

Factors Effecting the Electrical Conductivity and Zeta Potential of Alumina Nanofluids

by

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Abstract

This study investigates the effect of nanoparticle volume fractions, NaCl concentration and pH on size of agglomerates, electrical conductivity and zeta potential of alumina nanofluids. The volume fractions used were 1, 2, 3 and 5 vol%. Different base fluids were prepared by adding NaCl (100, 300 and 500 ppm) and adjusting the pH (9, 7, 5 and 3).

The results showed that the size of nanoparticle agglomerates was increased with an increase in nanoparticles concentration and NaCl concentration. Also, the electrical conductivity was increased with an increase in nanoparticle concentration and NaCl concentration.

The size of nanoparticle agglomerates was 110 nm and the electrical conductivity was 290.2 $\mu\text{S}/\text{cm}$ at pH 3 and 0 ppm, which was the highest value of electrical conductivity and smallest agglomerates nanoparticle size at 1 vol% with no salt. The highest value was 1830 $\mu\text{S}/\text{cm}$ at pH 9 and 500 ppm of NaCl with 5 vol% of nanoparticles.

List of Abbreviations Used

nm	Nanometer
MHD	Magnetohydrodynamics
SANSS	Submerged arc nanoparticles synthesis system
$\text{NaH}_2\text{PO}_2 \cdot \text{H}_2\text{O}$	Sodium hypophosphite
NaCl	Sodium chloride
HCl	Hydrochloric
NaOH	Sodium hydroxide
DI	deionized
MWCNT	long-multiwalled carbon nanotube
SWCNT	Single-walled carbon nanotubes
EDL	Electrical double layer
LDV	Laser Doppler Velocimetry
PLAL	Pulsed laser ablation in liquids
SDBS	Sodium dodecylbenzenesulfonate
CTAB	Cetyl Trimethyl Ammonium Bromide
DLS	Dynamic Light Scattering
PCS	Photon Correlation Spectroscopy

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Chapter 1 Introduction

Nanotechnology is the process of making and manipulating materials on a nanometer (nm) scale or nano-scale (Aitken et al., 2004). A nanometer is one-millionth of a millimeter (10^{-9} m).

Nanoparticles are nano-scale particles with unique properties and features that differ significantly from the same materials on a larger scale. There are a numerous types of nanoparticles, including those made of metal and metal oxide, carbon black, carbon nanotubes, fullerenes, silicate and nanowire (Aitken et al., 2004; Lauterwasser, 2005).

1.1 Methods of Manufacture of Nanoparticles

1.1.1 Top-down Process

This process manufactures nanoparticles in the traditional way by reducing the size of the raw material by various grinding operations. The milling operation is widely using to produce nanoparticles by crushing the raw materials until reaching the desired size, as shown in Figure (1.1).

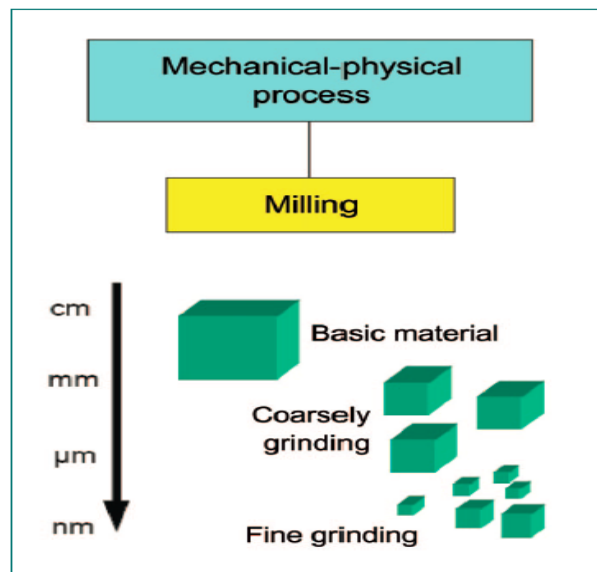


Figure 1.1: Top-down process (Christina et al., 2011)

Milling method: the mechanical production method uses milling to crush a material into very small pieces. This method is applied to produce metallic and ceramic nanopowder; for example, a high energy ball mill is used to pulverize the raw materials. In this approach the size of nanoparticles are difficult to predict and usually a broad size distribution will be produced.

1.1.2 Bottom-up Process

In this approach, the physicochemical principles of molecular or/and atomic self-organization are used. This method is better for control of particle size. In this method different ways are used to produce nanoparticles such as aerosol processes, sol-gel processes and precipitation reaction. It can be seen in Figure 1.2 (Aitken et al., 2004; Christina et al., 2011).

Aerosol Processes is also called a gas phase process, and it is widely used in industrial-scale technologies to manufacture nano-powder and nano-film form. By using chemical or physical methods, nanoparticles are formed. Aerosol nanoparticles are produced in two ways. First, by forming droplets from atomizing a solution of material where they will crystallize to solid particles after evaporation of solvent, or by using homogeneous nucleation to convert the gas to solid and growth by condensation and coagulation. This process is used to produce fullerenes and a carbon nanotube by using various techniques such as processes in flame, plasma, and hot wall reactors (Christina et al., 2011).

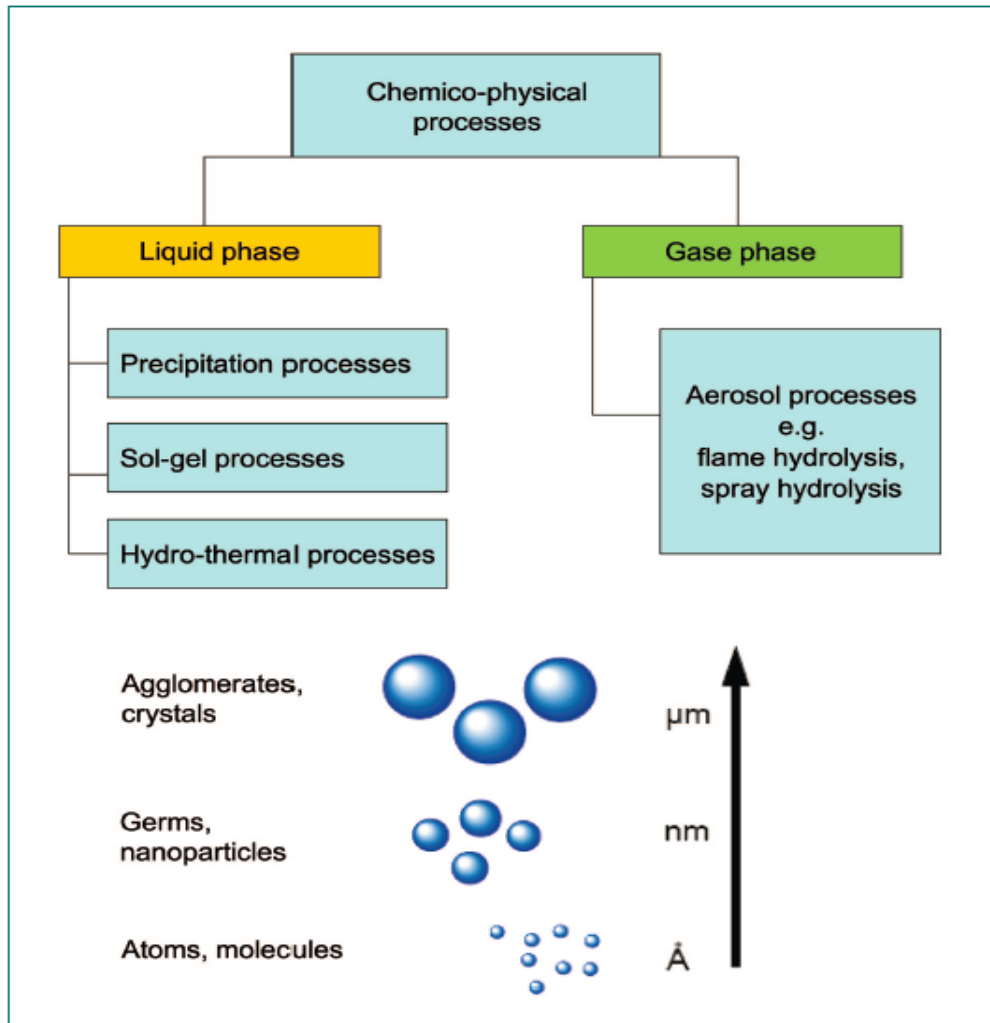


Figure 1.2: Bottom-up process (Christina et al., 2011)

Liquid Phase Processes: in this approach the wet-chemical synthesis of nanomaterials is used at low temperature. There are three methods used to produce the nanoparticles. First, a precipitation processes used to produce metal oxides as well as non-oxide or metallic nanoparticles. Second, sol-gel processes that it is able to produce a porous nanomaterials, ceramic nanostructured polymers and oxide nanoparticles. Finally, a hydrothermal process is a method to produce metal oxide crystals from metal salt aqueous solutions where the aqueous solution is heating (Lauterwasser, 2008)

1.2 Objective

The main objectives of the present work were to investigate the effect of concentration of alumina nanoparticles on the size of nanoparticle agglomerates, and the effect of concentration of nanoparticles on electrical conductivity. Moreover, the effect of pH on size and electrical conductivity has been measured, by changing of pH of the base fluid.

Also, the effect of sodium chloride salt on the size of nanoparticle agglomerates and electrical conductivity has been measured in this study. Moreover, the zeta potential of alumina nanofluids at 1vol% of alumina nanoparticles for salt and non-salt base fluids was measured. The effect of pH on Zeta potential has been investigated. The reason of this study is because there have been very few studies to investigate the electrical conductivity of nanofluids. The electrical conductivity may use in some applications like MHD (Magnetohydrodynamics) generator. There is very few studies have investigated the size of nanoparticle agglomerates, and variables that have influence on it. Moreover, the knowing of size of nanoparticles and the agglomeration that may cause helps to use the nanofluid in some application for example heat exchanger.

Chapter 2 Literature Review

Various investigations on nanofluids have been published by many researchers in the past. This chapter focuses on their works and reviews publications. This chapter provides a comprehensive idea about the topic; it deals with a literature review on electrical conductivity and the stability of nanofluids.

2.1 Preparation of Nanofluids

Choi and Eastman (1995) are reported to have been the first researcher to make a nanofluid by mixing nanoparticles with fluid. Since then, there has been a rapid development in synthesis techniques for nanofluids. However, as of yet, no standard method for nanofluid preparation has been developed. Nevertheless, many researchers have prepared nanofluids using the following two fundamental approaches:

- a) the one-step method, and
- b) the two-step method.

As its name implies, the one-step method uses one step to produce nanofluids. In other words, the process simultaneously makes and disperses nanoparticles in the base fluid. In this method, the agglomeration of nanoparticles as the result of storage and transportation is reduced and the stability of the nanofluid is increased (Li et al., 2009). There are three methods to prepare nanofluids in one step.

A vapor condensation method can be used to prepare copper/ethylene glycol nanofluid (Estman et al., 2001). Uniformly dispersed nanoparticles are used in this process, and the suspension is stabilized in the base fluid. Another one-step method for preparing nanofluids uses the vacuum-SANSS (submerged arc nanoparticles synthesis system). In this method, different dielectric liquids are utilized (Lo et al., 2005).

A chemical method has been developed for preparing copper nanofluids, where a solution of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ was mixed with polyvinylpyrrolidone, immediately after which a magnetic stirring was implemented to mix the solution. An ethylene glycol solution of sodium

hypophosphite ($\text{NaH}_2\text{PO}_2 \cdot \text{H}_2\text{O}$) was added to the previous solution, and the reaction is performed under microwave irradiation (Zhu et al., 2004).

