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Production of Al_2O_3 Nanofluids by two-step method

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Abstract:

Nanofluids are a novel category of heat transfer fluids, whereby nanoparticles are dispersed throughout a base fluid to form a composite medium. Aluminium oxide (Al_2O_3) nanofluids have emerged as a very promising category of nanofluids, primarily attributed to their exceptional thermal conductivity and commendable stability. The current work provides an experimental examination of the thermophysical parameters, heat transport characteristics, and friction factor of Al_2O_3 nanofluids. The nanofluids were synthesised via a two-step methodology, and their thermophysical characteristics were evaluated by a range of experimental approaches. The heat transfer and friction factor of the nanofluids were quantified by experimentation conducted in a forced convection loop. The findings indicated a positive correlation between the concentration of nanoparticles and the thermal conductivity of the nanofluids. The observed trend indicates that there is a positive correlation between the concentration of nanoparticles in the nanofluids and the heat transfer coefficient. Nevertheless, it was observed that the friction factor of the nanofluids exhibited an upward trend as the concentration of nanoparticles rose. The findings of this investigation indicate that Al_2O_3 nanofluids have promising characteristics for utilisation as heat transfer fluids with superior performance. Nevertheless, it is crucial to take into account the balance between heat transfer improvement and pressure drop during the design of heat transfer systems that use Al_2O_3 nanofluids.

Keywords:

Al_2O_3 Nanofluids Preparation, Thermophysical Properties, Heat Transfer, Friction Factor, Two Step Method, EDAX, TEM.

1. Introduction:

Heat transfer technology is of utmost importance in enhancing the rate of heat transmission and optimising the efficiency of various heat sources. To facilitate heat transmission, various fluids such as water and vegetable oil may be used. These fluids are known to cause corrosion, clogs, and other flow passage issues. The use of nanofluids may mitigate the drawbacks associated with conventional fluids, as they exhibit superior heat transfer capabilities and can effectively minimise difficulties such as corrosion, blockages, and other related concerns. Consequently, nanofluids are increasingly favoured in many industrial applications.

Nanofluids refer to the colloidal suspension of nano-sized particles, typically measuring in the range of nanometres ($\times 10^{-9}$), inside a particular fluid medium. There are two distinct categories of nanofluids: metallic nanofluids and non-metallic nanofluids. Metallic nanofluids, such as copper, aluminium, nickel, and other similar metals, are created by the dispersion of metal nanoparticles. Non-metallic nanofluids, such as metal oxides and different allotropes of carbon, are produced by the dispersion of non-metal nanoparticles. Numerous studies have been conducted pertaining to nanofluids.

Typically, the preparation of nanofluids is accomplished by two distinct approaches. There are two methods to consider: the one-step technique and the two-step way. The one-step approach is synthesised using a chemical process in base fluids. The use of this single-step technique effectively mitigates the phenomenon of agglomeration, as well as facilitates the dispersion of nanofluids in a simultaneous manner. The present approach involves the direct synthesis of nanofluids using a base fluid, resulting in decreased agglomeration and enhanced stability of the nanofluids. This technique eliminates the need for separate processes such as storage, shipping, pouring, mixing, and drying of nanoparticles. This study proposes an alternative and efficient approach for the preparation of nanofluids, using a vacuum submerged arc nanoparticle synthesis system. One of the primary drawbacks of the one-step process is the significant financial investment required for large-scale implementation. Additionally, this technology is unable to effectively synthesise nanofluids. However, the one-step technique offers many benefits in the development of nanofluid production. This method allows for quick synthesis of nanofluids by a single chemical process, which has the potential to be cost-effective in the future. The silver nanofluids were created using a one-step technique, with mineral oil serving as the basis fluid.

