

# An Evaluation Of The Stability Of ZnO And Al<sub>2</sub>O<sub>3</sub> Nanoparticles In Nanofluids For Heat Transfer Applications In Radiators

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## **Abstract:**

Nanofluids, which are suspensions of nanoparticles in a base fluid, have shown promising potential for enhanced thermal conductivity and heat transfer in various applications. Among these, Al<sub>2</sub>O<sub>3</sub> (aluminum oxide) and ZnO (zinc oxide) nanofluids are widely studied due to their favorable properties. This study focuses on the stability analysis of Al<sub>2</sub>O<sub>3</sub> and ZnO nanofluids prepared with water as the base fluid. Stability is a critical parameter for the effective utilization of nanofluids, as it directly affects their thermophysical properties and practical applications. To assess stability, various techniques such as UV-Vis spectroscopy, zeta potential measurements, and sedimentation analysis were employed. The effects of nanoparticle concentration, pH, surfactant addition, and ultrasonic agitation on the stability of these nanofluids were systematically investigated. The zeta potential analysis indicated that both Al<sub>2</sub>O<sub>3</sub> and ZnO nanofluids exhibit enhanced stability at optimal pH levels and with appropriate surfactant concentrations, ensuring electrostatic repulsion between particles. Moreover, the stability of nanofluids was found to be time-dependent, with ZnO nanofluids showing slightly better stability over extended periods compared to Al<sub>2</sub>O<sub>3</sub>. The findings highlight the importance of optimizing the preparation conditions to achieve stable nanofluids, which is crucial for their practical application in heat transfer systems. This study provides valuable insights into the formulation of stable nanofluids, paving the way for their effective use in industrial and engineering applications. In this research work the nanofluid stability for Al<sub>2</sub>O<sub>3</sub> and ZnO nanofluid for various Volume concentration is tested. From study it has been observed that the Al<sub>2</sub>O<sub>3</sub> nanofluid is more stable than the ZnO nanofluid.

**Keywords:** Nanofluid, heat transfer, stability, Zeta potential, Sedimentation analysis

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## **1. INTRODUCTION:**

Using a range of active and passive techniques, researchers are working harder to improve heat transfer performance in Automobile cooling system. Taking effort to create compressed thermal energy systems that are extremely efficient. Nanofluids are colloidal suspensions consists of nanoparticles dispersed within a base fluid, typically water or oil. These nanoparticles, such as Al<sub>2</sub>O<sub>3</sub> (alumina) and ZnO (zinc oxide), offer unique properties like enhanced thermal conductivity, which make nanofluids desirable for various applications including heat transfer enhancement, biomedical applications, and electronics cooling. Stability refers to the ability of a nanofluid to maintain its dispersed state over time, resisting aggregation and settling of nanoparticles. Stable nanofluids are crucial for consistent performance and longevity in practical applications. Zeta potential is a key parameter in understanding the stability of colloidal suspensions, including nanofluids. It represents the electro kinetic potential at the shear plane adjacent to a charged particle in a colloidal dispersion. Essentially, it measures the magnitude of the electrostatic repulsion or attraction between particles and serves as an indicator of colloidal stability.

While considering the stability of Al<sub>2</sub>O<sub>3</sub> and ZnO nanofluids, the zeta potential plays a critical role. A high absolute value of zeta potential (either positive or negative) indicates strong electrostatic repulsion between particles, which prevents them from agglomerating or settling. For example, if Al<sub>2</sub>O<sub>3</sub> nanoparticles have a high negative zeta potential, they will repel each other electrostatically, preventing aggregation and ensuring the stability of the nanofluid. Similarly, ZnO nanoparticles with a high negative zeta potential would exhibit enhanced stability due to electrostatic repulsion. Understanding and controlling the zeta potential of nanofluids is therefore essential for optimizing their stability and ensuring their suitability for various

applications. Techniques such as surface functionalization and pH adjustment can be employed to manipulate the zeta potential and enhance the stability of nanofluids containing  $\text{Al}_2\text{O}_3$  and ZnO nanoparticles.

A base or normal fluid containing nanoparticles of nanometric size is called a nanofluid. The goal of distributing the nanoparticles in the base fluid is to enhance its physical and thermal characteristics, including its viscosity, thermal conductivity, and rate of heat transfer. Good thermal conductivity nanofluids are employed as coolants or lubricants. In addition, they are used in numerous other applications, including freezers and air conditioning.

The investigation of nanoparticle sizes on nanofluid performance in transitional flow regime is studied by [1]. The four different nanoparticle sizes are used results in 48.86 % enhancement in Nussult's Number. The heat transfer enhancement in electronic devisees using  $\text{Al}_2\text{O}_3$  nanofluid results in 26% raise in heat transfer coefficient. An average size of 57 nm for the  $\text{Al}_2\text{O}_3$  nanoparticles is used in the microfluidic reactors [2]. Abdulelah Alhamayani et. al. [3] studied the experimental and machine learning algorithm for performance of hybrid nanofluid for solar trough collector. Lirong Li et. al. [4] studied  $\text{Al}_2\text{O}_3$  -methanol nanofluid in bubble column for improvement in heat transfer rate. The Abdelkrim Khelifa et. al. [5] reported the cooling of photovoltaic thermal collector by using  $\text{Al}_2\text{O}_3$  water based nanofluid with nanofluid concentration varies between 0.2 to 1%. Adding 3 wt% ferrofluid enhanced the system's overall efficiency by 45%, by employing an alternating magnetic field at a frequency of 50 Hz further boosted the efficiency to approximately 50%. Also it has been found that using a 1% concentration of  $\text{Al}_2\text{O}_3$  -water nanofluid as a cooling agent is the optimal concentration for maintaining the surface of the PVT system at a lower temperature. The Mohammed et. al.[6] studied the impact of surfactant on  $\text{Al}_2\text{O}_3$  nanofluid for electronic cooling application.  $\text{Al}_2\text{O}_3$  nanoparticles and SDS surfactant were combined in water at volume fractions of 0.5% to create the nanofluids used in the experiment. The aim of the study is that Evaluate the cooling performance of volume fractions of nanofluid at 0.1, 0.3, and 0.5%  $\text{Al}_2\text{O}_3$  nanofluid and pure water using Sodium Dodecyl Sulfate (SDS) as a surfactant. The different flow rates of 0.25 L/m, 0.75 L/m, and 1.25 L/m used with nanofluid during the testing process. The stability analysis of nanofluid for different time duration of sonication is studied by F.R. Siddiqui et. al. [7]. T.O. Scott et. al. studied the volume concentration's impact on natural convection heat transfer with  $\text{Al}_2\text{O}_3$ -MWCNT/water nanofluid. The  $\text{Al}_2\text{O}_3$  nanomaterial with 5 nm-diameter, 99.5% pure were utilized. It has found that 49.27% improvement over the base fluid at 0.10% volume concentration. Mathkar A. Alharthi et. al. [8] studied artificial neural network (ANN) to predict  $\text{Al}_2\text{O}_3$ /water nanofluid is used in conically coiled tubes (CCTs) for volume concentrations of 0.3-0.9 %. TRAINLM algorithm is used to predict Nu and  $f$  for which correlation coefficients is 0.99 and 0.94. Seungyeop Baek et. al. [9] studied the impact of amphoteric and anionic surfactants on  $\text{Al}_2\text{O}_3$ /water nanofluid stability. The results for stability and thermal conductivity show that SDBS can be a great stabilizer and dispersion agent to prevent alumina nanoparticles from clumping and sedimenting, but adding SDBS to alumina nanofluid can have the negative effect of somewhat lowering thermal conductivity. Pascaline Tiam Kapen et. al. studied Analysis of the linear stability of a hybrid nanofluid consisting of water and Cu- $\text{Al}_2\text{O}_3$ . [10] and it has been found that Darcy number affects the stability of the flow. M. K. Bahadori [11] studied effect of  $\text{Al}_2\text{O}_3$  and silica nanofluid for co2 absorption. It was discovered that  $\gamma$ - $\text{Al}_2\text{O}_3$ , Si-ZIF-8, and super activated carbon solutions have a stable Zeta potential in aqueous solvents. Talib K. Murtadha [12] experimentally studied the Improvement of photovoltaic performance through the use of hybrid nanofluids of  $\text{Al}_2\text{O}_3$ /TiO<sub>2</sub> with cooling fluid flow rate vary from (0.5 L/min) - (3 L/min).The Gyuchang Kim [13] studied  $\text{Al}_2\text{O}_3$ /water nanofluid stability, surface tension, and thermal conductivity in relation to various alcohol kinds and their ratio. It has been observed that, increasing the  $\text{Al}_2\text{O}_3$  content of the nanofluids, increases the instability during the zeta potential assessment of the nanofluid stability. Tahmidul Haque Ruvo et. al. [14] studied  $\text{Al}_2\text{O}_3$ -Water nanofluid thermo-physical property models for natural convective flow.S.S. Khaleduzzaman et. al. [15] experimentally observe the stability of  $\text{Al}_2\text{O}_3$  nanofluid with 0.10 to 0.25 vol. % of nanoparticle was used as coolants for electronic cooling system. Durga Bhavani J [16] studied the preparation and stabilization of  $\text{Al}_2\text{O}_3$ /CuO nanofluids and the physiothermal properties for the nanofluids.