A laser ablation technique is another method used to prepare nanofluids in a single step. In this technique, as shown in figure 2.1, a laser focuses on the solid materials or polymers that have already been submerged into the base fluid for an appropriate time (Tran et al., 2007).

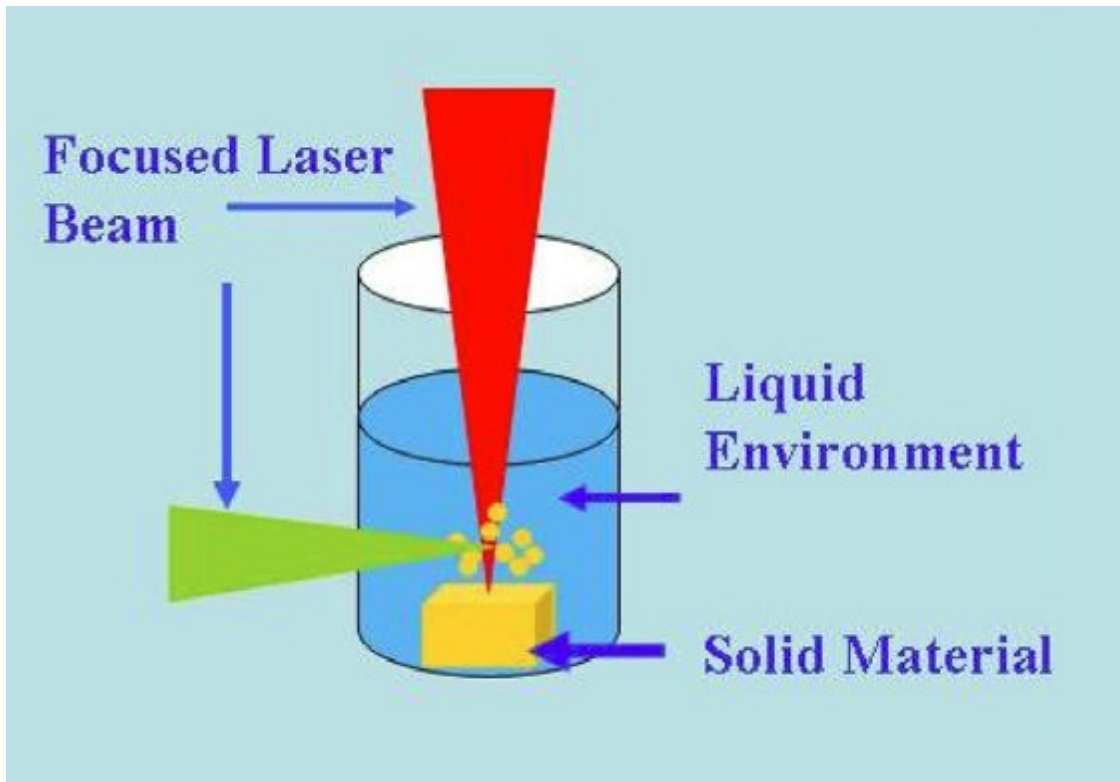


Figure 2.1: Laser ablation technique (Tran et al., 2007).

However, the high cost of preparing nanofluids and inability to manufacture in large quantities are major disadvantages of the one step method, and hence this approach could not be used in industry. An equally important shortfall of this method is the residual reactant left behind in the nanofluid due to incomplete reaction (Yu and Xie, 2011).

In contrast to the one-step method, the two-step approach is widely used in preparing nanofluids. In the two-step method, a dry powder, as nanoparticles, is first produced by

either a physical or a chemical manufacturing method as a separate product. In the second step, the nanoparticles are dispersed into a base fluid such as water, ethylene glycol or oil (Yu et al., 2011). Mechanical equipment, like ultrasonic or magnetic stirring, is usually used to reduce the agglomeration and increase the homogenization of the nanofluid (Ganguly et al., 2009). This approach is considered the most economic method to prepare nanofluids. It also has the proven ability for large-scale production due to the availability of nanoparticles (Yu et al., 2011).

2.2 Electrical Conductivity

To date, only a few studies have investigated the electrical conductivity of nanofluids. Glory et al., (2008) carried out experimental work where a long-multiwalled carbon nanotube (MWCNT) was utilized as nanomaterial. The two-step approach was used, and the nanoparticles were dispersed into distilled water. They prepared different weight fractions of MWCNT between 0.01 and 3 wt. %. All samples were sonicated for 50min and 2 wt. % gum Arabic (GA) was added to nanofluid samples. The nanotube diameter was 40 nm on average and 1.7 μm was an average of the length.

The results showed that at 0.01 wt. % the electrical conductivity was $0.35\mu\text{S}/\text{cm}$ and it was increased with an increase of concentration of MWCNT in the base fluid. The electrical conductivity at 0.1wt % was about $0.448\mu\text{S}/\text{cm}$. However, at 2 and 3 wt. % there was no significant change in electrical conductivity where the electrical conductivity was between 0.454 and $0.453\mu\text{S}/\text{cm}$, respectively. The enhancement of electrical conductivity of MWCNT comparing to base fluid was 18%.

Single-walled carbon nanotubes (SWCNT) (Glover et al., 2008) were dispersed in a mixture of 50% deionized water and 50% ethylene glycol to ensure the efficiency of nanofluid dispersion. Various concentrations of SWCNT were used between 0.05 and 0.5 wt. %. They prepared just one sample at 0.5 wt.% and other samples were prepared by diluting the highest concentration 0.5 wt.% suspensions by adding 50% DI water/50% ethylene glycol solution to get a lower concentration 0.2 wt.% suspension, and diluting the 0.2 wt.% suspension to prepare a 0.1 wt.% suspension.

In Figure 2.2, the relationship between the electrical conductivity of nanofluid as a function of a wt. % carbon nanotube is a linear relationship. Thus, increasing the nanotube load increased the electrical conductivity.

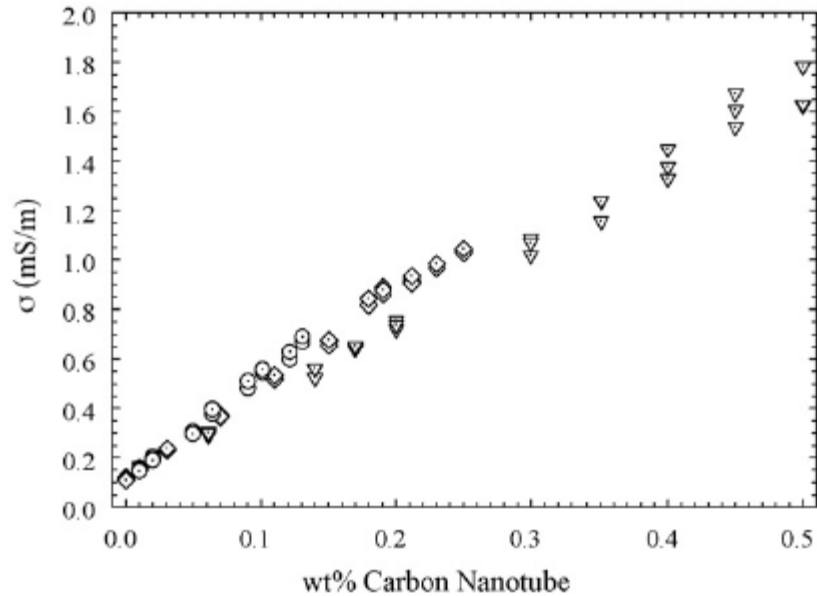


Figure 2.2: The electrical conductivity as a function of wt. % carbon nanotubes. Circles, diamonds and triangles represent three separate mixtures each with similar conductivity at 0.01 wt. % carbon nanotube (Glover et al., 2008).

The increase of the electrical conductivity was from 0.12×10^{-3} to 1.7×10^{-3} S/m for 0 and 0.5 wt. % respectively. They conclude that the total increase of electrical conductivity of nanotube at 0.5wt. % was around 13 times.

Ganguly et al., (2009) prepared aluminum oxide nanofluids. The preparation was done by dispersion a various nanoparticles volume fractions: 0.005, 0.01, 0.015, 0.02, 0.025, and 0.03 into deionized water. They noticed that the nanofluid samples were stable for several days without appearance sedimentation. The results showed that the electrical conductivity of alumina was increased almost linearly by increasing of volume fraction of alumina nanoparticles as shown in Figure 2.3. Also the electrical conductivity was used as function of temperature where a highly temperature gave a high electrical conductivity.

The highest value of the electrical conductivity was 351 and 252 $\mu\text{S}/\text{cm}$ at the volume fraction at 0.03 for two different temperatures 45 °C and 24 °C respectively.

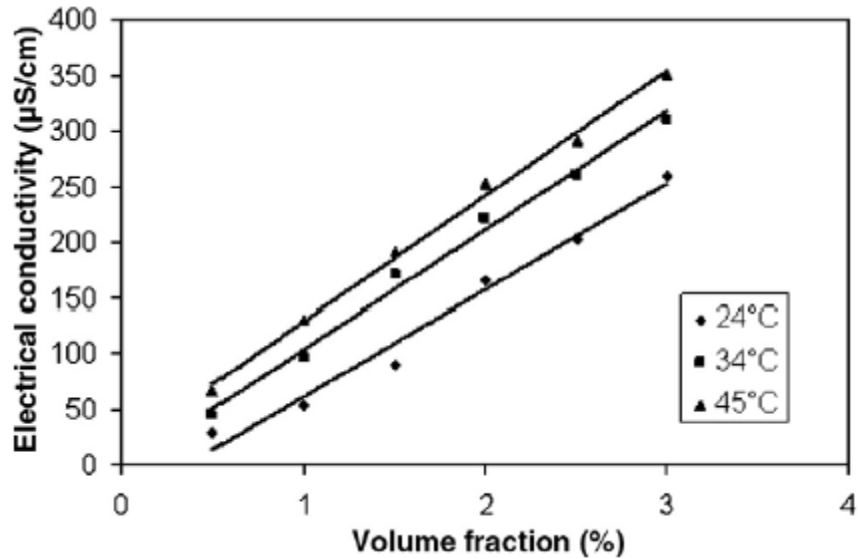


Figure 2.3: The electrical conductivity as function of volume fraction of alumina nanofluid (Ganguly et al., 2009).

