed in a base fluid and most of the nanoparticles nearly spherical in shape. It is found that there is no considerable agglomeration.

3. Measurement of nanofluid thermal conductivity

Nanofluid attracted a vast attention due to increment in thermal conductivity compared to base fluid. Measuring thermal conductivity is a challenge for a long time since different methods and techniques presented different results. On comparing the effect of nanofluid density and specific heat capacity, thermal conductivity and viscosity on heat transfer play a key role in enhancing heat transfer. Over the years, different techniques have been adopted for measuring the thermal conductivity of liquids. A number of such techniques have also been used for Nanofluid. Out of all the techniques, the transient hot-wire method has been used most extensively.

The transient hot-wire (THW) method was first suggested by Stalhane and Pyk in 1931 to measure the absolute thermal conductivity of powders. Paul et al (2010) proposed the Transient Hot-Wire (THW) method is the most popular method for measuring the thermal conductivity of nanofluid used by scientists and researchers and it gives a lower experimental error. This is because of simplicity, and eliminating convective contribution to the heat transfer from the measurements. In this investigation, Transient hot-wire method is used to measure the nanofluid thermal conductivity. The thermal conductivity of nanofluid was measured by using a KD2 Pro thermal property meter,

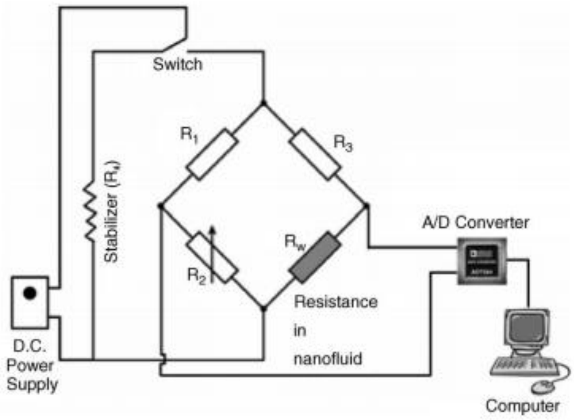

Figure 4.4: Schematic of transient hot-wires experimental setup.

Fourier’s law for conduction heat transfer can be utilized to measure the thermal conductivity of a material. The temperature difference can cause heat transfer through materials which are known as conduction heat transfer. This method is based on applying a constant current to a platinum wire and measuring the time evolution of its electrical resistance due to temperature increase. It consists of a handheld microcontroller and sensor needles. The KD2’s sensor needle contains both a heating element and a thermistor.The controller module contains a battery, a 16-bit microcontroller/AD converter, and power control circuitry (Fig.4.4). The thermal conductivity measurement assumes several things like:

a) The heating source is infinitely long
b) The medium is both homogeneous and isotropic, and at uniform initial temperature To.

Although these assumptions are not true in the strict sense, they are adequate for accurate thermal properties measurements. The sensor needle used was KS-1 which is made of stainless steel having a length of 60 mm and a diameter of 1.3 mm, and closely approximates the infinite line heat source which gives the least disturbance to the sample during measurements. The sensor needle can be used for measuring the thermal conductivity of fluids in the range of 0.2–2 W/mK. The Al_2O_3/water nanofluid up to 3% volume concentrations has been used for thermal conductivity measurement. The 45ml sample was taken just after the preparation of nanofluid. This is because the minimum amount of nanofluid required for thermal conductivity measurement is 45 ml. At the beginning of a measurement, a period of time, 30 sec, was needed for the system to become steady at 20°C. Then, a heating power 'q' was applied abruptly and briefly for 30 sec through a needle. Finally, the solution temperature was cooled naturally.

During the cooling period, the fluid temperature T_1 at time t_1 and temperature T_2 at time t_2 were recorded. Then, the thermal conductivity is calculated using Equation 4.2. At the end of the reading, the controller computes the thermal conductivity using the change in temperature (T) – time data.The thermal conductivity of nanofluid was calculated according to the following Equation (4.2)

$$k = \frac{q}{4\pi(\Delta T_2 - \Delta T_1)} ln\left(\frac{t_2}{t_1}\right) \qquad (4.2)$$

where 'k' is thermal conductivity of nanofluid, 'q' is constant heat rate applied to an infinitely long and small 'line' source, T_1 and T_2 are the changes in the temperature at times 't_1' and 't_2' respectively. At least five measurements were taken for each concentration and their average values were reported.
The measured thermal conductivity values have been given in Figure 4.5 and 4.6