These nanofluids were made at pH 2.7 without the use of any stabilizer. It demonstrated that when nanofluid concentrations grew, so did the thermal conductivity. Ramin Tahmasebi-Boldaji et. al [17] studied the thermal conductivity of water/ $\alpha$ - $\text{Al}_2\text{O}_3$  nanofluid stability using the ultrasonic cycle and magnetic stirrer effect. In this research the  $\alpha$ - $\text{Al}_2\text{O}_3$  nanofluid stability predicted using particle swarm optimization (PSO). ultrasonic cycle demonstrated that it is a crucial factor in establishing the stability of nanofluids. By using this method, the zeta potential value was 32.8 mV after 10 minutes of sonication operation with cycle 7, PH 11, and volume concentration of 0.25 vol%. Abid Ali Memon [18] studied the Numerical investigation on Cu- $\text{Al}_2\text{O}_3$  hybrid nanofluid-based photovoltaic thermal energy efficiency enhancement. The goal of his work is to use hybrid nanofluids for cooling in order to improve the efficiency of two-dimensional photovoltaic thermal systems. From that it has been found that as the volume percentage of copper nanoparticles and Reynolds number rise, so does the cell efficiency. Bhavin Mehta et. al [19] expediently studied the enhancement of  $\text{Al}_2\text{O}_3$ -water nanofluid stability and thermophysical characteristics with the use of cationic CTAB surfactant. Synthesized sample is evaluated for 1, 8, 15, and 30 days. The stability of the nanofluid without surfactant was low after 15 days of manufacturing. Greater UV-vis light absorption has been demonstrated by nanofluid with surfactant due to better particle suspension. Likhan Das et. al [20] has experimentally examined a double pipe heat exchanger's thermohydraulic performance with nanofluid. By generating additional vortices, ribbed inserts added to a conventional TT insert increase the intensity of turbulence. A. Azman et. al [21] studied the flow properties and heat transfer efficiency numerically using a hybrid  $\text{Al}_2\text{O}_3$ -CuO nanofluid. L. A. Lund [22] experimentally studied the effect shrinking surface on Cu- $\text{Al}_2\text{O}_3$ /H<sub>2</sub>O nanofluid stability. M.F. Zawrah et. al [23] studied the Stability of water-base  $\text{Al}_2\text{O}_3$  nanofluids for different applications.

Prasanna Shankara et. al [24] studied the Radiator system performance with graphene oxide nanofluids based on ethylene glycol and water. The Stability is assessed through visual inspection and the zeta potential test. From the above literature work it has been found that stability of nanofluid is one of the important factor for use of nanofluid. The goal of this research is to analyses the stability of nanofluid with combined use of sonication and use of surfactant. The stability of nanofluids is crucial for many reasons, especially in applications related to heat transfer, energy storage, and medical technologies. Nanofluids are suspensions of nanoparticles in a base fluid (like water, oil, or ethylene glycol), and their unique properties make them useful in various fields. However, their performance is highly dependent on maintaining stability over time.

### Nomenclature

Nu	Nusselt number
Re	Reynolds number
T	temperature
Pr	Prandtl number
$V_s$	sedimentation velocity
R	particle radius
$(V_s)$	sedimentation velocity
$\mu$	dynamic viscosity
$\rho$	density of the fluid
$\phi$	solid volume fraction
k	thermal conductivity,

### Subscripts

nf	nanofluid
bf	Base fluid
np	Nanoparticle
av	average
Inlet	Inlet pipe
outlet	Outlet pipe m mean

## 2. Experimentation

### 2.2.1 Nanofluid Preparation

The nanofluid is prepared by Two-stage method, where Nanoparticles are first synthesized in powder form and then dispersed into the base fluid using mechanical mixing, magnetic stirring, ultrasonication, or a combination of these methods. Magnetic stirrer is used for continuous stirring of nanofluid. In order to reduce agglomeration and increase stability, surfactants or dispersants—such as sodium dodecyl sulfate (SDS) and cetyltrimethylammonium bromide (CTAB) may be occasionally added. The prepared fluid is sonicated using a probe sonicator with frequency of 10 hz to 1o KHz to further improve stability. A probe sonicator is used to sonicate the nanofluid for 60 minutes, resulting in improved long-term stability and particle dispersion.

The Geometrical and Chemical properties for  $\text{Al}_2\text{O}_3$  and  $\text{ZnO}$  is as shown in Table 1.

Table 1. Geometrical properties of  $\text{Al}_2\text{O}_3$  and  $\text{ZnO}$

Parameter	$\text{Al}_2\text{O}_3$	$\text{ZnO}$
Purity	99.9%	99.9%
Average Particle Size	2 0 - 5 0 nm	1 0 - 4 0 nm
SSA	~ 110 $\text{m}^2/\text{g}$	100 - 120 $\text{m}^2/\text{g}$
Molecular Weight	101.96 g/mol	81.408 g/mol
Molecular Formula	$\text{Al}_2\text{O}_3$	$\text{ZnO}$
Melting Point	2055 $^\circ\text{c}$	1975 $^\circ\text{c}$
Bulk Density	0.5 g/cm <sup>3</sup>	0.5 8 g/cm <sup>3</sup>
Physical Form	Powder	Powder
Morphology	Near spherical	Spherical
Colour	White (pure bright)	Milky white

The nanofluid is then tested with XRD result and SEM image. multiple volume concentrations of a nanoparticle like 0.01,0.015,0.02,0.025% of VC is used for the study.



Fig. 1 Magnetic Stirrer used for mixing of nanofluid

### 2.2.2 SEM and XRD images

Characterization of the prepared  $\text{Al}_2\text{O}_3$  and  $\text{ZnO}$  nanofluids is verified by using SEM and XRD microscope images. The process of scanning a sample's surface with concentrated electron beams is known as scanning electron microscopy, or SEM as shown in fig. 2 & 4. The signal that is produced when the electron beam interacts with the sample tells us about the composition, surface topography, and other characteristics of the sample. X-ray diffraction (XRD), which focusses on the crystalline structure of materials, offers bulk information regarding crystallinity and phase identification as shown in fig. 3 & 5.