The rate of enhancement of the electrical conductivity was calculated by getting the difference between the electrical conductivity of a nanofluid and the electrical conductivity of the base fluid divided by the electrical conductivity of the base fluid for all volume fractions of nanofluid. They demonstrated that the enhancement increases with increase of volume fraction and temperature as shown in Figure 2.4. The increase in the enhancement of electrical conductivity at 0.5% of nanoparticles and temperature at 24°C was 833%, while the increase at the same nanoparticles concentration and different temperature at 45°C was 2127%. (Ganguly et al., 2009)

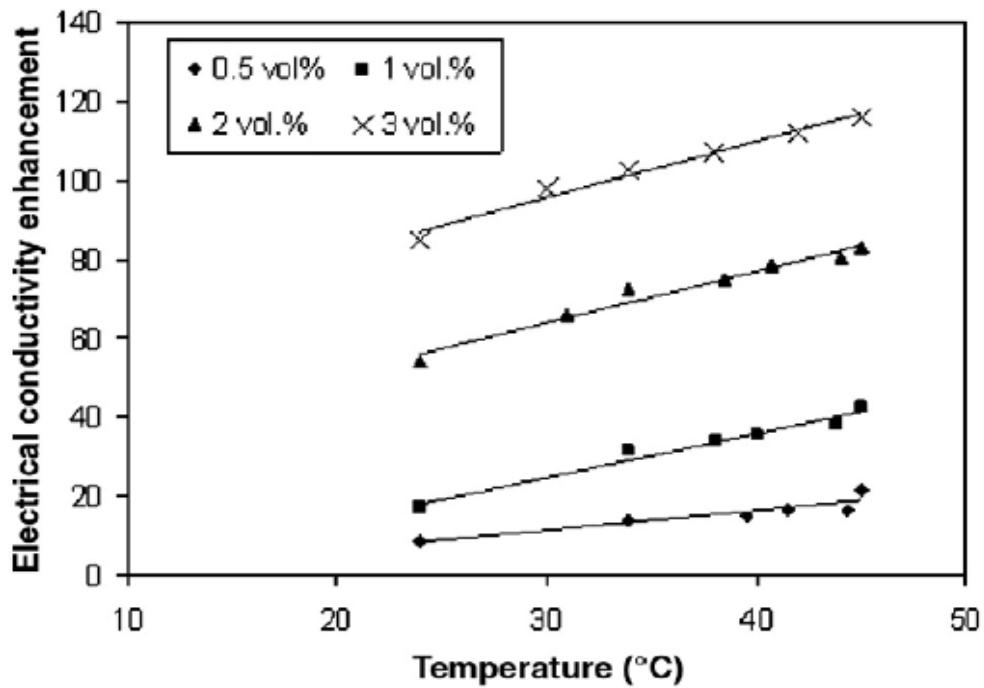


Figure 2.4: The electrical conductivity enhancement as function of temperature (Ganguly et al., 2009).

2.3 Stability of nanofluids

The stability of nanofluids is a major challenge confronting researchers, as the agglomeration of nanoparticles has an effect on both the stability and properties of nanofluids. The DLVO theory named after the initial letter of names of two groups of scientists; Boris Derjaguin and Lev Landau, and Evert Verwey and Theo Overbeek. They independently published theoretical analyses of the problem of colloidal stability. The stability of a colloid system depends on attractive and repulsive forces. If the attractive force is bigger than the repulsive force between two particles, the particles will collide. On other hand; if the repulsive force is greater than the repulsive forces, the particles will repel each other

The zeta potential is electrical potential that is used as an indicator of repulsive force. In general, a high magnitude of the zeta potential (negative or positive) is an indication that the system is electrically stabilized. A zero zeta potential, or isoelectric point (IEP), is where particles tend to agglomerate

2.3.1 Zeta potential

The electrical double layer (EDL) is the ionic concentration that is different from ionic concentration of solution and it is surrounding the particle. The electrical double layer has divided into two regions. The first region is called the Stern layer where the ions are of opposite charge to the particle, are the strongly bound to the particle and they moved with particle. The second layer is the diffuse layer where the ions are less strongly attached. Inside the diffuse layer there is a boundary line within which the ions move with the particle and beyond which ions do not travel. This region is known as the surface of hydrodynamic shear, and it is called the slipping plane, (see Figure 2.5), and it exists within the diffuse layer. It is the potential that exists at the region that is called as the zeta potential. Figure 2.6 shows the relationship between zeta potential and pH value.

The most widely used technique for measuring zeta potentials in electrophoresis is by applying an electric field across a sample, where the electric field induces charged particles to move.

The velocity of a particle (electrophoretic mobility) in an electric field is dependent on:

- 1- The strength of the electric field
- 2- The dielectric constant of the liquid
- 3- The viscosity of the liquid
- 4- The zeta potential

By directly measuring the electrophoretic mobility of a particle, the zeta potential may then be determined using the Henry Equation:

$$U_E = \frac{2\varepsilon\zeta f(K_a)}{3\eta}$$

Where

U_E = Electrophoretic mobility of particle ($\frac{m^2}{s} \cdot V$)

ϵ = dielectric constant,

η = Viscosity of solution ($Pa \cdot s$),

ζ = Zeta potential (V),

a = radius of particle (m).

$f(k_a)$ = Henry correction factor

$f(k_a)$ in this case is 1.5, and is referred to as the Smoluchowski approximation.

Zeta potential cannot be measured directly but it can be calculated by using theoretical models and an experimental determination of the motion of dispersed particles. Two methods are used to measure the motion of dispersed particles; electrophoretic mobility or dynamic electrophoretic mobility. The only difference between them is that dynamic electrophoretic mobility is measured at a high frequency.

Two different experimental techniques use the motion of dispersed particles, Microelectrophoresis and electrophoretic light scattering. In this study, the electrophoretic mobility of particles is measured by using electrophoresis Laser Doppler Velocimetry (LDV).

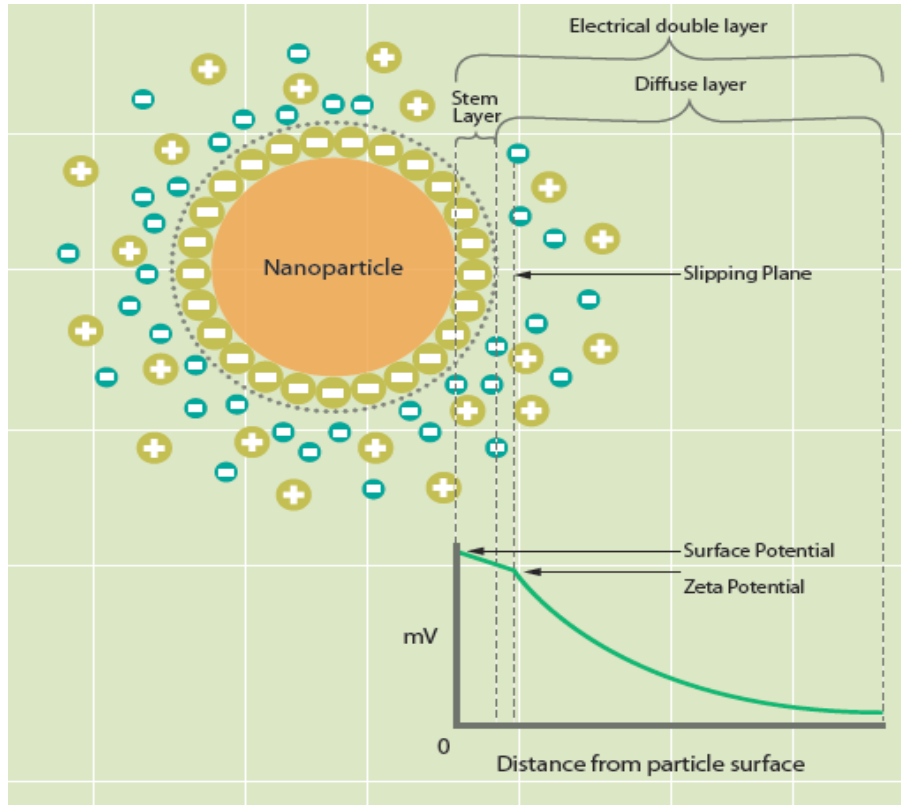


Figure 2.5: Diagram demonstrating the potential difference as a function of distance from the surface of a particle in a dispersion medium (Anon, 2004).

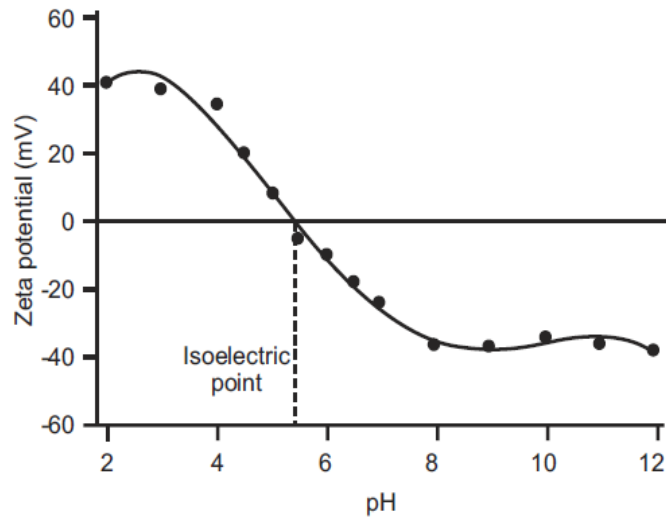


Figure 2.6: Diagram showing the relationship between zeta potential and pH value (Anon, 2004).

Kim et al., (2009) measured the zeta potential of gold (Au) nanofluids, where water was used as a base fluid, they also measured the pH for all samples. They observed that the Au nanoparticles concentration has an effect on zeta potential; the highest zeta potential was around -35 mV regardless of pH in the range of 4 to 6 as shown in figure (2.7).

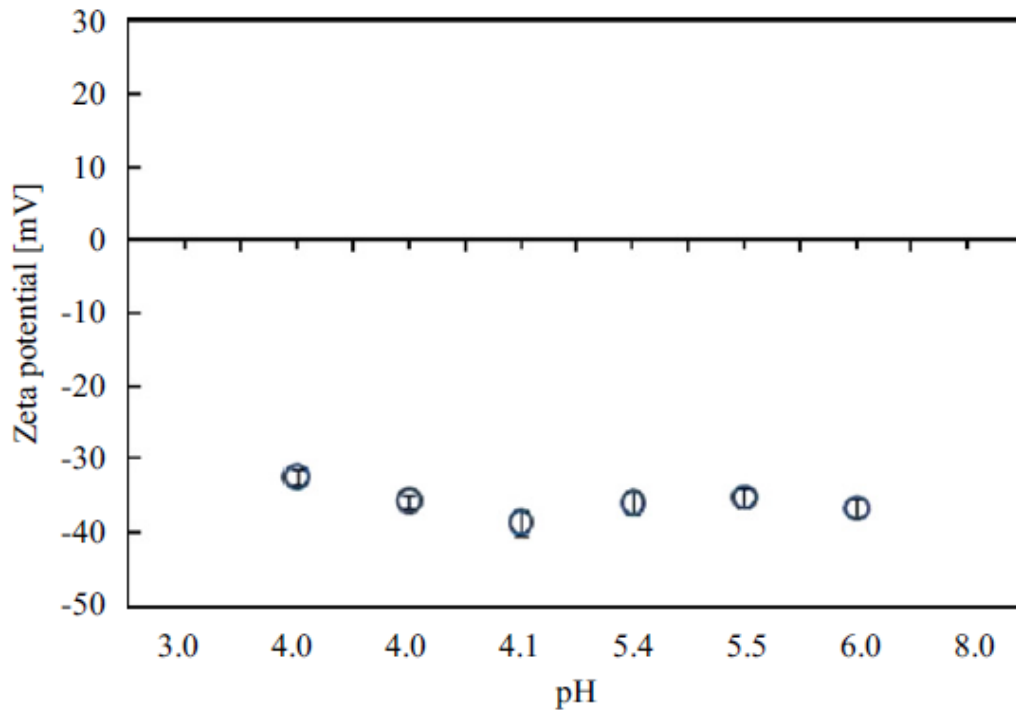


Figure 2.7: Zeta potential of the bare Au-NPs in water (Kim et al., 2009)

They conclude that increasing the PLAL (pulsed laser ablation in liquids) time causes an increase in the volume fraction of Au nanoparticles and decrease in pH value, since they used the one step method to prepare the nanofluids, the changing in pH effect on zeta potential. They found that the value of the zeta potential of Au nanofluid that was prepared by irradiation for 18 h was -21.1 mV after 3 months.

Kim et al., (2009) measured the zeta potential as function of pH value. They adjusted the value of pH for nanofluid by adding HCl and NaOH, where the volume fraction of Au nanoparticles was 0.0001 vol%. The original pH was 5.5; it was decreased by adding HCl to get different a pH value until it reached around 1 while NaOH was added to get two

values of pH 8 and 10. They found the IEP of Au nanofluid was 3, as shown in Figure 2.8.