The two-step approach is often used in the synthesis of nanofluids, nanotubes, and several other types of nanomaterials. The nanoparticles are first synthesised in a dry powdered form by a combination of physical and chemical processes. Subsequently, these nanoparticles are distributed inside base fluids utilising magnetic stirring and ultrasonication techniques. The physical techniques of magnetic stirring and ultrasonication are used to enhance the compatibility of fluids, with the stirring duration, ultrasonic vibration, and temperature being influential factors. During this particular procedure, a multitude of bubbles manifested at the interface of the suspension nanoparticles subsequent to the agitation operation. It has the ability to stick the bubbles to the wall of a beaker. The stirring process facilitates the dissolution of air in fluids and promotes the formation of bubbles due to its high surface activity. In this particular case, the decrease in the stirring velocity from 1200 revolutions per minute (r/min) to 800 r/min, as well as the mitigation of bubble formation, were successfully achieved. The use of nanofluids in the form of dilute suspensions offers greater advantages compared to colloidal solutions. The dilute suspension nanofluids exhibit a notable enhancement in surface heat transfer efficiency between the fluid and the particles. Due to the aforementioned factors, nanofluids have found increased use in enhancing heat transfer, facilitating transportation, and cooling industrial equipment. The purposes of the technology include magnetic sealing, nuclear cooling, and medicinal applications, among others.

2. Literature Review:

An extensive review of the existing literature has been conducted on nanofluids based on Aluminium oxide.

Mukherjee et al. (1) conducted a study in which they compared the thermal conductivity data of DI water acquired in their experiment with the data provided by the National Institute of Standards and Technology (NIST) 16. The comparison was carried out throughout a temperature range of 25-65°C, with intervals of 10°C, and the results are displayed in Table-1. According to the data shown in Table-1, the observed discrepancy between the experimental results and the standard data falls within an acceptable range of 1.10%. Therefore, it demonstrated the precision of the measurements.

Purna Chandra Mishra and colleagues (2) The thermal conductivity of Al_2O_3 nanofibers was determined by calculating the sonic velocities, and the resulting data is shown in Table 1. The data presented in Table 1 demonstrates a positive correlation between sound velocity and both temperature and concentration. As previously stated, the device measures hydro-acoustic vibrations, which are enhanced by an increase in temperature resulting from heat input. Furthermore, the introduction of additional particles resulted in an increase in the frequency of nanoparticle collisions. This, in turn, led to a further enhancement in Phonon vibration in the particles present in the supernatant. Consequently, the velocity of sound saw a rise.

Table. 1: Sound velocity in Al_2O_3–water NFs at studied weight fraction and temperatures.

Sound velocity (m/s)					
Temperature (^{O}C)	1 %	0.50%	0.10%	0.05%	0.01%
25	1535	1530	1525	1520	1515
35	1584	1579	1574	1569	1564
45	1631	1624	1619	1614	1609
55	1675	1670	1665	1660	1655
65	1714	1709	1705	1701	1697

The study conducted by Paritosh Chaudhuri and colleagues (3) the thermal conductivity experimental results were compared to the projected data using Maxwell's model23 and the Hamilton-Crosser model (H-C model) 24 at a temperature of 25°C. As seen in Fig. 1. The contrast illustrates that the classical models lack the ability to accurately anticipate the present experimental observations. The prevalence of such an augmentation in the data may be attributed to the fact that standard models fail to include the micro-scale mechanisms that contribute to the enhancement of thermal conductivity in NF25.

The study conducted by Chakrabarty et al. (4) The coefficient of excess thermal conductivity in order to further explore the presence of TCE in NF, Keblinski et al., introduced the concept of the excess TCE coefficient (κ), which is defined as $K = \frac{Kr-1}{KrHC-1}$.

According to the provided definition, K represents the ratio between the experimental measurement of TCE and the TCE measured by the H-C model. In the case when K=1, the measurement aligns with traditional macroscopic theories. Conversely, if K>1, the thermal conductivity enhancement (TCE) is consistent with micro- or nanoscale theories, such as Brownian movement, micro-convection, thermophoresis, and so forth. The values of K, as determined by experimental data and the H-C model, are shown in Fig. 1. The K values in this study exhibit values greater than 1, suggesting that the observed increase in heat conductivity may be attributed to nano- or microscale theories.