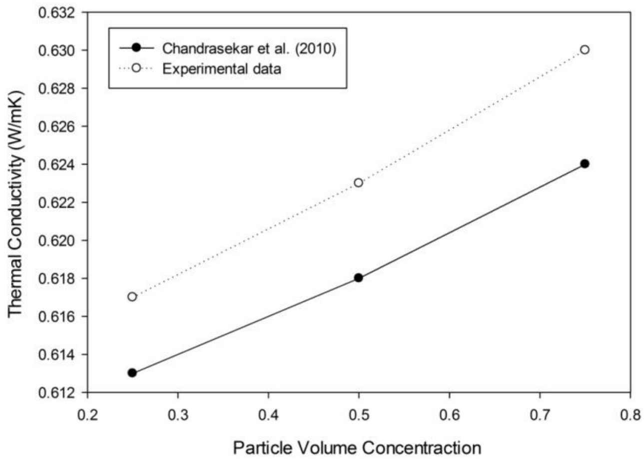

Figure 4.5: Variation in thermal Conductivity (W/mK) of Al_2O_3/water nanofluid recorded as a function of particle volume concentration.

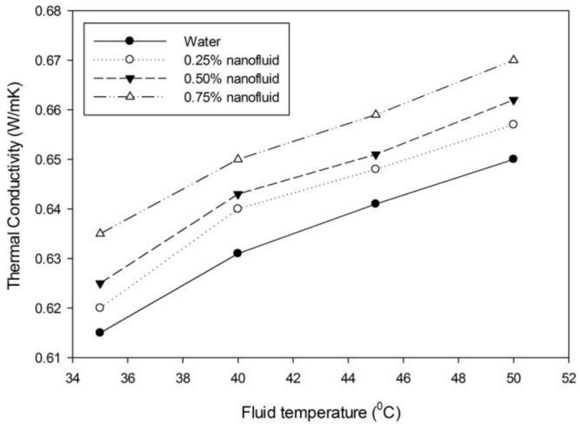

Figure 4.6: Variation in thermal Conductivity (W/mK) of Al_2O_3/water nanofluid recorded as a function of fluid temperature (^{0}C).

It is studied from Figure 5.7 that the thermal conductivity of nanofluid is higher than water. The thermal conductivity of 0.25%, 0.50% and 0.75 % nanofluid is 1.2%, 2% and 3.2% respectively higher than water at 35^{0}C. It is also found that the thermal conductivity of nanofluid increases with increasing particle volume concentration. This is because of more particles loading has higher particle surface to volume ratio. The mechanism for this enhancement may be because of the particle to particle interactions, nanoparticles cluster, and Brownian motion. The deviation between the experimental data and predicted value are in the range of 0.2% - 0.4%. The measured thermal conductivity of 0.25%, 0.5% and 0.75%,nanofluid at 50^0C is 5.5%, 6% and 6.5% respectively higher than the nanofluid at 35^0C.This is because at elevated temperature the viscosity decreases which leads to intensify the Brownian motion and enhance the nano convection effect.

4. Measurement of nanofluid viscosity

Nanofluid viscosity is an important parameter like thermal conductivity for practical applications since it directly affects the pressure drop and pumping power in forced convection. Thus from the application point of view, ideal nanofluid should not only possess high thermal conductivity but also should have low viscosity.

Viscosity measurements of Al_2O_3Nanofluids were performed using a Schott rotational viscometer, equipped with a spindle of coaxial cylindrical geometry (LCP) equipped with a stainless steel flow jacket. This viscometer is a controlled shear rate instrument. By using a multiple-speed transmission and interchangeable spindles, a variety of viscosity ranges can be measured, enhancing device versatility. Flow behavior of nanofluid was tested at a shear rate of 123 s-1. The LCP adaptor holds a sample volume of 16-18 ml and is connected to a PolyScience fluid circulation bath, which controls temperature measured inside the cell with a PT100 probe that ensures an uncertainty of 0.05 K. The estimated uncertainty in viscosity using this device is guaranteed to within ± 1%.

It is studied from Figure 4.7 that the viscosity of nanofluid increases with increasing particle volume concentration**.** The measured viscosity of 0.25%,0.50% and 0.75% nanofluid at 35^0C are 3%, 3.7% and 6% respectively higher than water at the same temperature. The maximum viscosity increase is 6% at 0.75% nanofluid. The deviation between the experimental data and predicted value are in the range of 1%-2%.