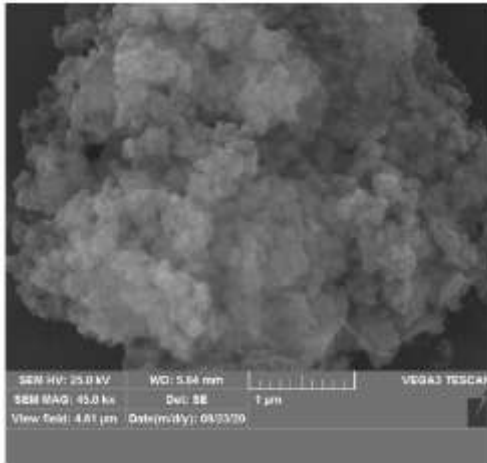
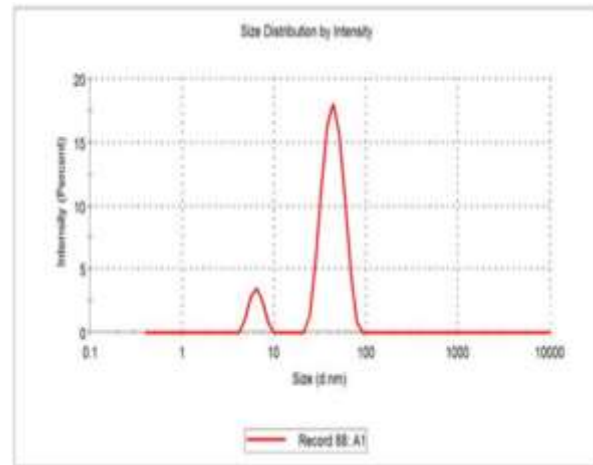
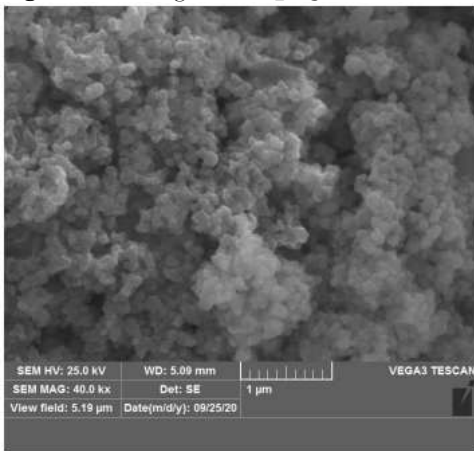
Fig.2 SEM image for Al<sub>2</sub>O<sub>3</sub>Fig. 3. XRD Image for Al<sub>2</sub>O<sub>3</sub>

Fig. 4 SEM image for ZnO

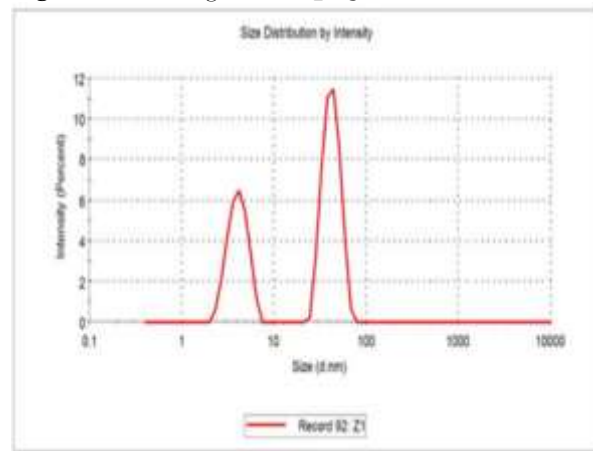


Fig. 5. XRD Image for ZnO

### 2.2.3 Nanofluid Stability

A two-step procedure was used to create the Al<sub>2</sub>O<sub>3</sub> and ZnO nanofluid, with deionized water (DI water) and ethylene glycol serving as the base fluid. The sedimentation velocity ( $V_s$ ) in a colloid can be expressed as follows using Stokes' law as given in 1.

$$V_s = \frac{2R^2}{9\mu} (\rho_p - \rho_l)g \quad (1)$$

As particle radius ( $R$ ) drops, base liquid viscosity ( $\mu$ ) increases and the density differential between the particle and the liquid ( $\rho_p - \rho_l$ ) increases, the rate of sedimentation reduces. so, basically Each of these factors is crucial for a kinetically stable nanofluid. Utilizing optical and electron microscopes, one may also determine the stability of nanofluids.

The stability of nanofluid is basically depends upon use of surfactant and process of stirring the nanofluid which assist for proper mixing of nanofluid. Some of the factors like use of surfactant and stirrer affecting the nanofluid stability is discussed below.

#### A. Surfactant

The stability of the nanofluid is improved using 0.5 wt.% of SDBS surfactant. The mixture was then put to magnetic stirring for 30 min and then sonicated for 1 hour at an amplitude of 90 using an Ultra-sonicator, which breaks the particle's agglomerations and properly disperses the nanoparticles in the base fluid. Results also show that nanofluid's pH decreased with the increasing temperature [1]. In order to increase the cooling efficiency of Al<sub>2</sub>O<sub>3</sub> nanofluid in electronic cooling, Sodium Dodecyl Sulfate (SDS) is used as a surfactant. The capacity of SDS to disseminate and stabilize nanoparticles in a fluid media is well established. In order

to create a stable nanofluid, it is crucial to prevent agglomeration and guarantee uniform distribution of nanoparticles throughout the fluid. Additionally, SDS can enhance the nanofluid's capacity for heat transfer. [6] [25] Compared to anionic surfactants (SDS and SDBS), amphoteric surfactant (LB) has a higher heat conductivity.[9] The cationic surfactant CTAB surfactant (LOBA chemie) is used to increase the repulsive force between two successive molecules of nanoparticles, hence preventing the agglomeration and sedimentation of nanoparticles and enhancing their long-term stability[19]. The ultra-sonication method is used to create  $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$  nanofluids utilizing sodium dodecylbenzenesulfonate (SDBS) as a dispersing agent. The produced nanofluids were tested with varying concentrations of SDBS, i.e., 0.1, 0.2, 0.3, 0.6, 1 and 1.5 wt%. The most stable nanofluid, according to the results, was one with 1% SDBS. A higher viscosity was seen in the fluid with 0.75 vol.%  $\text{Al}_2\text{O}_3$  nanoparticles, which caused settling.[23]

### B. Stirrer

The  $\text{Al}_2\text{O}_3$  nanofluid is stirred with a magnetic stirrer for 30 minutes before being sonicated for an hour.[1] The  $\text{Al}_2\text{O}_3$  methanol nanofluid is stirred using hand stirrer in a beaker using a glass stirring rod. The nanofluid is then sonicated to obtain stable nanofluid. The ultra-sonication process is a highly effective technique for dispersing aggregated nanoparticles evenly throughout the base fluid. To transmit vibration waves, the transformer with power ranging 750–1500 W and with the frequency range of 20–25 HZ. The three different time for ultrasonication was used i.e. 60, 120 and 180 min. The longer vibration times enhance the dispersion of nanoparticles, with diminishing effects observed after 45 minutes of sonication. Excessive vibration at 1500 W significantly raises both the temperature and the Brownian motion of the solution. [4]. By signification, the nanofluids were produced by utilizing an ultrasonic cleaner for three hours at a frequency of 37 kHz.[6]. In an ultra-sonication bath, samples were subjected to a set frequency and power of 40 kHz and 130 W, respectively. The 0.01% volume fraction for ultra-sonication study is used.[7] A frequent technique to break up nanoparticle clusters and encourage the dispersion of the nanoparticles in the base fluids in order to generate a long-term stable suspension is ultra-sonication, which can change the surface of nanoparticles.[9] A hot plate-equipped REMI (2 MLH) magnetic stirrer is utilized to continuously stir nanofluid. [19]



**Fig. 6** The preparation process of ethanol glycol based nanofluid.

The size distribution and morphology of the produced nanoparticles can be ascertained using TEM, which is thought to be the most crucial instrument. Assessing the stability of nanofluids is crucial because the performance of nanofluids in applications such as heat transfer, cooling, and lubrication depends significantly on their stability. Here are some common techniques used to assess the stability of nanofluid.