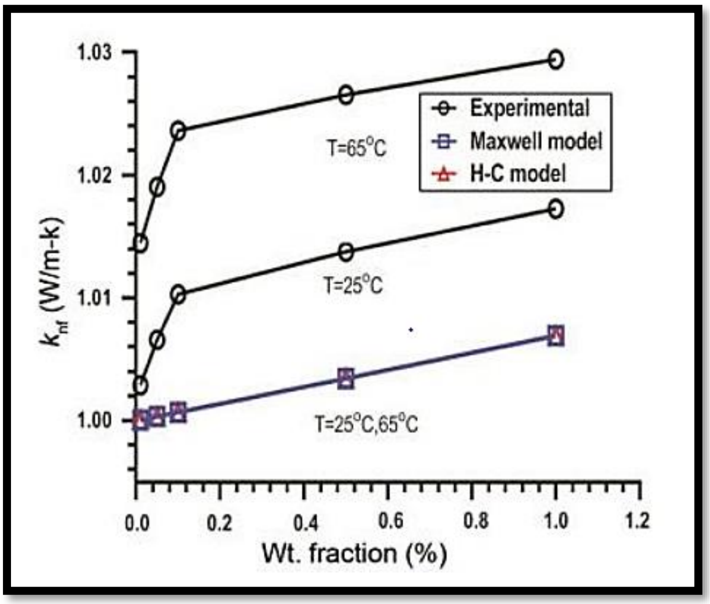

Figure. 1: Comparison of experimental thermal conductivity data with theoretical predictions.

Hence, it is once again shown that conventional theories are inadequate in their ability to describe the phenomenon of TCE in non-fungible assets. Furthermore, as seen in Fig. 2, it is evident that the value of K drops as the concentration rises, but it increases with an elevation in temperature. Hence, it may be inferred that the impact of temperature outweighs the influence of particle inclusion in nanofluids. This discovery is intriguing as it suggests that the value is anticipated to rise with both concentration and temperature elevation. One plausible hypothesis for these phenomena is that the presence of particles leads to enhanced sedimentation in nanofluids (NFs), leading to a reduction in the concentration of trichloroethylene (TCE).

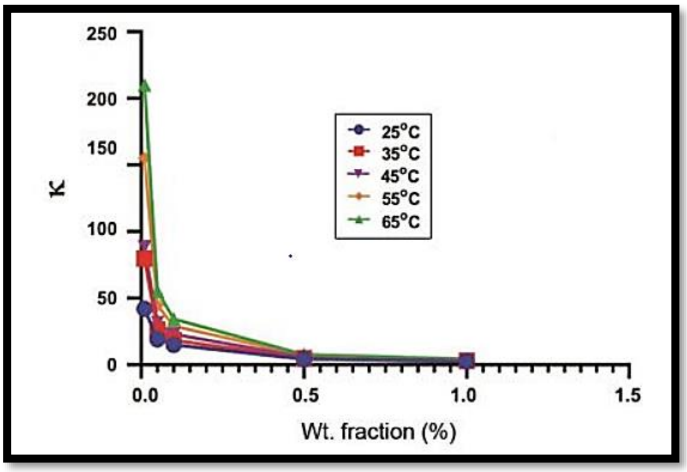

Figure. 2: Excess thermal conductivity coefficient (κ) values at different concentrations and temperatures

3. Summary of Literature Survey:

Based on the comprehensive literature review conducted,

- A two-step procedure was used in order to develop the Al_2O_3-water nanofiltration formulation. The images obtained from sedimentation examination using both NF (Nano-Fluid) and (Dynamic Light Scattering) DLS techniques demonstrate favourable dispersion characteristics and satisfactory stability of the nanofluids.
- The thermal conductivity of nanofluids (NF) is significantly influenced by variations in weight fraction and temperature. The thermal conductivity of NF exhibits a linear relationship between concentration and temperature, resulting in an increase in thermal conductivity.
- Conversely, the augmentation in thermal conductivity of NF, relative to its base fluid (K_r), shows a non-linear trend with increasing concentration and temperature. This alludes to the nano- or microscale mechanisms that contribute to the enhancement of thermal conductivity in these fluids.
- The experimental findings on thermal conductivity do not align with recognised classical theories.
- The user's text does not contain any information to rewrite. The observed inconsistencies between actual thermal conductivity measurements and theoretical models may be attributed to the presence of an excess thermal conductivity coefficient. The regulation of TCE in NF is influenced by micro-nanoscale events that cannot be well explained by conventional micro-scale theories.