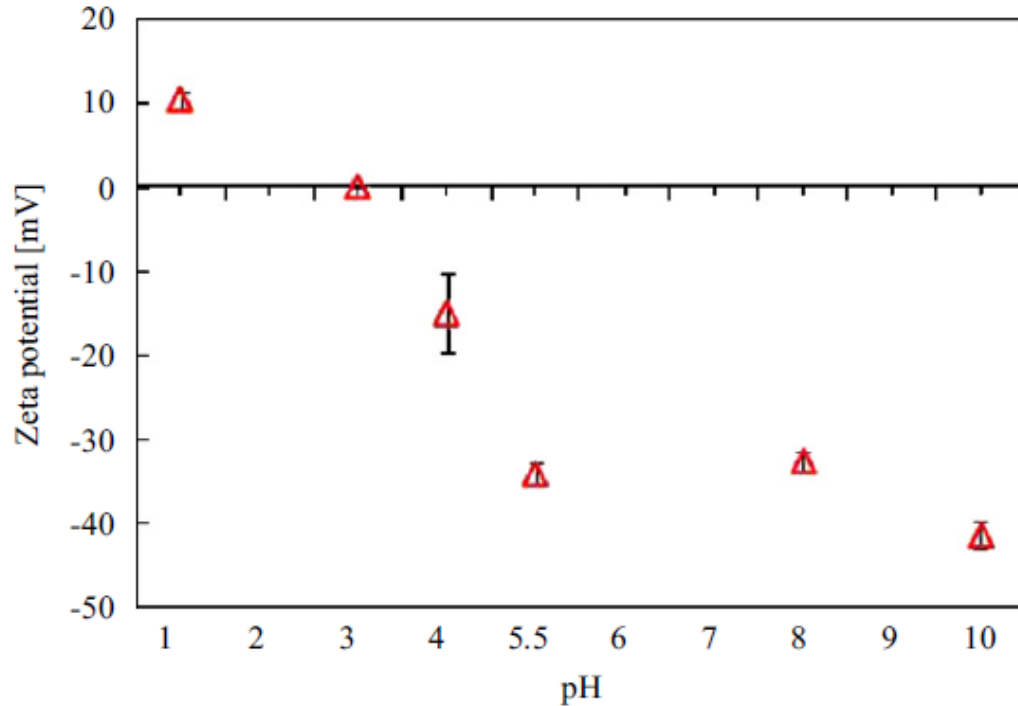


Figure 2.8: Zeta potential as a function of pH (Kim et al., 2009)

The influence of pH on the stability of nanofluids was investigated by Wang and Way, (2009) and Zhu et al., (2009). They prepared 0.05wt% alumina and Cu and a different sodium dodecylbenzenesulfonate (SDBS) concentration was added to both suspensions. Stirring and ultrasonication were used to mix the nanofluid. The zeta potential was measured by using a Malvern ZS Nano S analyzer.

They measured the effect of pH and SDBS on the zeta potential. They found that the charges of alumina and Cu nanofluids are negative. They also measured the absorbency for both nanofluids where it is related to electrokinetic properties.

They found that the dispersion stability of both nanofluids was weak as a result of the zeta potential. Where the zeta potential was the lowest below pH 2; therefore, the repulsion

force at that region was not enough to subdue the attraction force between the nanoparticles as implied in Figure 2.9.

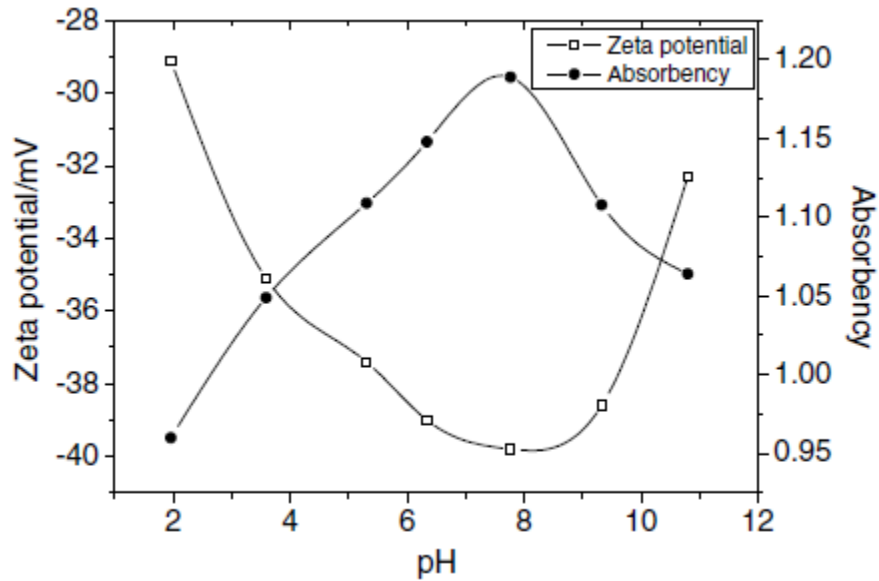


Figure 2.9: zeta potential and absorbency as a function of pH value (Wang et al., 2009)

The zeta potential was increased with increasing pH in the presence of SDBS until a certain point where the pH reached 8. After that, the zeta potential decreased until the pH reached 10, where it was the maximum pH used in their study. Also, the zeta potential for Cu was increased with an increase of pH until a certain value; in this case, the optimum zeta potential was found at 9.5 for Cu nanofluid, while it was found to be 8 for Al_2O_3 , where a high zeta potential was found.

They compared the effect of pH on alumina and Cu nanofluids. They found that in zones where the pH was located between 2 and 8 for alumina the dispersion of alumina nanofluids was better than the dispersion of Cu nanofluids, while in zones where the pH was above 8 the dispersion of Cu nanofluid was better than the dispersion of alumina nanofluid.

They also studied the effects of SDBS concentration on the stability of both nanofluids at certain pH; it was 8 for alumina and was 9.5 for copper, as is shown in figure (2.10). They observed that the SDBS was improved in the value of zeta potential. The optimized value

of zeta potential was found at 0.1wt% of SDBS for alumina and 0.07wt% of SDBS for copper.

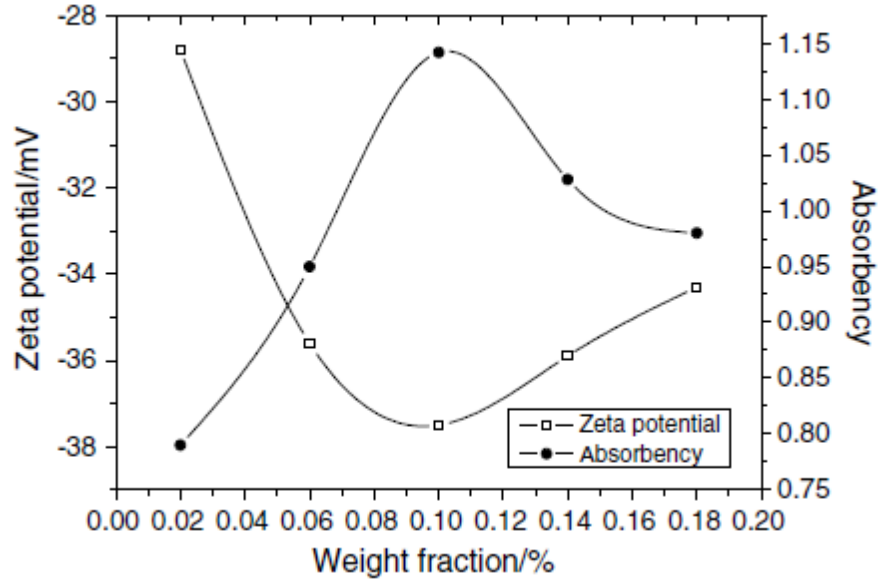


Figure 2.10: Zeta potential and absorbency as a function of wt. % of nanoparticles (Zhu et al., 2009)

Murshed et al., (2008) measured the effects of pH values and electrolyte concentration on zeta potential. First, they measured the effect of pH on the zeta potential of TiO_2 nanofluids, where they prepared two types of nanofluid. The first one was prepared by dispersing nanoparticles into water, while another was also by dispersing nanoparticles but a surfactant was added. The surfactant was Cetyl Trimethyl Ammonium Bromide (CTAB). They used HCl and NaOH to change the pH. They found that zeta potential had a positive charge at pH 4 and below, which means that the particles also had a positive charge. The zeta potential was decreased with increase in pH value. The IEP was found at 4.9, and beyond this point the charge of the zeta potential was changed to a negative value. As can be seen in Figure 2.11, the maximum magnitude zeta potential was observed at a high pH value (7 and up), which means that a stable nanofluid was gotten at a high pH, around 9, since high zeta potential was found at high pH.

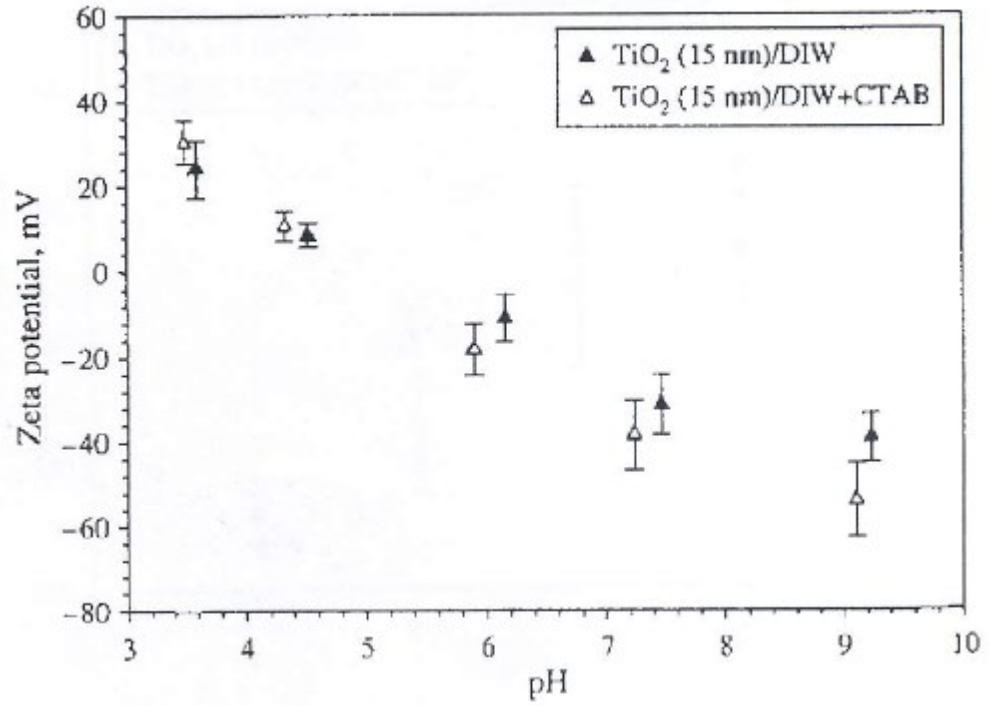


Figure 2.11: Zeta potential as a function of pH (Murshed et al., 2008)

In the next step, they added various concentrations of NaCl. They found that the salt can also change the charge of the zeta potential as shown in Figure 2.12, since when more salt was added into both nanofluids the zeta potential decreased. It was noticed that the pH value stayed the same at each concentration of NaCl.