### Visual Inspection

This is the simplest method, involving visual monitoring of the suspension over time to check for sedimentation or phase separation. Periodic photographs can be taken to compare the height of the sedimented layer over time.

### Zeta Potential Measurement

Zeta potential measures the electrostatic repulsion between particles in a suspension. Higher absolute values (typically  $> \pm 30$  mV) indicate good stability due to strong repulsive forces preventing aggregation. It involves using electrophoretic light scattering or electroacoustic methods to measure the potential near the particle surface.

**Dynamic Light Scattering (DLS)**

DLS measures the size distribution of particles in suspension, providing information on aggregation over time. It uses the scattering of light by particles in motion, with fluctuations in scattered light intensity corresponding to the Brownian motion of the particles.

**UV-Vis Spectroscopy**

This technique monitors the absorbance or transmittance of light through the nanofluid at specific wavelengths to assess particle dispersion and agglomeration. A stable nanofluid will show consistent absorbance over time, while a decrease suggests aggregation or sedimentation.

**Thermogravimetric Analysis (TGA)**

TGA measures weight changes in a sample as it is heated, which can indicate the stability of nanoparticles in the fluid by detecting the loss of volatiles or decomposition. It involves heating the nanofluid under controlled conditions and measuring the weight change with temperature.

**Fourier Transform Infrared Spectroscopy (FTIR)**

FTIR helps to identify chemical changes on the surface of nanoparticles that could affect stability, such as oxidation or changes in surfactant coverage. It analyzes the infrared spectrum of absorption, emission, and photoconductivity of the nanofluid.

**pH Measurement:**

The pH of the nanofluid can influence the stability, especially for nanoparticles stabilized by charge (electrostatic stabilization). Monitoring pH over time helps in identifying stability issues that arise due to changes in the surface chemistry of the particles.

**Centrifugation:**

Centrifugation can be used to accelerate the sedimentation process to observe stability under stress. The nanofluid is spun at high speeds, and the amount of sediment formed is measured to assess stability.

**2.2.4 Zeta potential**

The zeta potential test is a primary analytical tool for nanofluid stability. Good nanofluid stability is indicated by a high zeta potential. On the other hand, low zeta potential values suggest unfavorable stability and particle buildup in the nanofluid. The stability can be explained using a theory proposed by Derjaguin, Landau, Vewey, and Overbeek (DLVO). According to the DLVO theory, colloidal stability is dependent on the total potential energy, VT which is expressed as Fig.7 below.

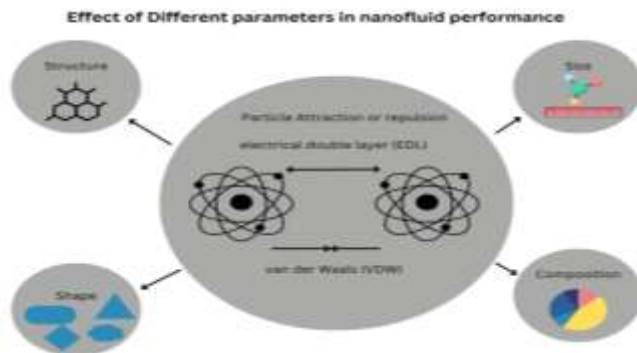


Fig. 7 DLVO

$VT = VA + VR$  where VA and VR represent van der Waals attractive potential and electrostatic repulsive potential respectively.

**2.2.5 Stability mechanism and evaluation methods**

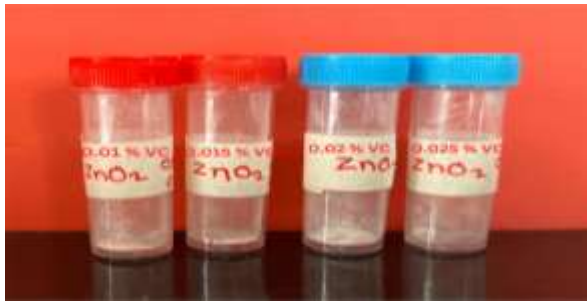


Fig. 7. The 0.01, 0.015, 0.02, 0.025%VC of ZnO nanoparticle

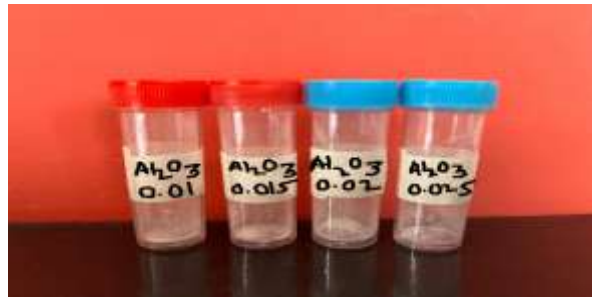


Fig. 8. The 0.01, 0.015, 0.02, 0.025%VC of Al<sub>2</sub>O<sub>3</sub> nanoparticle