4. Methodology:

4.1. Preparation of nano fluids:

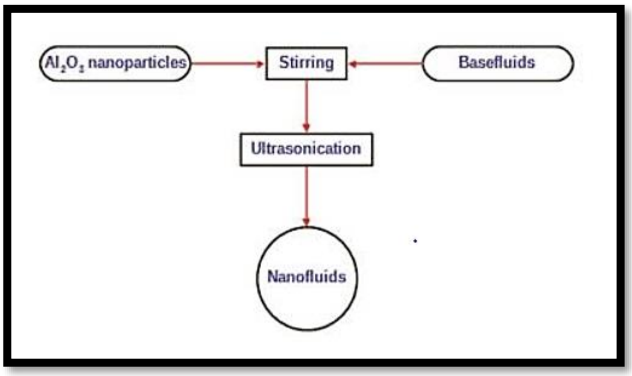

Figure. 3: Schema diagram of two-step preparation process of nanofluids.

The importance of adequate preparation cannot be overstated when it comes to the implementation of nanofluids (NFs) for enhancing heat transmission. Typically, the production of nanofluids involves the implementation of either a single-step or two-step method. The two-step procedure has been identified as the most effective and cost-efficient approach for the preparation of nanofluids (NFs) that include oxide nanoparticles. Therefore, in this experimental study, aluminium oxide nanofluids (Al_2O_3 NFs) were synthesised using a two-step approach. The method of formulation is shown in Fig. 3.

4.2. Experimental Setup:

The two-step method: The two-step approach is often used in the synthesis of nanofluids, nanotubes, and several other nanomaterials. The procedure is straightforward and has a cheaper cost compared to the one-step method. The approach involves first producing nanoparticles in a dry powdered form by a combination of physical and chemical processes. Subsequently, these nanoparticles are disseminated in base fluids using magnetic stirring and ultrasonication techniques. A beaker containing 250 ml of distilled water is used for the experiment. An accurate amount of 0.2 gm of Al_2O_3 nanoparticles, which corresponds to a concentration of 0.8 gm per litre of distilled water, is added to the beaker. Once the beaker has been positioned on a magnetic stirrer, the stirring speed is adjusted within the range of 1200 rpm to 800 rpm for a duration of 40 minutes. During this particular operation, a significant number of bubbles manifested at the surface of the suspension nanoparticles subsequent to the stirring procedure. It has the ability to stick the bubbles to the inside wall of the beaker. The stirring process facilitates the dissolution of air in fluids and promotes the formation of bubbles due to its high surface activity. In this particular scenario, the stirring speed is decreased from 1200 rpm to 800 rpm, and the duration of stirring is prolonged to 40 minutes. Through the use of this technique, the occurrence of bubbles was significantly reduced, resulting in an enhanced quality of the nanofluids created. Following the stirring operation, the beaker is subjected to an ultrasonication procedure. During this experimental procedure, the temperature of sonication is varied between 40°C and 60°C for samples with the same concentration. Please provide an example of temperature measurements that are widely recognised and accepted. The duration of sonication is set at 45 minutes, resulting in enhanced efficiency and reduced settling of nanoparticles inside Al_2O_3 – distilled water nanofluids. The achievement of stability in Al_2O_3-distilled water nanofluids is effectively accomplished by the manipulation of magnetic stirring time, ultra sonication time, and temperature.

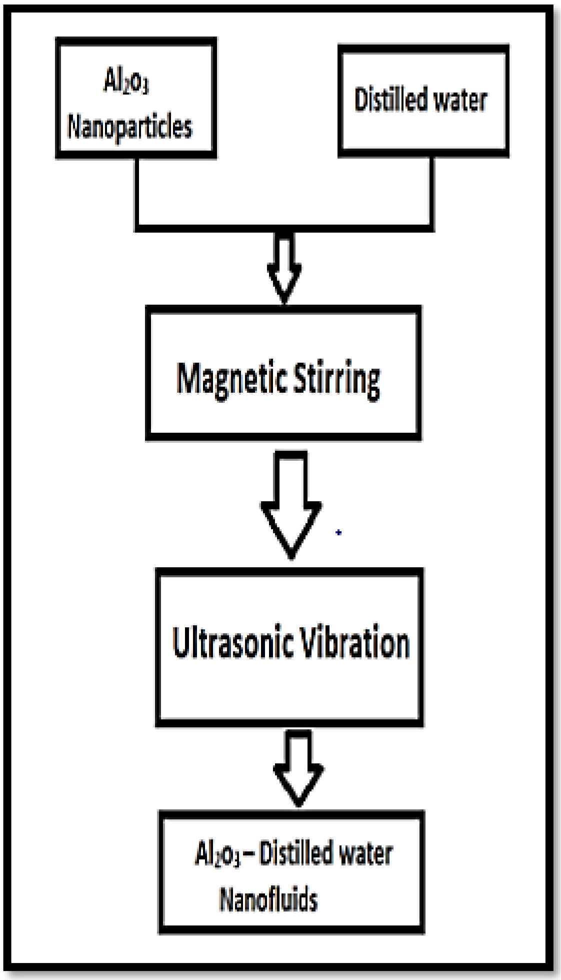

Figure. 4: Procedure to prepare Al_2O_3 – distilled water nanofluid using two step method.