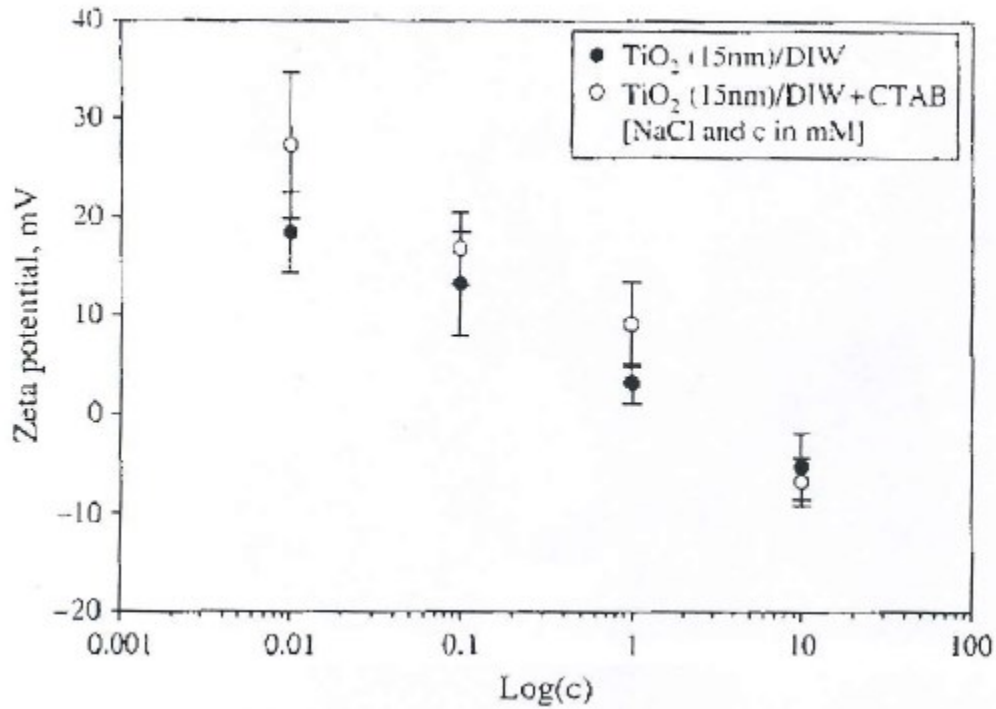


Figure 2.12: Zeta potential as a function of NaCl concentrations (Murshed et al., 2008)

The zeta potential was measured by Gustafsson et al, (2000) for a TiO₂ nanofluid. They measured the effect of NaCl on zeta for pH values of 3 to 10. In this study, 10% of the weight of TiO₂ nanoparticles was dispersed into various concentrations of NaCl. They started with deionized water without any salt added into the nanofluid. After that, some amount of salt was added by preparing a different concentration of NaCl. They found that the zeta potential was decreased when a higher salt concentration was added. The zeta potential at a low concentration of NaCl (0, 0.01 and 0.1 mol dm⁻³) was very high while at a high concentration was very low and it was indicative of an unstable nanofluid. The zeta potential was very high at a low pH value of 3, and the zeta potential slightly decreased when the pH value was increased. Also, low pH value regions had a positive charge for each salt concentration. The IEP was found to have a range of 5.9 and 6.3 for low salt concentration. The charge of zeta potential was changed to a negative charge when the pH was increased. At a high salt concentration, there was not a big change in zeta potential value, where the relationship between the zeta potential at a high salt concentration was almost linear, as is shown in Figure 2.13.

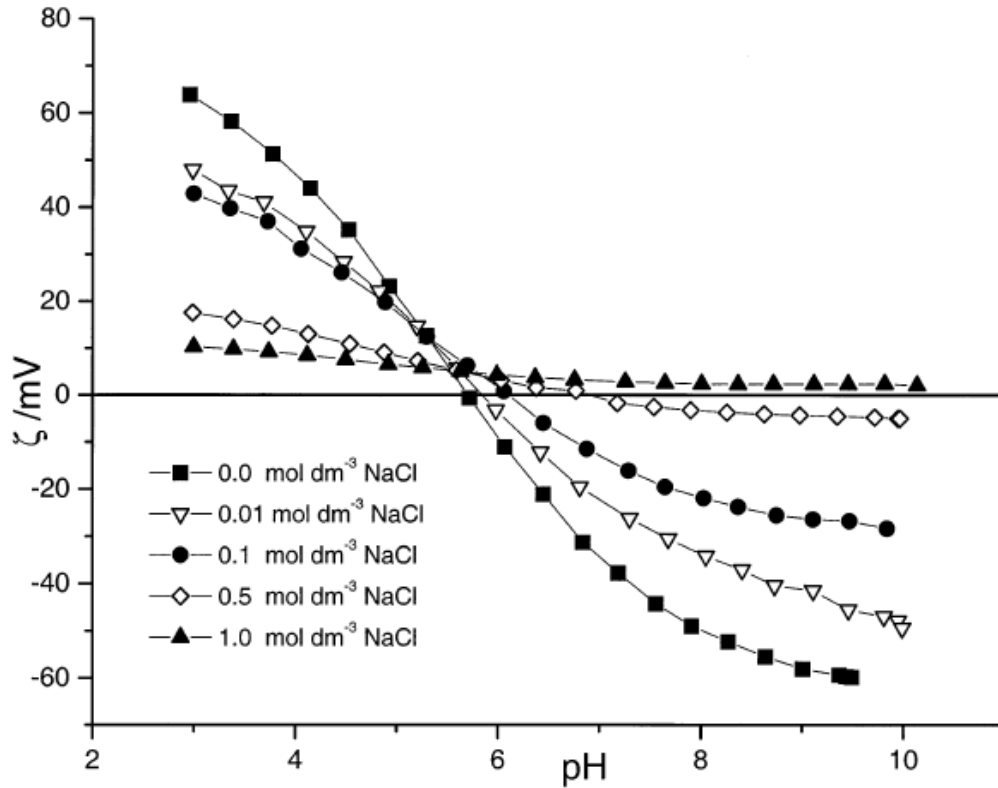


Figure 2.13: Zeta potential as a function of pH for various NaCl loading (Gustafsson et al., 2000)

2.3.2 Size of Nanoparticle Agglomerates

There is not much research devoted to the size of nanoparticles in dispersion, even though some researchers have studied some factors that may affect size.

Murshed et al., (2008) measured the effect of pH on the size of nanoparticles agglomerate. They observed that the size of agglomerate rose with increasing pH value as in Figure 2.14. According to DLVO theory, when pH was increased more than IEP, the size of the particles have to decrease, which was noticed in their study where, the size of nanoparticles agglomerate was increased beyond pH 5, which was IEP.

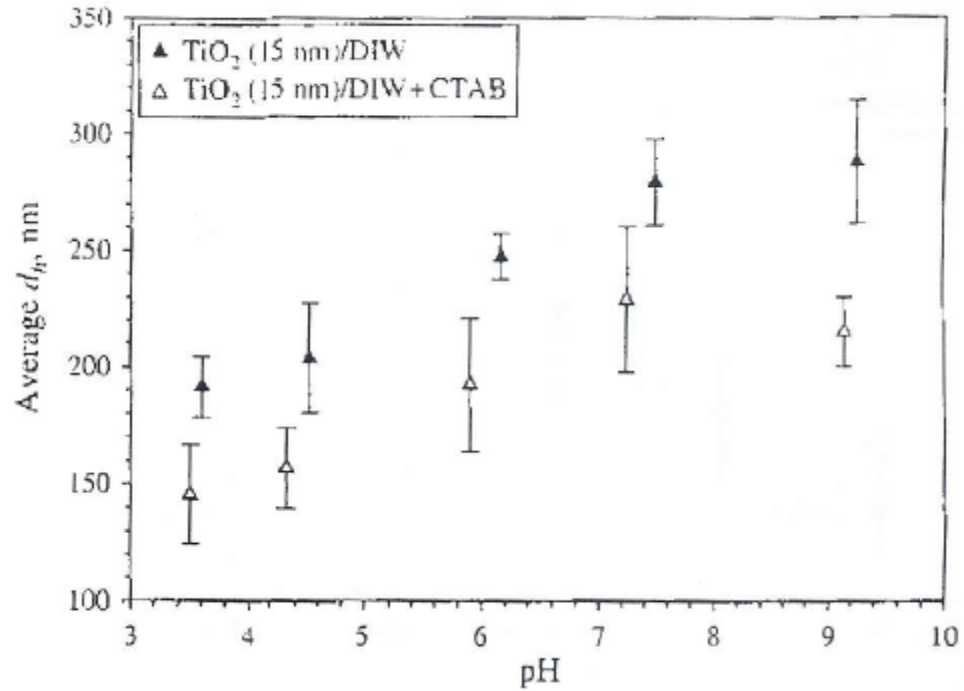


Figure 2.14: Size of nanoparticle agglomerate as a function of concentration of pH value (Murshed et al., 2008)

They also studied the effect of electrolyte concentration on size of nanoparticles agglomerate as in Figure 2.15. The size of nanoparticles increased with an increase in NaCl concentration, which means that adding salt causes agglomeration.

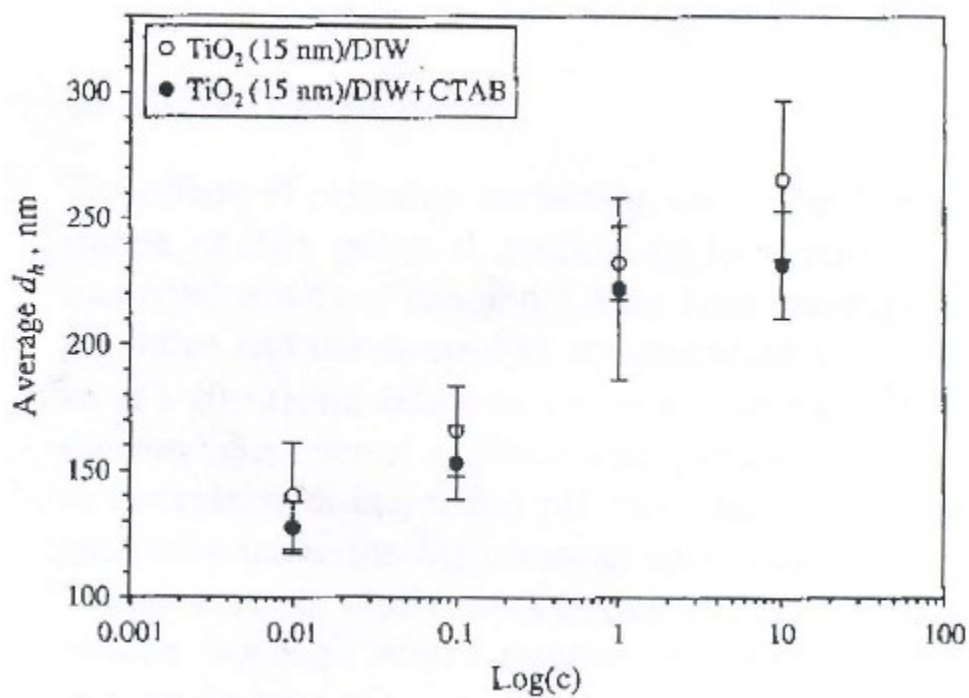


Figure 2.15: Size of nanoparticle agglomerate as a function of concentration of NaCl (Murshed et al., 2008)

Gustafsson et al., (2000) measured the effect of pH value at various NaCl concentrations on the size of anatase nanoparticles. They found that the size of nanoparticles agglomerate was growth when pH value approached pH_{iep} . Also, they noticed a slight increase in size when NaCl was added as in Figure 2.16.