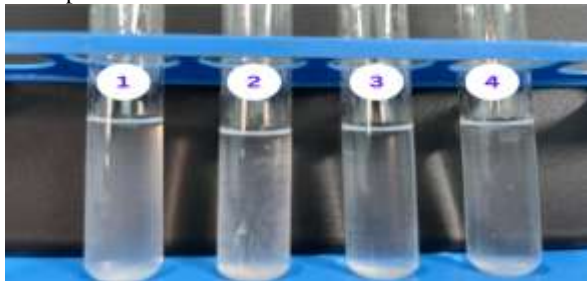


Fig. 9. ZnO nanoparticle after preparation

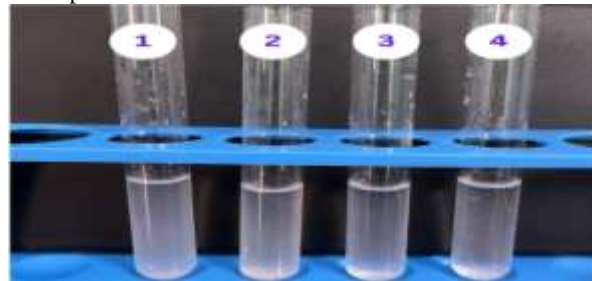


Fig. 10. Al<sub>2</sub>O<sub>3</sub> nanoparticle after preparation

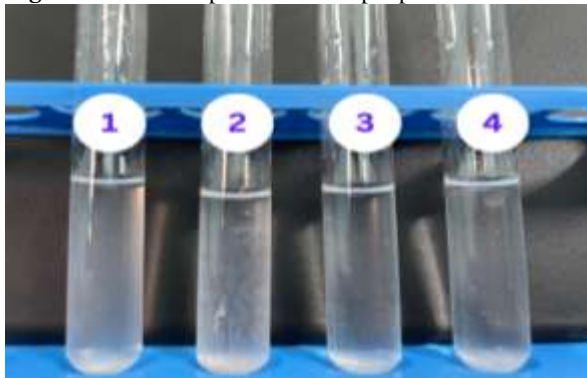


Fig. 12. ZnO nanoparticle after 6 days

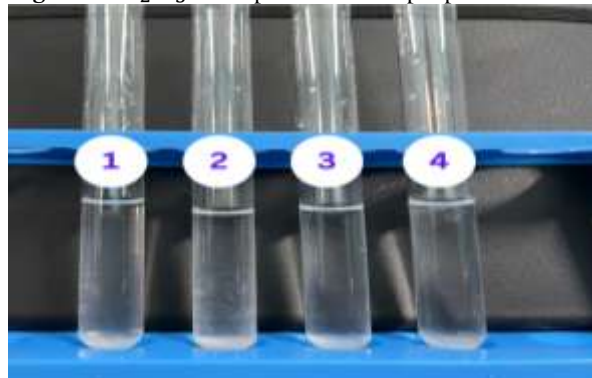


Fig. 11. Al<sub>2</sub>O<sub>3</sub> nanoparticle after 6 days

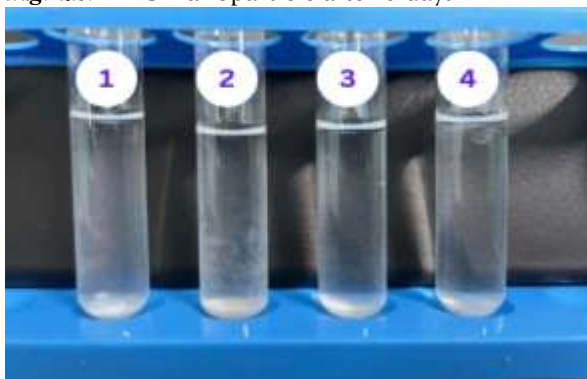


Fig.13. ZnO nanoparticle after 12 days

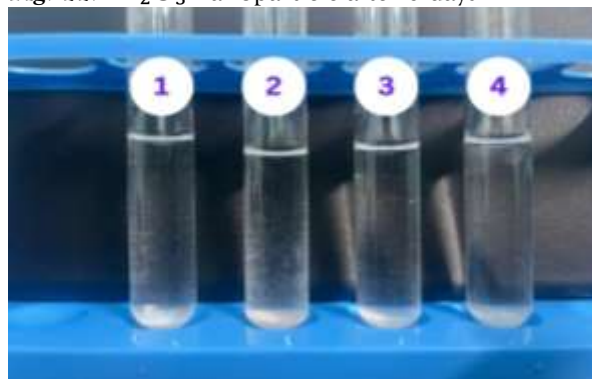


Fig. 14. Al<sub>2</sub>O<sub>3</sub> nanoparticle after 12 days

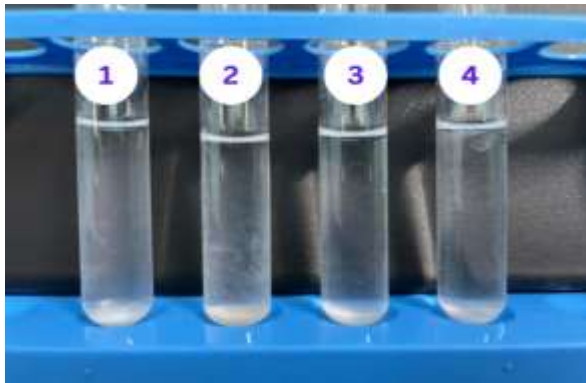


Fig. 16. ZnO nanoparticle after 15 days

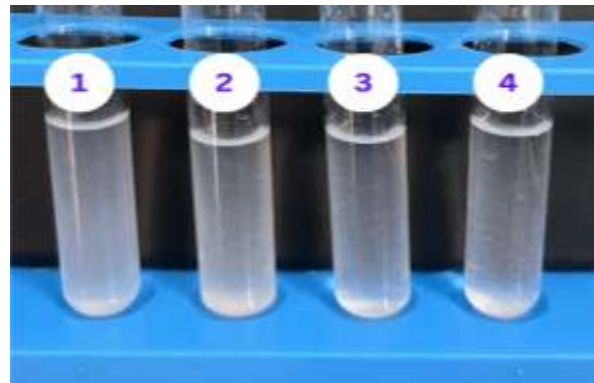


Fig. 15. Al<sub>2</sub>O<sub>3</sub> nanoparticle after 15 days

The stability of nanofluids was visually evaluated for five samples of Al<sub>2</sub>O<sub>3</sub> and ZnO with EG/DW combinations of 60:40. The samples were examined for any aggregation of nanoparticles at the bottom of the glass test tubes. Visual inspection revealed sedimentation formation at the bottom of the glass tube for samples on the 25th and 30th days. The stability of colloidal dispersions in the fluid is indicated by the strength of repulsion between particles that have identical charges. The degree of repulsion increases and should result in good stability if the dispersant's zeta potential is high, at 40 to 60 mV as shown in fig.9-15.

### 2.2.6 Mathematical modeling

Below is the equation which demonstrates the relationship between the mass of the nanoparticles, the base fluid's volume, and the volume fraction.

$$\phi = \frac{\frac{m_{np}}{\rho_{np}}}{\frac{m_{np}}{\rho_{np}} + \frac{m_{bf}}{\rho_{bf}}} \quad (2)$$

The mass of the particles is represented by  $m_{np}$ , their density by  $\rho_{np}$ , their volume in carrier fluid by  $m_{bf}$ , and their volume concentration by  $\phi$ .

The conventional theory of a two-phase mix, which is provided by equation (3) can be estimated as [6], determines the nanofluid density.

$$\rho_{nf} = (1 - \phi)\rho_{bf} + \phi\rho_{np} \quad (3)$$

Where,  $\rho_{nf}$ : The nanofluid density,  $\rho_{bf}$ : The base fluid density,  $\phi$ : The nanoparticles volume fraction,  $\rho_{np}$ : The nanoparticles density

The heat transfer from hot side of radiator is represented by equation (3) can be estimated as [27]

$$Q_h = \dot{m}_h c_p (t_i - t_o) \quad (4)$$

Where,  $\dot{m}_h$ : mass transfer,  $c_p$ : specific heat,  $t_i$ : inlet temperature,  $t_o$ : outlet temperature

## 3. RESULTS AND DISCUSSION

In this study, the sedimentation of nanoparticles in nanofluids with varying concentrations of Al<sub>2</sub>O<sub>3</sub> and ZnO was observed over 0, 3, 6, 9, 12, and 15 days. Nanofluids with 0.01 to 0.025 % by volume concentration of nanoparticles were prepared to analyze the effects of concentration on stability. After preparation of nanofluids appeared uniformly dispersed. No visible sedimentation was observed in any sample, indicating that the initial mixing method was effective across all concentrations. Slight sedimentation began to appear, particularly in higher concentration samples (e.g., 0.02%). Lower concentration samples (e.g., 0.01%) still showed minimal sedimentation, indicating better stability at lower concentrations.

On Day 06, significant sedimentation was observed in higher concentration samples, while samples with lower nanoparticle concentrations continued to exhibit better dispersion. This trend suggests that lower nanoparticle concentrations may contribute to prolonged suspension stability due to reduced aggregation forces among particles. Concentration had more noticeable effects on sedimentation. Sedimentation created a thick layer at the bottom of high-concentration samples (0.025%), whereas medium-concentration samples

(0.015%) showed mild sedimentation. Even though there was now some noticeable sedimentation, the stability of the 0.025% sample was still improved. All samples exhibited discernible sedimentation by Day 15. The 0.05% nanofluid exhibited the least amount of sedimentation, but the high concentration (0.025%) samples had developed a thick sediment layer. However, over long periods of time, some degree of sedimentation was unavoidable, even in the low-concentration samples.

Table 2 Zeta Potential comparison for Al<sub>2</sub>O<sub>3</sub> and ZnO

Concentration	No of days	Zeta potential Al <sub>2</sub> O <sub>3</sub>	Zeta potential ZnO
0.01	0	56.939	38.500
	3	55.990	35.120
	6	54.537	31.090
	9	54.153	27.840
	12	53.204	25.480
	15	52.215	21.290
0.015	0	55.809	37.509
	3	54.900	33.400
	6	53.971	29.771
	9	53.184	25.684
	12	52.538	24.238
	15	51.243	17.843
0.02	0	55.284	33.984
	3	53.911	31.411
	6	52.768	28.568
	9	52.053	24.553
	12	51.508	23.208
	15	50.539	17.139
0.025	0	54.335	32.035
	3	52.720	30.220
	6	51.657	27.457
	9	51.367	23.867
	12	50.277	21.977
	15	49.126	15.726