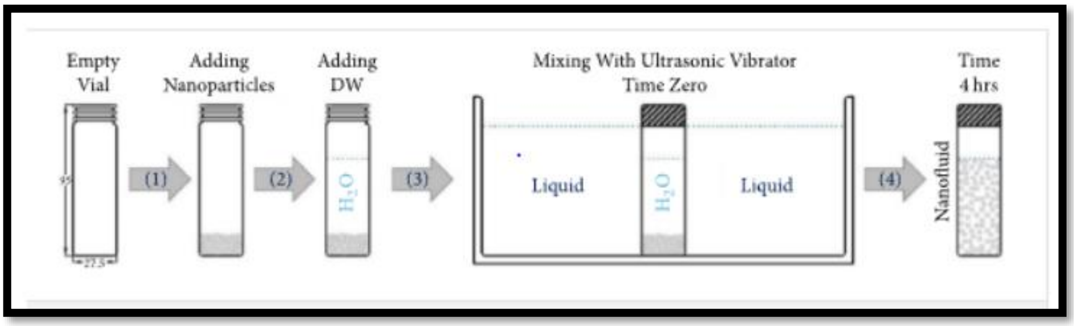

Figure. 5: Schematic procedure of the two-step nanofluids preparation.

4.3. Experimental Phenomena:

The nanofluids consisting of Al_2O_3 nanoparticles and distilled water were generated at different temperatures ranging from 40^{O}C to 60^{O}C. The concentration of Al_2O_3 nanoparticles used in the nanofluids was 0.8 grammes per litre of distilled water. We obtained samples of Al_2O_3 – distilled water nanofluids at temperatures of 50^{O}C, 55^{O}C, and 60^{O}C. Fig. 6 depicts the newly manufactured nanofluids consisting of Al_2O_3 and distilled water. The distilled water has a milky white appearance of uniform colour, indicating the presence of well-dispersed Al_2O_3

nanoparticles. The Al_2O_3 – distilled water nanofluid samples were subjected to gravitational forces in a controlled environment to assess their suspension stability. The provided illustration displays images of recently created nanofluids consisting of Al_2O_3 particles dispersed in distilled water.

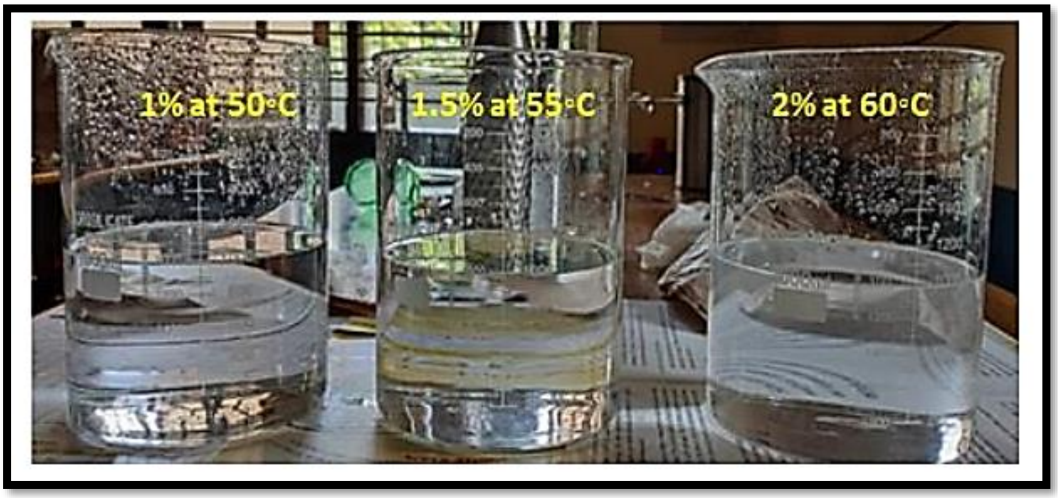

Figure. 6: Freshly prepared Al_2O_3 – DI water nanofluids.