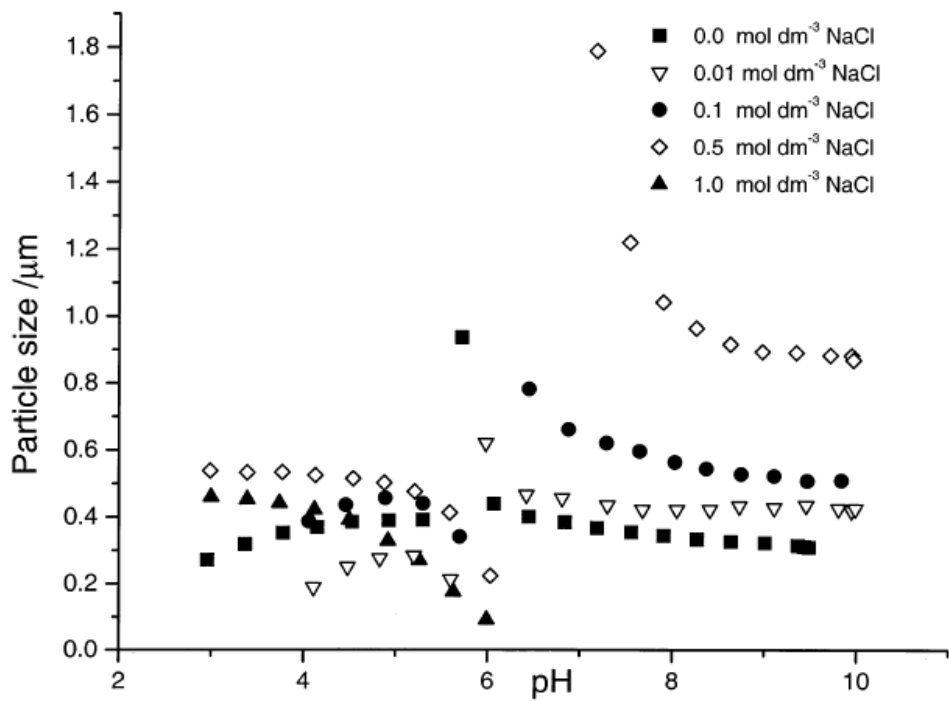


Figure 2.16: Size of nanoparticle agglomerate as a function of concentration of pH for various NaCl concentrations (Gustafsson et al., 2000)

Chapter 3 Experimental Setup

3.1 Ultrasonication

Sonication acts by applying sound (wave) energy to disperse particles in a sample. In the laboratory, two kinds of ultrasonic methods are usually applied: using an ultrasonic bath or an ultrasonic probe. Sonication can be used to speed dispersion, and break or weaken interactions between particles. Moreover, in cases when a sample is difficult to mix by using a stirrer. Sonication is very useful to get good stability colloidal solution. Sonication is commonly used in nanotechnology for evenly dispersing nanoparticles in liquid. The specification of the sonicator used in this study is Fisher Scientific model 505; it has a generator, converter and standard 12" horn as in Figure 3.1.

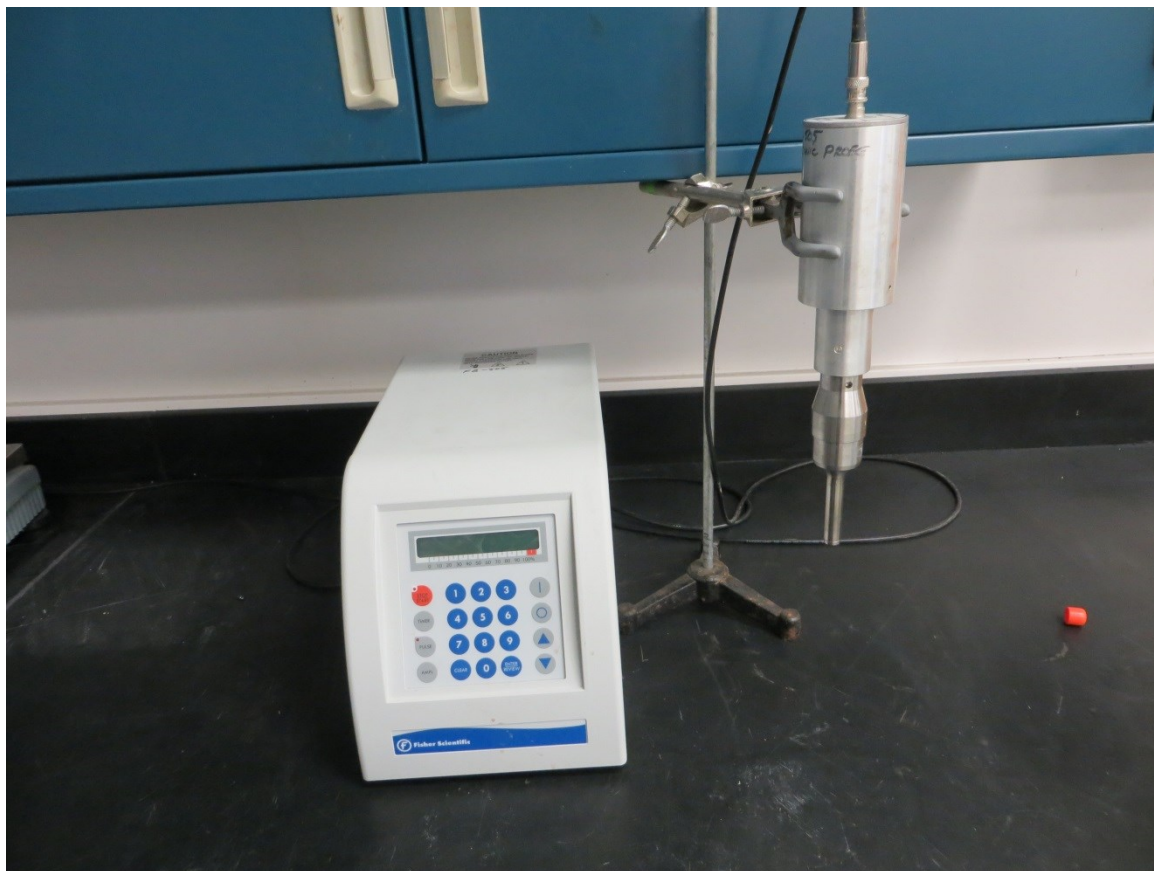


Figure 3.1: ultrasonic

3.2 Zetasizer nano sz

Zetasizer nano zs is a device that was designed to measure particle size, zeta potential and molecular weight in a liquid medium.

3.2.1 Size

The Zetasizer system uses Dynamic Light Scattering (DLS) to determine the size of particles by measuring the Brownian motion of the particles in a liquid; it is also called as Photon Correlation Spectroscopy (PCS). The size range is 0.6nm to 6 μ m.

The mechanism works by illuminating a laser on the particle and then analyzing the intensity fluctuations in the scattered light.

3.2.1.1 Operation of the Zetasizer Nano- Szie Measurements

A basic feature of a DLS system is that it consists of six basic components as in Figure 3.3. The principal light source is a laser. The sample is illuminated with the cell a beam of a laser, as shown in Figure 3.2. Not all laser beams penetrate through the cell because of particles which cause them to scatter. The intensity of the scattered light was measured by a detector. There are two positions, 90 ° and 173 °, of the detector depending on the brand of the zetasizer nano. In this study, a zetasizer ZS nano was used, for which the detector position is 173°.



Figure 3.2: Sizing cell

There is an attenuator; which is used to minimize the intensity of scattered light of the laser. If too much light reaches the detector, it will be overloaded. Therefore, the

attenuator is specified for the range of light that must be reached to the detector. To make successfully measurement of size; the scattered light must be within a specific range.

A digital signal processing board receives a signal of the scattering intensity from the detector. The correlator, digital signal processing board, derives the rate at the intensity, by comparing the scattering intensity at sequential time intervals.

The information that is collected on a correlator is sent to a computer, which has special zetasizer software; to analyze the data.

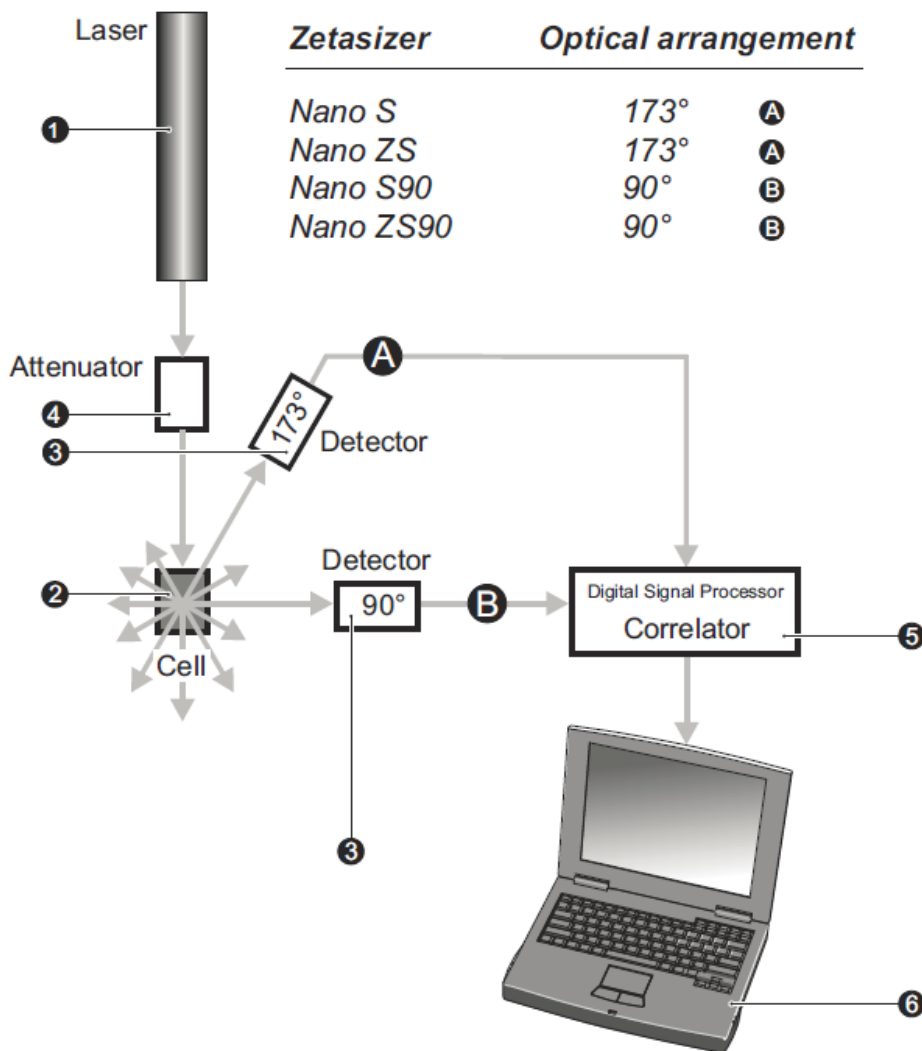


Figure 3.3: Experimental set up of size system (Nano. 2004).

3.2.2 Zeta Potential

The majority of liquids contain ions; they are divided into two types depending on their atomic charge. A positive charge is called an anion and a negative charge is called cation. The ions attract an oppositely charged particle, where positive ions attract to the negative surface of a particle and vice versa.

3.2.2.1 Operation of the Zetasizer Nano- Zeta Potential Measurements

The zeta potential measuring system consists of six essential components or compounds. The principal light source is the laser. The sample was illuminated with a beam of the laser, as is shown in Figure 3.4. The light source in the zeta potential system is divided into two lights, an incident which is the provider and a reference beam. The reference beam, also called Modulator, provides the Doppler Effect that is necessary. An attenuator is used to adjust the intensity of the laser to allow measurement for the detector.

The laser beam penetrates the center of the sample cell (Folded Capillary cell) as shown in Figure 3.4 and scatters at an angle of 17° . Any movement of the particle will cause the intensity of light when the electric field is applied to the cell.