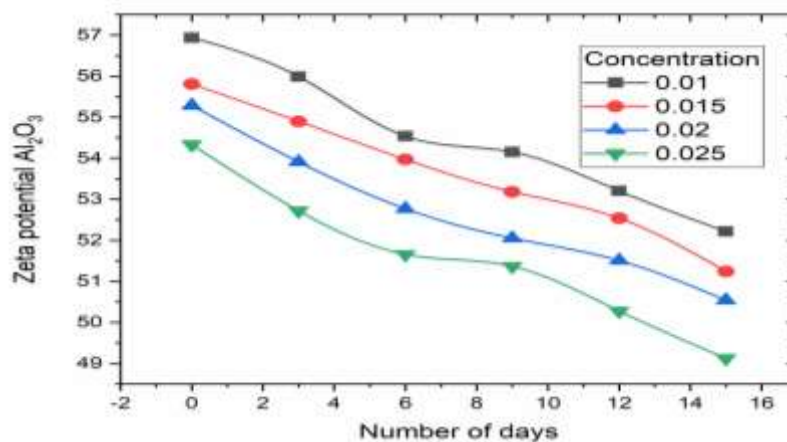


Fig. 16 Stability analysis of Al<sub>2</sub>O<sub>3</sub> nanoparticle

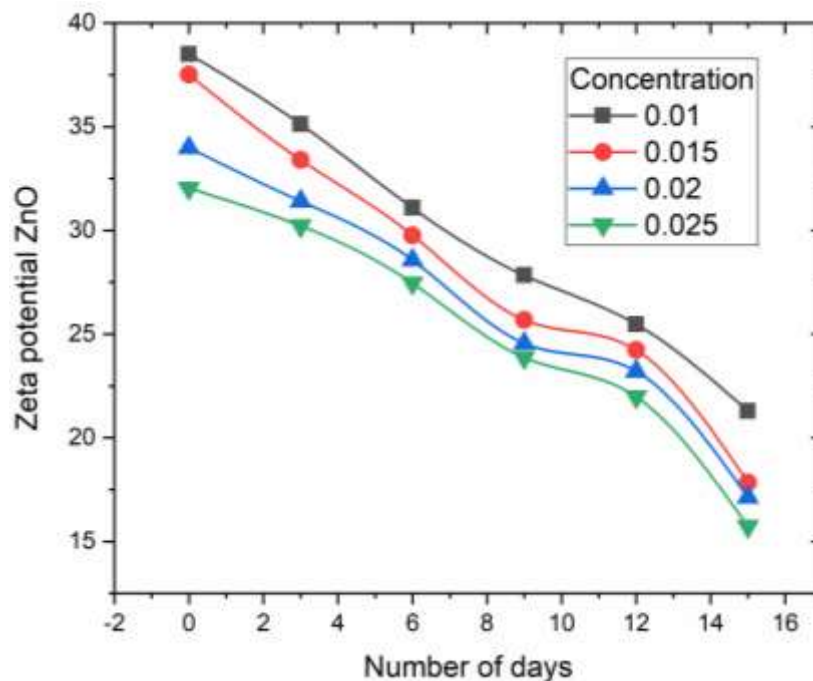


Fig. 17 Stability analysis of ZnO nanoparticle

From the above Fig. 16 & 17 it has been found that,

1. The aluminium oxide ( $\text{Al}_2\text{O}_3$ ) and Zinc oxide (ZnO) nanofluids are tested for different concentrations like 0.01,0.015,0.02,0.025.
2. The stability experimentation was carried out for 0 to 15 days' time span.

From the above graph following conclusions are made,

- The elevation of ZnO is more rigid than that of  $\text{Al}_2\text{O}_3$ , although the Zeta potential of both nanofluids tends to decrease with time.
- After 15 days almost the zeta potential to its lower limit because of sedimentation and coagulation of nanoparticles.

In general, Zinc oxide (ZnO) nanofluids typically have a lower zeta potential than aluminium oxide ( $\text{Al}_2\text{O}_3$ ) nanofluids. Because  $\text{Al}_2\text{O}_3$  nanoparticles have a larger zeta potential than ZnO, they are more electrostatically repelled, which helps keep them from aggregating and sedimentation. Better colloidal stability is indicated by a greater zeta potential (above  $\pm 30$  mV).

- **Intrinsic Surface Charge:** Since  $\text{Al}_2\text{O}_3$  nanoparticles have a larger surface charge by nature, they have a higher zeta potential in the majority of base fluids, including ethylene glycol and water. By strengthening the repulsive forces between particles, this increased zeta potential lowers the chance of agglomeration and improves stability.
- **pH Sensitivity and Stability Range:** Both ZnO and  $\text{Al}_2\text{O}_3$  nanoparticles have a pH-dependent zeta potential, whereas  $\text{Al}_2\text{O}_3$  tends to have a greater, more stable zeta potential throughout a wider pH range. However, at some pH values, ZnO exhibits a faster decline in zeta potential, which makes it more prone to agglomeration in a range of pH values.
- **Influence of Ionic Strength:** The zeta potential of ZnO nanoparticles drops more quickly than that of  $\text{Al}_2\text{O}_3$  when dissolved ions (high ionic strength) are present. This causes ZnO to silt more quickly and be less stable in situations with fluctuating ionic concentrations.
- **Slower Sedimentation Rate:** Compared to ZnO nanoparticles,  $\text{Al}_2\text{O}_3$  nanoparticles are typically smaller and less dense. Because ZnO nanoparticles are denser, they tend to settle in suspension more quickly, which causes sedimentation to occur more quickly and reduces stability over time.

### ● Zeta potential analysis

The electrical potential at a particle's sliding plane in a fluid is known as the zeta potential. It indicates the stability of the solution by showing how strongly particles repel or attract one another. The stability of the  $\text{Al}_2\text{O}_3$  and  $\text{ZnO}$  nanofluids based on ethylene glycol and water was examined using zeta potential experiments.[27] The aggregation of nanoparticles within the hybrid nanofluids was directly observed using zeta potential. For half month, the visual technique was used once 3 days. After half months, the visual approach revealed sedimentation of the hybrid nanofluids. The  $\text{Al}_2\text{O}_3$  and  $\text{ZnO}$  nanofluids are tested for their stability for different sonication time and using surfactant.

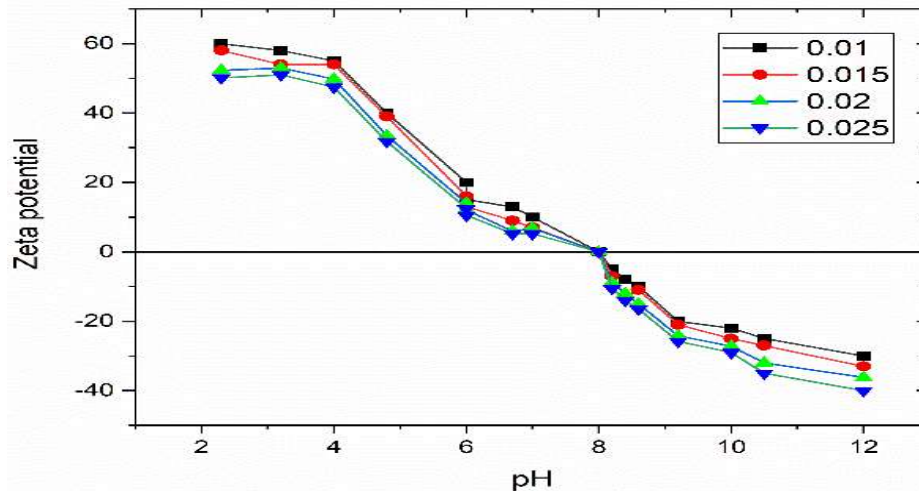


Fig. 18 Zeta potential Vs pH for  $\text{Al}_2\text{O}_3$

The Fig. 18 represents The Zeta potential Vs pH for  $\text{Al}_2\text{O}_3$  nanofluid for four different concentrations of nanofluid i.e. 0.01, 0.015, 0.02, 0.025. Because  $\text{Al}_2\text{O}_3$  is amphoteric, it can function as a basic or an acid. The maximum zeta potential is 60 at pH 2.3. From the graph it has been observed that at low point of pH below 4 i.e. acidic conditions the suspension is strongly positive and stable dispersion. On the other hand, the isoelectric point (IEP) has been observed at pH 8 where particles tend to agglomerate. At this point, the net surface charge is near close to zero, leading to instability and aggregation. Whereas after pH 9, the Zeta potential is strongly negative reaches up to -40 and the nanofluid suspension is strongly negative and stable again.