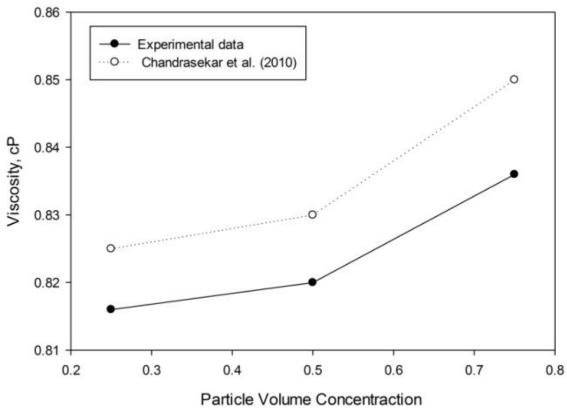

Figure 4.7: Variations of the Viscosity of Al_2O_3/water nanofluids recorded as a function of particles volume concentration.

From Fig. 4.8, it is observed that the nanofluid viscosity decreases with increasing temperature. Viscosity of the 0.25 % nanofluid at 50^0C is 30% lower than 0.25 % nanofluid at 35^0C. The viscosity of 0.5% nanofluid at 50^0C is 35% lower than 0.5% nanofluid at 35^0C. The viscosity of 0.75% nanofluid at 50^0C is 38% lower than0.75 % nanofluid at 35^0C.This is because at elevated temperature the shear stress decreases which leads to intense the particle to particle interaction and Brownian motion. The present viscosity results hold good agreement with the experimental data presented by Choi (1999), Hwang et al(1999) Murshed et al (2008).Therefore, it is expected that the higher the particle concentration may increase the pressure drop and pumping power.

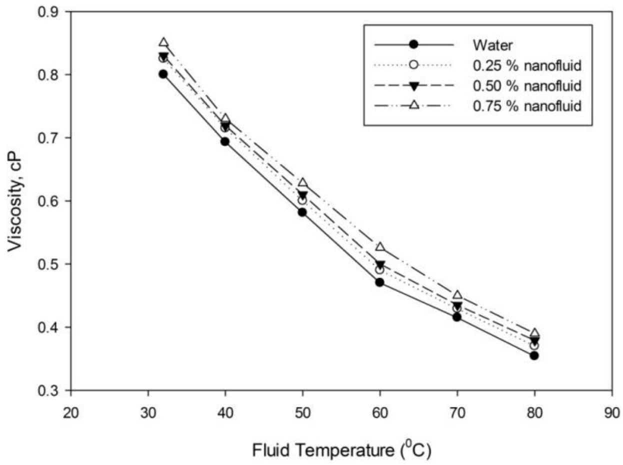

Figure 4.8: Variations of the Viscosity of Al_2O_3/water nano fluids recorded as the function of nanofluid temperature.

5. Inspection of nanofluid stability

Stability of the nanofluid suspension is a crucial issue for both scientific research and practical applications to provide better cooling. To consider and evaluate the stability of nanoparticles inside the base fluid, sedimentation velocity calculation of small spherical particles is found by using Stokes law. Stokes law (Equation 5.3) includes the effective parameters for stability of Nanofluids.

$$v = \frac{2r^2}{9\mu}(\rho_p - \rho_f)g \qquad (4.3)$$

where, 'v' is the sedimentation velocity, 'r' the radius of particles, ρ_f is the viscosity of the fluid; $\rho_p$is the density. Finally, 'g' is the gravity acceleration, which is the main reason of sedimentation.

There are three forces acting on suspended particle such as buoyancy force, drag force and body force. Their balance makes the nanoparticles stable. Buoyancy and drag forces are acting upward and resisting against body force acting downwards resulting from gravitational attraction Hiemenz and Dekker (1986). Therefore, lower particle size, lower viscosity, lower temperature difference are the stability parameters. The addition of surfactant, pH control and ultrasonic agitation (vibration) are the three common techniques for making stable Nanofluid. Additions of surfactant and pH control are the two techniques to prevent clustering and agglomeration while ultrasonic vibration is applied to break down agglomeration.

V. CONCLUSION

The present study provides significant and comprehensive information about Al_2O_3/water nano fluid.The study is done in the moderate Reynolds number regime with focus on the transition regimes Present research with nanofluid shows that thermal conductivity and viscosity increase with increasing particle volume concentration. It was found from the experimental investigation that the heat transfer coefficient and pressure drop increase with increasing particle volume concentration.

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