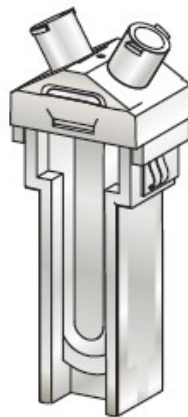


Figure 3.4: Zeta potential cell (Folded Capillary cell) (Anon, 2004).

Comparison of the data is done by a detector, and this information is sent to a digital signal processor. The computer receives the information from the digital signal processor.

The Zetasizer Nano software will analyze the data and determine the electrophoretic mobility. It will then calculate the zeta potential.

A detector sends this information to a digital signal processor. This information is then passed to a computer as in Figure 3.5, where the Zetasizer Nano software produces a frequency spectrum, from which the electrophoretic mobility and hence the zeta potential information is calculated.

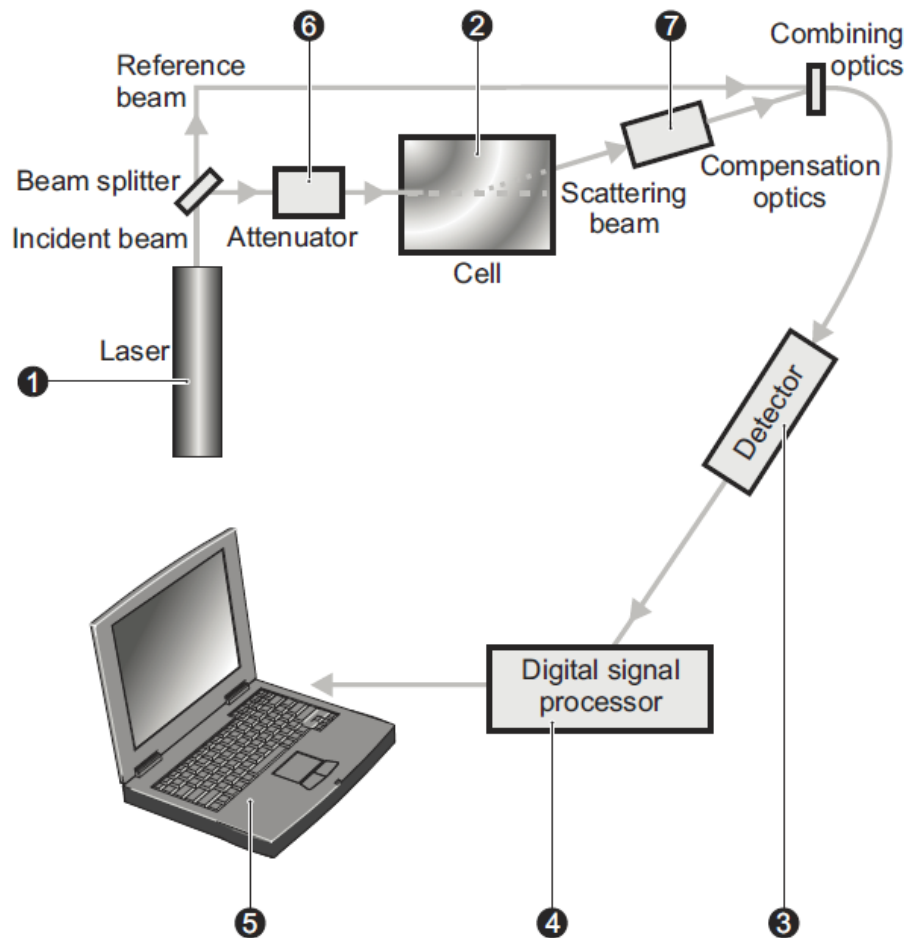


Figure 3.5: Experimental set up of zeta potential system (Anon, 2004).

3.3 Electrical Conductivity/ pH Meter

A PC 2700 benchtop meter is just one of many tools used in the analysis of common water quality parameters. It contains a PC 2700 meter with a pH electrode, conductivity/ATC electrode and an integral electrode holder.

Repetition of calibration is important for getting the best results. Therefore, during this work, the calibration was done every two weeks. A three pH standard solution was chosen (1.68, 7.00 and 10.01) and two for the electrical standard solution, which are 84 and 1413 μS .

Chapter 4 Materials and Methodology

4.1 Properties of Materials

The main aim of this chapter is to prepare nanofluids with Al_2O_3 nanoparticles and water and salt water solution as a base fluid.

4.1.1 Materials Required

- Nanoparticles; Aluminum oxide, NanoDur (Average size- 45 nm), 99.5%. The stock number is 44931. Aluminum oxide or alumina (Al_2O_3) nanoparticles are manufactured by Alfa Aesar. The specific surface area is 32-40 m^2/g and the molecular weight is 101.96.
- Deionizer water: the electrical conductivity less than 1.
- Salt (Sodium chloride), purity 98+%.manufactured by Aldrich

4.2 Methodology

4.2.1 Preparation of Nanofluids

Nanofluids were prepared by a two-step process. The nanoparticles were dispersed into the base fluid. The particles were obtained from different Alfa Aesar as dry powders. The volume concentrations of 1%, 2%, 3%, and 5% were made by mixing 2 g, 4.04 g, 6.12 g, and 10.42 g of nanoparticles in 50 ml of base fluids at different pH (3, 5, 7, and 9) where the changing of the pH was done by using HCl and NaOH at pH 1 and 12 and molarity 0.01M HCl and 0.01M NaOH, respectively, before the nanoparticles were added. To disperse and stabilize the nanoparticles, an ultra sonicator was used.

4.2.1.1 Estimation of Nanoparticle Volume Fraction

The amount of alumina nanoparticles that are required to prepare nanofluid was calculated using a mass balance. A sensitive balance with a resolution of 0.1 mg was used to weigh the alumina nanoparticles very accurately and NaCl salt. The weight of the nanoparticles required for the preparation of 50 ml Al_2O_3 of nanofluid of a specific volume fraction.

$$\phi = \frac{V_n}{V_t}$$

Where Φ is volume fraction

V_n is volume of nanoparticles

V_t is total volume fraction of the solution

Since the volume of nanoparticles is unknown, and the weight of nanoparticles can be measure by balance, therefore the volume could be obtained by using the particle density of alumina, which is 39.6 g/m^3 .

$$V_n = \frac{m_n}{\rho_n}$$

The volume of nanoparticles is unknown, and the weight of nanoparticles can be measured by balance; therefore, the volume could be obtained by using the solid density of alumina.

The weight and volume of alumina nanoparticles required for the preparation of nanofluids of different volume fractions in 50 ml of base liquid is summarized in the table shown below.

Table 4.1: The weight and volume concentrations of alumina

No.	Nanoparticles volume concentration. (%)	Nanoparticles weight (g)
1	1	2
2	2	4.04
3	3	6.12
4	5	10.42

4.2.1.2 Nanofluid Preparation Using Alumina Nanoparticles

Alumina nanoparticles with an average size of 50 nm are used for investigation in the present experimental work. The photograph which shows the nanoparticles as seen by the naked eye is shown in Figure 4.1.



Figure 4.1: Picture of alumina nanoparticles

In the present work, the base fluids were DI water and NaCl/DI water mixture. Three different stages were used to prepare nanofluids and are listed below.

4.2.1.3 Mixing of Nanopowder in the Base Liquid

In this method, the nanoparticles were directly mixed in the base liquid and without any additional components. The nanofluids prepared in this method, were given poor suspension stability, after the nanofluid preparation time, the nanoparticles settled down because of agglomeration and due to gravity. Therefore, the nanofluid should be stabilized using the sonicator. The particle settlement time depends on the type of nanoparticles were used, density, viscosity properties and electrochemistry.

4.2.1.4 Treatment of Base Fluids

The pH value of the base fluid can be lowered or raised by adding a suitable acid or alkaline to it. A nanofluid with uniform particle dispersion can be prepared by mixing nanoparticles in a treated base fluid. In the present work, four pH values were used to investigate the effect of pH on the stability of the nanofluid. Different base fluids were used in this study; DI water and NaCl solution. The resistivity of the pure deionized water was greater than $18 \text{ M}\Omega\cdot\text{cm}$ and less than $18.5 \text{ M}\Omega\cdot\text{cm}$ and electrical conductivity was less than $1 \mu\text{S}/\text{cm}$. Its characterization was changed by adding HCl and NaOH; therefore, three base fluids were derived by changing the pH of the DI water. In total, four base fluids were prepared in this stage. The second type was the NaCl base fluid. Different concentrations of NaCl were prepared by dissolving an amount of NaCl salt into DI water. Three NaCl solutions were prepared: 100, 300 and 500 ppm. Also, the pH for every NaCl solution was changed, where each salt solution produced three base fluids besides the original one. The total number of base fluids was sixteen samples.

4.2.1.5 Add Surfactants to the Base Fluid

Nanofluids prepared using surfactants may give a stable suspension with uniform particle dispersion in the host liquid. In the present work, no surfactant was added.

After estimating the amount of nanoparticles that are required for the preparation of alumina nanofluid for given volume fractions by using mass balance, nanoparticles are mixed in the base fluids. In the present investigation, no surfactants were added in the alumina nanofluids, because with the addition of surfactants the electrical conductivity and the zeta potential of nanofluids would be affected.

Aluminum oxide nanofluids of five different volume fractions in the range of 1, 2, 3 and 5% were prepared for measuring nanoparticles' size and zeta potential and the electrical conductivity of all the nanofluids fractions considered in the present work. Normally, the agglomeration of nanoparticles takes place when nanoparticles are suspended in the base fluid. All the test samples of alumina nanofluids were subjected to ultrasonic vibration for about 1 hour. Since the ultrasonic device produces thermal energy and thus the temperature of nanofluid rises, a cooling system was used, as shown in Figure 4.2, where The sample was put into the bath and temperature was calculated it, by passing cold water

into where the sample was placed in the Beaker that contained the nanofluid. The photographic view of the alumina nanofluid sonification process using an Ultrasonic probe is shown in Figure 4.2.

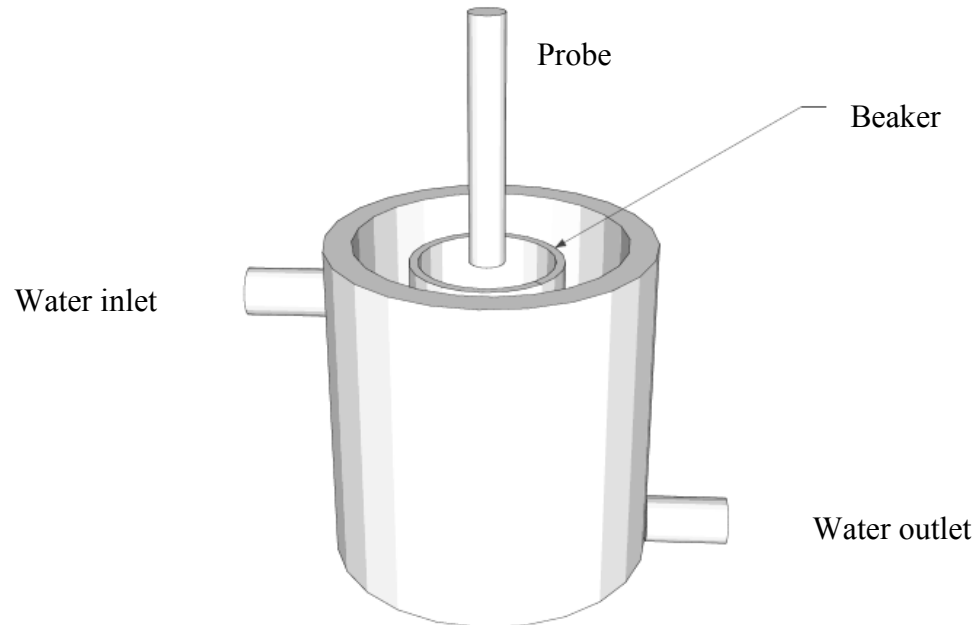


Figure 4.2: Cooling system

4.3 Statistical Analysis

Statistical analysis was performed by using Minitab 16 to determine the best model for size and electrical conductivity. All data are given as the mean of a least 2 samples ± 2 standard deviations.