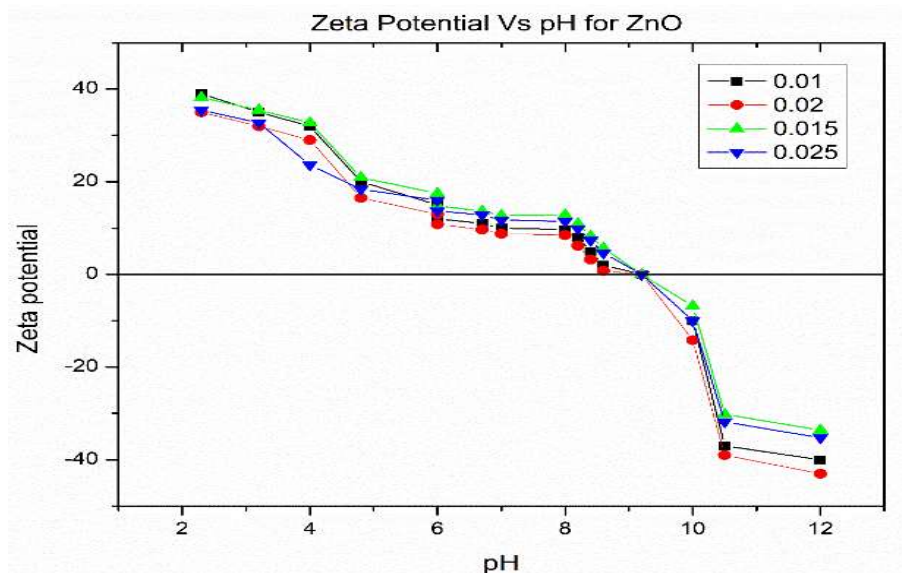


Fig. 19 Zeta potential Vs pH for  $\text{ZnO}$

The Fig. 19 represents The Zeta potential Vs pH for ZnO nanofluid for four different concentrations of nanofluid i.e. 0.01, 0.015, 0.02, 0.025. ZnO exhibits pH-dependent surface charge and behaves similarly to other metal oxides. From the graph it has been observed that at low pH value below 4 the Zeta potential is maximum i.e. about 40. At these regions the solution is highly stable and Zeta potential is at positive higher side (acidic in nature). Whereas the isoelectric point (IEP) has been observed at pH 9.2 at which the nanofluid is become more unstable. Surface charge is neutral, resulting in maximal instability and probably aggregation. After pH value more than 10 it has been observed that the Zeta potential is increases in negativity as the pH rises. At this region the nanofluid is Strongly negative but stable again.

#### 4. CONCLUSIONS

The experimentation is done for the stability analysis of  $\text{Al}_2\text{O}_3$  and ZnO nanofluid. For  $\text{Al}_2\text{O}_3$  and ZnO nanoparticles, the nanofluids are produced at volume concentrations of 0.01, 0.015, 0.02, and 0.025. Zeta potential is measured for these nanofluids over a period of 0–15 days, so the study is focused on the zeta potential of nanofluid after preparation of nanofluid. Also, it is clear that as nanofluid concentration changes there is significant change in zeta potential. Because of improved particle-particle interactions in samples with increasing concentrations, which promoted agglomeration, the sedimentation rate rose as the concentration of nanoparticles increased. Since sedimentation can lower thermal efficiency, nanofluid stability is essential for real-world applications in heat transfer systems like radiators. Stability and efficient heat transfer performance may therefore be balanced at lower concentrations, albeit occasional re-dispersion may be required to preserve ideal circumstances.

From the above experimental work following conclusions are made,

- Among  $\text{Al}_2\text{O}_3$  and ZnO nanofluids,  $\text{Al}_2\text{O}_3$  (aluminum oxide) nanofluids generally exhibit greater stability compared to ZnO (zinc oxide) nanofluids.
- $\text{Al}_2\text{O}_3$  nanoparticles react favourably to surfactants and stabilising chemicals, which are frequently added to increase stability by further preventing agglomeration.
- Since  $\text{Al}_2\text{O}_3$  nanoparticles have a larger surface charge by nature, they have a higher zeta potential in the majority of base fluids, including ethylene glycol and water.
- The zeta potential of ZnO nanoparticles drops more quickly than that of  $\text{Al}_2\text{O}_3$  when dissolved ions (high ionic strength) are present. This causes ZnO to silt more quickly and be less stable in situations with fluctuating ionic concentrations.
- The zeta potential of  $\text{Al}_2\text{O}_3$  nanofluids for 0.01 % of VC of nanofluid is 56.939 whereas, for 0.025 % of VC its 54.335 after preparation of nanofluid.
- The zeta potential of ZnO nanofluids for 0.01 % of VC of nanofluid is 38.500 whereas, for 0.025 % of VC its 32.035 after preparation of nanofluid.

#### REFERENCES

- [1] I. U. Ibrahim, M. Sharifpur, J. P. Meyer, and S. M. S. Murshed, "Experimental investigations of effects of nanoparticle size on force convective heat transfer characteristics of  $\text{Al}_2\text{O}_3$  - MWCNT hybrid nanofluids in transitional flow regime," *Int. J. Heat Mass Transf.*, vol. 228, p. 125597, Aug. 2024, doi: 10.1016/j.ijheatmasstransfer.2024.125597.
- [2] J. Hou et al., "Microfluidic flow synthesis of  $\text{Al}_2\text{O}_3$  nanofluids for efficient phase-change boiling heat transfer enhancement of electronic devices," *Case Stud. Therm. Eng.*, vol. 58, p. 104458, Jun. 2024, doi: 10.1016/j.csite.2024.104458.
- [3] A. Alhamayani, "Performance analysis and machine learning algorithms of parabolic trough solar collectors using  $\text{Al}_2\text{O}_3$ -MWCNT as a hybrid nanofluid," *Case Stud. Therm. Eng.*, vol. 57, p. 104321, May 2024, doi: 10.1016/j.csite.2024.104321.
- [4] L. Li, Z. Xiao, S. Liu, and C. Xu, "Synthesis and characterization of  $\text{Al}_2\text{O}_3$ -methanol nanofluid and its usage in bubble column for an improved mass transfer rate," *Case Stud. Therm. Eng.*, vol. 56, p. 104299, Apr. 2024, doi: 10.1016/j.csite.2024.104299.
- [5] A. Khelifa, A. E. Kabeel, M. E. H. Attia, M. Abdelgaied, M. Arıcı, and M. M. Abdel-Aziz, "3D numerical analysis of a photovoltaic thermal using bi-fluid:  $\text{Al}_2\text{O}_3$ -water nanofluid at various concentrations," *Int. J. Thermofluids*, vol. 20, p. 100523, Nov. 2023, doi: 10.1016/j.ijft.2023.100523.
- [6] M. G. Habbeb, A. H. Yaseen, and A. M. Hussien, "Impact of surfactant on  $\text{Al}_2\text{O}_3$ /water nanofluids stability for cooling the central processing unit of computer," *Case Stud. Therm. Eng.*, vol. 54, p. 104094, Feb. 2024, doi: 10.1016/j.csite.2024.104094.