5. Result and Discussion:

The laboratory conducted an investigation on test materials in the form of fluid utilising a two-step approach. The analysis included the identification of nano phases via the use of Transmission Electron Microscopy (TEM), as well as the examination of chemical composition data through the use of Energy Dispersive X-ray Spectroscopy (EDAX) linked to TEM.

5.1. Transmission Electron Microscopy (TEM):

Transmission electron microscopes (TEM) are scientific instruments that use a focused beam of electrons to observe and visualise objects, so producing a picture with a significantly enhanced level of magnification. Transmission electron microscopes (TEMs) have the capability to achieve magnification levels of up to 2 million times for objects. To have a more comprehensive understanding of the magnitude of its size, one may consider the minuteness of a cell. The increasing value of TEMs in the biological and medicinal domains is not surprising.

Transmission electron microscopes (TEMs) use a high voltage electron beam for the purpose of generating a picture. The electron cannon located in the upper portion of a transmission electron microscope (TEM) releases electrons which subsequently traverse the vacuum tube of the microscope. In contrast to the use of a glass lens for light microscopes, the transmission electron microscope (TEM) utilises an electromagnetic lens to concentrate the electrons into a highly refined beam. The electron beam thereafter traverses the specimen, characterised by its minimal thickness, whereby the electrons undergo either scattering or impact against a fluorescent screen situated at the lowermost region of the microscope. The screen displays a picture of the specimen, with its various components shown in varying hues to represent their respective densities. The picture may thereafter be examined directly using a transmission electron microscope (TEM) or captured via photography.

The transmission electron microscopy (TEM) images of the samples Al 1%, Al 1.5%, and Al 2% are shown in Figs. 7-12.