- [7] F. R. Siddiqui, C. Y. Tso, K. C. Chan, S. C. Fu, and C. Y. H. Chao, "Dataset on critical parameters of dispersion stability of Cu/Al<sub>2</sub>O<sub>3</sub> nanofluid and hybrid nanofluid for various ultra-sonication times," *Data Brief*, vol. 22, pp. 863–865, Feb. 2019, doi: 10.1016/j.dib.2019.01.007.
- [8] M. A. Alharthi, B. A. Almohammadi, M. A. Sharafeldin, M. T. Abdelghany, S. Bendoukha, and H. A. Refaey, "Heat transfer and pressure drop of Al<sub>2</sub>O<sub>3</sub>/water nanofluid in conically coiled tubes: Experimental and artificial neural network prediction," *Case Stud. Therm. Eng.*, vol. 54, p. 104043, Feb. 2024, doi: 10.1016/j.csite.2024.104043.
- [9] S. Baek *et al.*, "Influence of amphoteric and anionic surfactants on stability, surface tension, and thermal conductivity of Al<sub>2</sub>O<sub>3</sub>/water nanofluids," *Case Stud. Therm. Eng.*, vol. 25, p. 100995, Jun. 2021, doi: 10.1016/j.csite.2021.100995.
- [10] P. Tiam Kapen, C. Gervais Njingang Ketchate, D. Fokwa, and G. Tchuen, "Linear stability analysis of (Cu-Al<sub>2</sub>O<sub>3</sub>)/water hybrid nanofluid flow in porous media in presence of hydromagnetic, small suction and injection effects," *Alex. Eng. J.*, vol. 60, no. 1, pp. 1525–1536, Feb. 2021, doi: 10.1016/j.aej.2020.11.007.
- [11] M. K. Bahadori, R. Golhosseini, M. Shokouhi, and A. T. Zoghi, "Mixing  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>, silica-ZIF-8 and activated carbon nanoparticles in aqueous N-methyldiethanolamine+sulfolane as a nanofluid for application on CO<sub>2</sub> absorption," *J. CO<sub>2</sub> Util.*, vol. 79, p. 102650, Jan. 2024, doi: 10.1016/j.jcou.2023.102650.
- [12] T. K. Murtadha, "Effect of using Al<sub>2</sub>O<sub>3</sub> / TiO<sub>2</sub> hybrid nanofluids on improving the photovoltaic performance," *Case Stud. Therm. Eng.*, vol. 47, p. 103112, Jul. 2023, doi: 10.1016/j.csite.2023.103112.
- [13] G. Kim *et al.*, "Stability, surface tension, and thermal conductivity of Al<sub>2</sub>O<sub>3</sub>/water nanofluids according to different types of alcohol and their proportion," *Case Stud. Therm. Eng.*, vol. 28, p. 101385, Dec. 2021, doi: 10.1016/j.csite.2021.101385.
- [14] T. H. Ruvo, Md. S. Shuvo, and S. Saha, "Revisiting thermo-physical property models of Al<sub>2</sub>O<sub>3</sub>-Water nanofluid for natural convective flow," *Heliyon*, vol. 10, no. 5, p. e26964, Mar. 2024, doi: 10.1016/j.heliyon.2024.e26964.
- [15] S. S. Khaleduzzaman, M. R. Sohel, R. Saidur, and J. Selvaraj, "Stability of Al<sub>2</sub>O<sub>3</sub>-water Nanofluid for Electronics Cooling System," *Procedia Eng.*, vol. 105, pp. 406–411, 2015, doi: 10.1016/j.proeng.2015.05.026.
- [16] D. Bhavani J *et al.*, "Ultrasonic Interferometry and Physiothermal properties of Al<sub>2</sub>O<sub>3</sub>/CuO nanofluids," *Case Stud. Therm. Eng.*, vol. 55, p. 104120, Mar. 2024, doi: 10.1016/j.csite.2024.104120.
- [17] R. Tahmasebi-Boldaji, S. Ghazanfari, H. Rajabi Kuyakhi, N. Tahmasebi Boldaji, and M. Toriki, "Experimental investigation of ultrasonic cycle/magnetic stirrer (UC/MS) effect on water/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub> nanofluid stability and thermal conductivity and its ANFIS/PSO modeling," *Results Eng.*, vol. 19, p. 101284, Sep. 2023, doi: 10.1016/j.rineng.2023.101284.
- [18] A. A. Memon, Usman, W. A. Khan, and T. Muhammad, "Numerical investigation of photovoltaic thermal energy efficiency improvement using the backward step containing Cu-Al<sub>2</sub>O<sub>3</sub> hybrid nanofluid," *Alex. Eng. J.*, vol. 75, pp. 391–406, Jul. 2023, doi: 10.1016/j.aej.2023.06.003.
- [19] B. Mehta, D. Subhedar, H. Panchal, and K. K. Sadasivuni, "Stability and thermophysical properties enhancement of Al<sub>2</sub>O<sub>3</sub>-water nanofluid using cationic CTAB surfactant," *Int. J. Thermofluids*, vol. 20, p. 100410, Nov. 2023, doi: 10.1016/j.ijft.2023.100410.
- [20] L. Das, N. Aslfattahi, K. Habib, R. Saidur, A. Das, and K. Kadrigama, "Thermohydraulic performance investigation of a heat exchanger with combined effect of ribbed insert and Therminol55/MXene+ Al<sub>2</sub>O<sub>3</sub> nanofluid: A numerical two-phase approach," *Heliyon*, vol. 9, no. 3, p. e14283, Mar. 2023, doi: 10.1016/j.heliyon.2023.e14283.
- [21] A. Azman, A. Mukhtar, M. Z. Yusoff, P. Gunnasegaran, N. Khai Ching, and A. S. H. Md Yasir, "Numerical investigation of flow characteristics and heat transfer efficiency in sawtooth corrugated pipes with Al<sub>2</sub>O<sub>3</sub>-CuO/Water hybrid nanofluid," *Results Phys.*, vol. 53, p. 106974, Oct. 2023, doi: 10.1016/j.rinp.2023.106974.
- [22] L. A. Lund, Z. Omar, I. Khan, A. H. Seikh, E.-S. M. Sherif, and K. S. Nisar, "Stability analysis and multiple solution of Cu-Al<sub>2</sub>O<sub>3</sub>/H<sub>2</sub>O nanofluid contains hybrid nanomaterials over a shrinking surface in the presence of viscous dissipation," *J. Mater. Res. Technol.*, vol. 9, no. 1, pp. 421–432, Jan. 2020, doi: 10.1016/j.jmrt.2019.10.071.
- [23] M. F. Zawrah, R. M. Khattab, L. G. Girgis, H. El Daidamony, and R. E. Abdel Aziz, "Stability and electrical conductivity of water-base Al<sub>2</sub>O<sub>3</sub> nanofluids for different applications," *HBRC J.*, vol. 12, no. 3, pp. 227–234, Dec. 2016, doi: 10.1016/j.hbrj.2014.12.001.
- [24] R. Prasanna Shankara *et al.*, "An insight into the performance of radiator system using ethylene glycol-water based graphene oxide nanofluids," *Alex. Eng. J.*, vol. 61, no. 7, pp. 5155–5167, Jul. 2022, doi: 10.1016/j.aej.2021.10.037.
- [25] T. O. Scott, D. R. E. Ewim, and A. C. Eloka-Eboka, "Experimental study on the influence of volume concentration on natural convection heat transfer with Al<sub>2</sub>O<sub>3</sub>-MWCNT/water hybrid nanofluids," *Mater. Today Proc.*, p. S2214785323041603, Aug. 2023, doi: 10.1016/j.matpr.2023.07.290.
- [26] Ding, Y., *et al.*, Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids). *International Journal of Heat and Mass Transfer*, 2006. 49(1-2): p. 240-250.
- [27] M.S.Y. Ebaid, A.M. Ghrair, M. Al-Busoul, Experimental investigation of cooling photovoltaic (PV) panels using (TiO<sub>2</sub>) nanofluid in water-polyethylene glycol mixture and (Al<sub>2</sub>O<sub>3</sub>) nanofluid in water-cetyltrimethylammonium bromide mixture, *Energy Convers. Manag.* 155 (2018) 324–343.