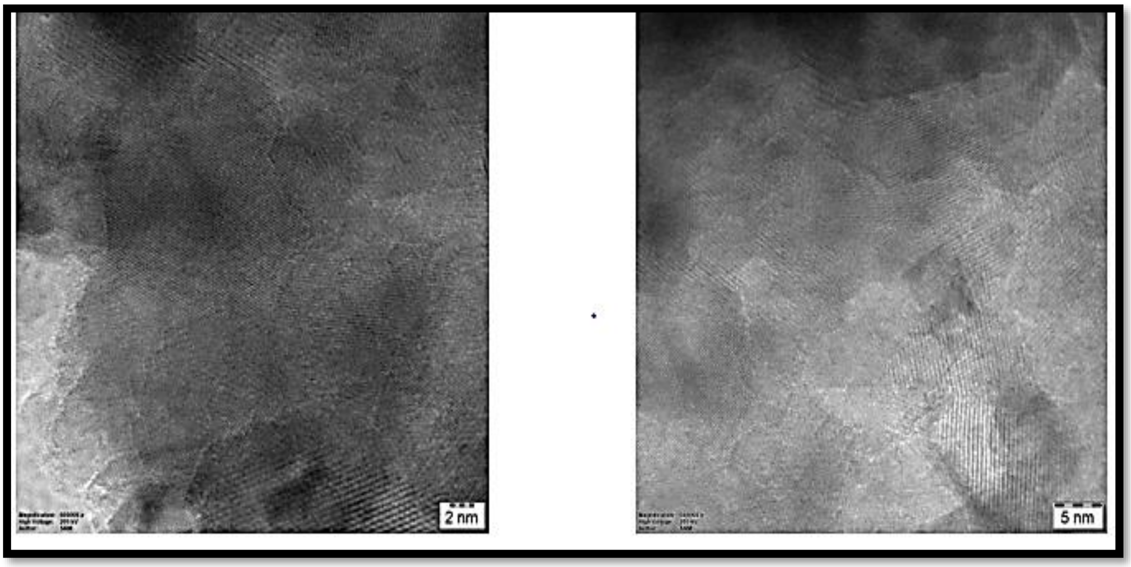

Figure. 7: TEM photographs of the samples Al 1%

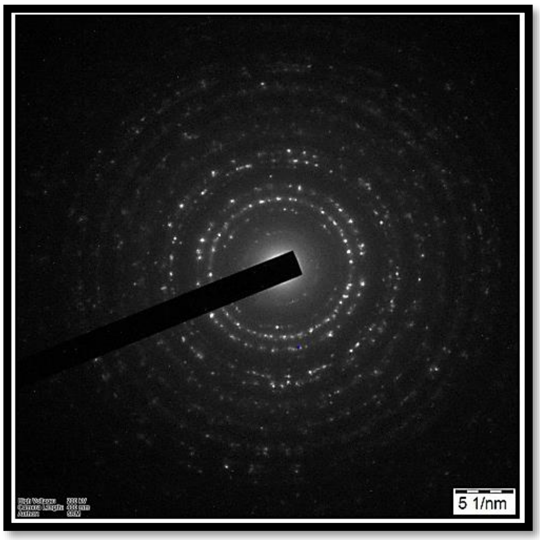

Figure. 8: Spectra image of Al 1%

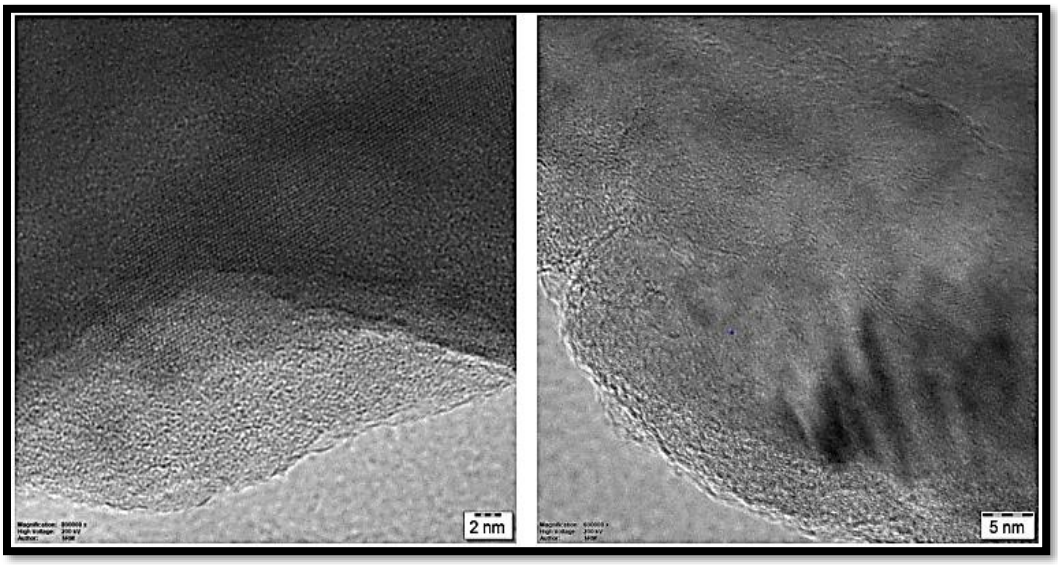

Figure. 9: TEM photographs of the samples Al 1.5%

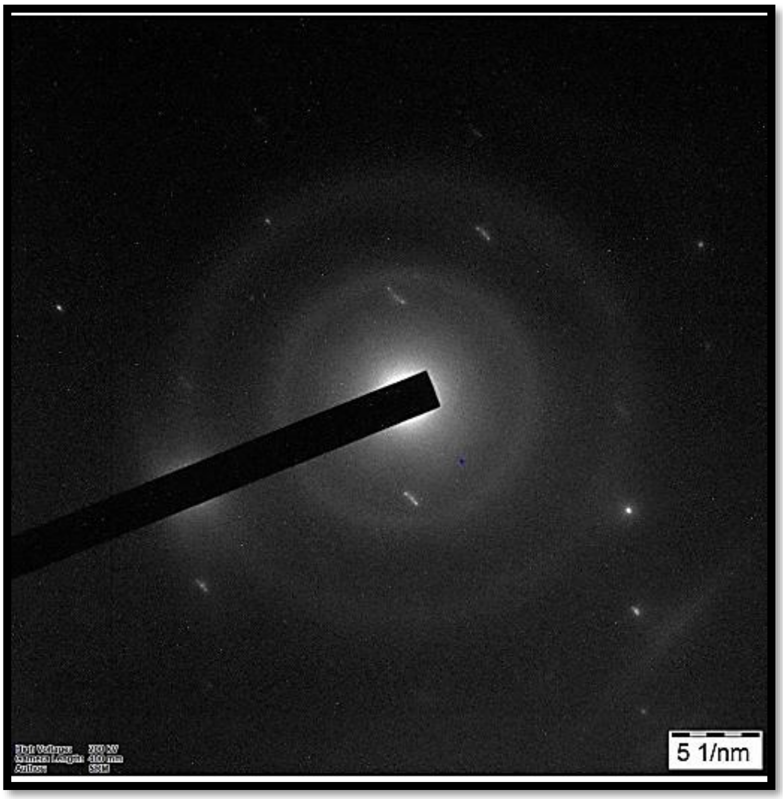

Figure. 10: Spectra image of Al 1.5%

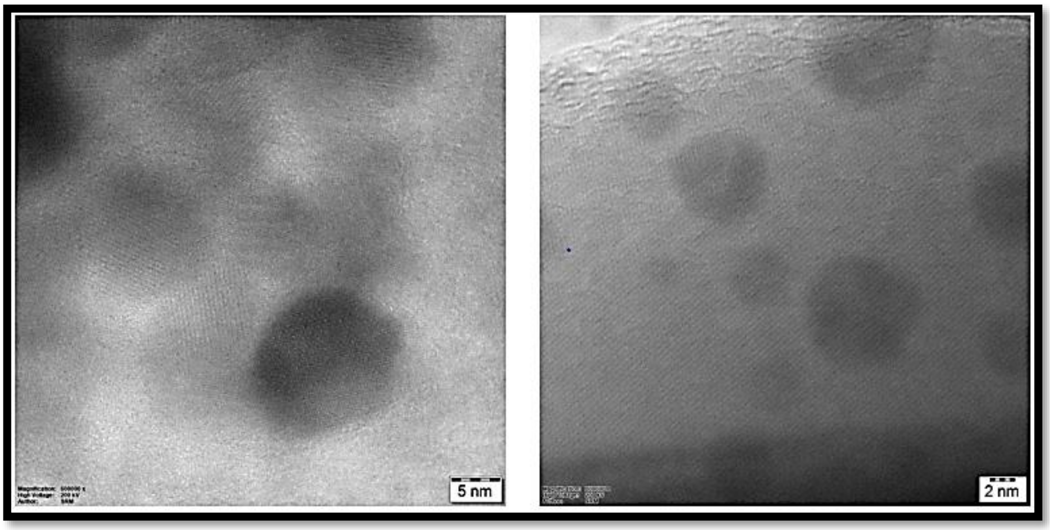

Figure. 11: TEM photographs of the samples Al 2%

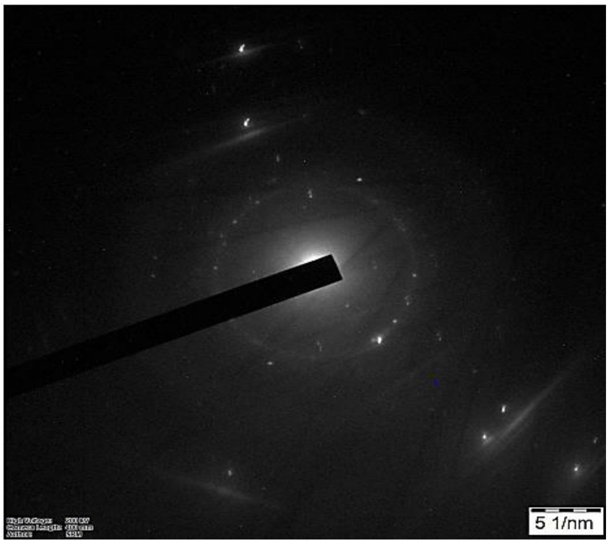

Figure. 12: Spectra image of Al 2%

6. Conclusion:

Based on the findings and discussion presented in this research study titled "Experimental Analysis of Al_2O_3," the following conclusions may be drawn:

The process of synthesising nanoparticles from micron-sized particles has undergone development.

The transmission electron microscopy (TEM) and energy-dispersive X-ray spectroscopy (EDAX) measurements provide evidence for the nanoscale dimensions of the Al_2O_3 particles.

This approach has the potential to be further expanded to include various nanoparticles of nano size, such as TiO_2, Fe_2O_3, and so on.

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