Basic parameters are nanoparticles volume fraction, sodium chloride salt and pH value. Different parameters were derived to improve the fit. Parameter combinations were also used to improve the model. For instance, square of NaCl concentration (ppm^2), nanoparticle volume fraction multiplied by NaCl concentration ($F \times ppm$), nanoparticles volume fraction multiplied by pH value ($pH \times F$), and NaCl concentration multiplied by pH value ($pH \times ppm$). A 95% confidence interval was chosen.

All parameters were performed and finally model was tested and the results were drawn in all figures.

Regression Equation

The result in this study was performed to determine which variable had an effect of size of nanoparticles and electrical conductivity

Size

More variables were initially included to try reaching improve fit. Cubic salt concentration was added to fit model but it was eliminated because it did not improve it. T-value and P-value both used to determine which variable should stay in fit model. All variables in this equation below had very lowest P-values and highest T-values; therefore, they are significant variables.

$$\begin{aligned} \text{Size} = & 112.95 + 303.4 F + 0.03484 \text{ ppm} + 19.80 \text{ pH} \times F + 0.583 F \times \text{ppm} \\ & - 0.000029 \text{ ppm}^2 \end{aligned}$$

Where

Size: the size of nanoparticle agglomerates (*nm*)

F: nanoparticles volume fraction

ppm: NaCl concentration (*ppm*)

The analyses showed that the T value of volume fraction is 7.23 which is the highest number. The highest number in T value test is high significant, following by (*ppm*) which is salt concentration and term ($F \times \text{ppm}$) with 5.03 and 5.33. The salt concentration is also high significant, if it was alone other with volume fraction. The other term ($\text{pH} \times F$) and (ppm^2) are less significant than other, but there exists necessary for the fit.

Electrical conductivity

Same variables that were done for size fit also they applied for electrical conductivity fit. The temperature may effect on electrical conductivity, therefore, it will cause an error in data.

$$\begin{aligned} E.C = & 201.1 + 2738 F + 1.802 \text{ ppm} - 13.84 \text{ pH} + 0.0906 \text{ pH} \times \text{ppm} + 6.98 F \\ & \times \text{ppm} + 0.000528 \text{ ppm}^2 \end{aligned}$$

E.C: electrical conductivity ($\mu\text{S}/\text{cm}$)

pH: pH of base fluid

The analyses for electrical conductivity showed that the T value of salt concentration is 14.89 which is the highest number. Therefore, the salt concentration is high significant. The second high value is 8.45 for pH × ppm, this term has two part pH and salt concentration. The pH is necessary for fit but it is not high significant than volume fraction. The T value for pH is small 4.36. Therefore, the volume fraction is second high significant with T value is 5.71

Standard deviation

Standard deviation is measurement of the dispersion of the amount of variability or dispersion around an average. It uses to calculate the error between two repeat data.

$$S_N = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})^2}$$

Temperature

Since the temperature has an effect of electrical conductivity of nanofluid as it was mentioned in literature review. The temperature was measured after the preparation of nanofluids, the cooling beaker kept the temperature of sample around 20°C, since the temperature of the base fluids was at 15 °C -17 °C. Moreover; the electrical conductivity was measured with different temperature between 20 to 25°C, because of effect of room temperature. The temperature in zetasizer nano was set up works at 25°C

Chapter 5 Results and Discussion

5.1 Size of Nanoparticle Agglomerate

The size of dispersed alumina was measured at different nanoparticle fractions in DI water with a salt concentration of 0 ppm and various NaCl concentrations.

Tables in appendix show the results of the experiments, each of which was performed twice. The standard deviation and average were calculated for all of them.

For example, Figure 5.2 shows the effects of both nanoparticle concentration (1, 2, 3 and 5%) and NaCl concentration (0 ppm [no salt], 100, 300 and 500ppm). The increase in size of nanoparticle agglomerate is due to the concentration of nanoparticles. At 0 ppm there is no added salt, so it is just DI water, not HCl or NaOH. The size of nanoparticle agglomerate then increases with the presence of NaCl in the base fluid. The results show that size of nanoparticle agglomerate is greater in the presence of NaCl than in the absence of it. In Figure 5.2, it is clear that the size of nanoparticle agglomerate of 1% of the nanoparticles at 0, 100, 300 and 500 ppm rises as a result of NaCl.

5.1.1 Size as a Function of Nanoparticle Concentration for Different Salt Concentrations at Different pH Values

Figures 5.1, 5.2, 5.3 and 5.4 represent the data of experimental work. Each figure illustrates various pH values, and each line indicates the predicted size of nanoparticle agglomerate by using the derived model. The points show the real size of nanoparticle agglomerate with various salt concentrations.

Each figure represents the measuring size of nanoparticle agglomerate at a different pH value (9, 7, 5 and 3). There were noticeable differences in size of nanoparticle agglomerate as a result of the effect of nanoparticle concentration. In other words, the size of nanoparticle agglomerate was increased as the nanoparticle concentration increased. In addition to increases in size of nanoparticle agglomerate, there were also clear increases in the presence of NaCl. The size of nanoparticle agglomerate increases with increases in salt concentration

For example, Figure 5.1 shows the effects of both nanoparticle concentration (1, 2, 3 and 5%) and NaCl concentration (0 ppm [no salt], 100, 300 and 500ppm). The rise in size of nanoparticle agglomerate is due to the concentration of nanoparticles. At 0 ppm there is no added salt, so it is just DI water, however, the pH was changed by adding NaOH. The size of nanoparticle agglomerate then increases with the presence of NaCl in the base fluid. The results show that size of nanoparticle agglomerate is greater in the presence of NaCl than in the absence of it. It is clear that the size of nanoparticle agglomerate at any the nanoparticles concentrations rise as a result of NaCl.

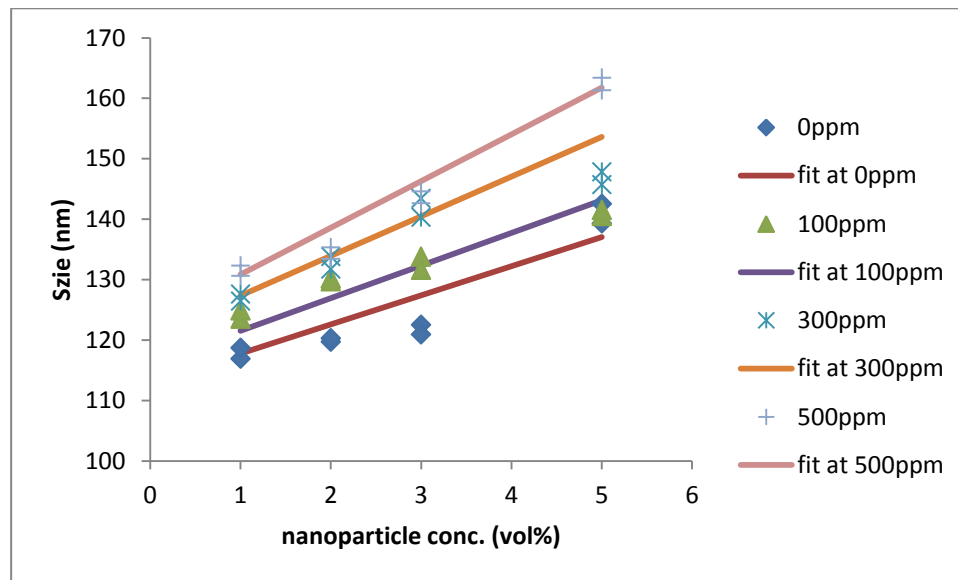


Figure 5.1: Size of nanoparticle agglomerate as a function of nanoparticle concentration at different salt concentrations at pH 9.

From figure 5.2, the relationship of size of nanoparticle agglomerate as function of nanoparticles volume fraction at pH 7; the results show that the size of nanoparticle agglomerate increases with an increase in alumina nanoparticle concentration. Also, it can be observed that adding NaCl salt causes an increase in size of nanoparticle agglomerate, which is clear at any volume fraction of alumina. It is a sign that the salt causes an agglomeration of the nanoparticles. The size of nanoparticle agglomerate at the same concentration of nanoparticle increases with an increase in the salt concentration.

The next step was changing the pH value; different pH values were used besides 7, which are 9, 5 and 3.

They all share the same approach, where the size of nanoparticle agglomerate increases with an increase in nanoparticle concentration. Also the salt has the same effect on the size of nanoparticle agglomerate, where the size of nanoparticle agglomerate grows at the same nanoparticle concentration when salt was added for each different pH. Even though it was observed that the size of nanoparticle agglomerate was smaller at a pH of 3 compared to the result for other pH values that were used in this study, especially at 0 ppm.

Figure 5.1 shows the relationship of size of nanoparticle agglomerate as a function of nanoparticle concentration; it also shows different salt concentrations at different pH values. The line and points of 0 ppm is the lowest one (the smallest size of nanoparticle agglomerate is at 0 ppm) and the other are beyond that as a result of the presence of NaCl.

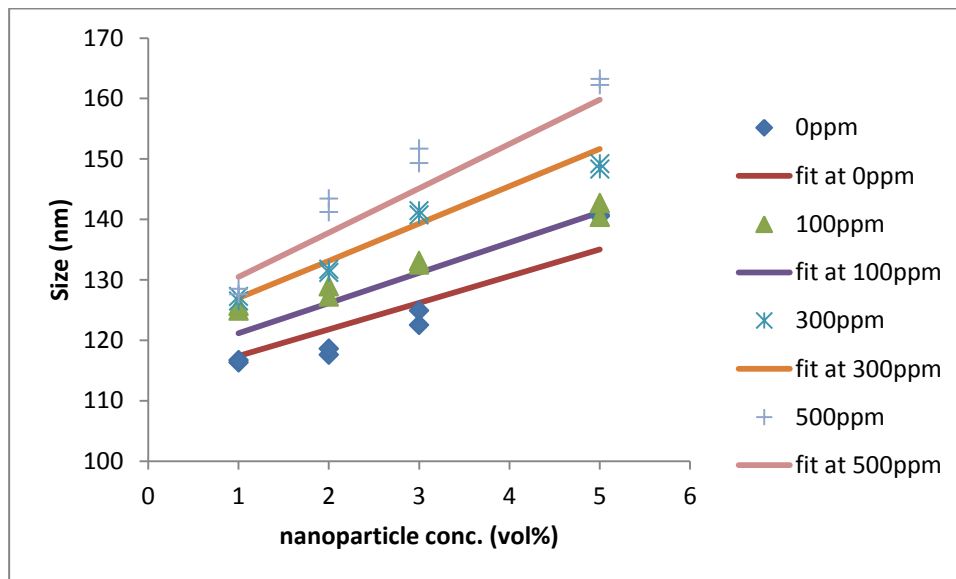


Figure 5.2: Size of nanoparticle agglomerate as a function of nanoparticle concentration at different salt concentrations at pH 7.

Moreover, the relationship between the size of nanoparticle agglomerate and nanoparticle concentration regardless to salt is the same, which it is a positive relationship. In other words, the size of nanoparticle agglomerate gets bigger with an increase of nanoparticle volume fraction. The smallest size was 110 nm at a pH of 3 when no salt was added.

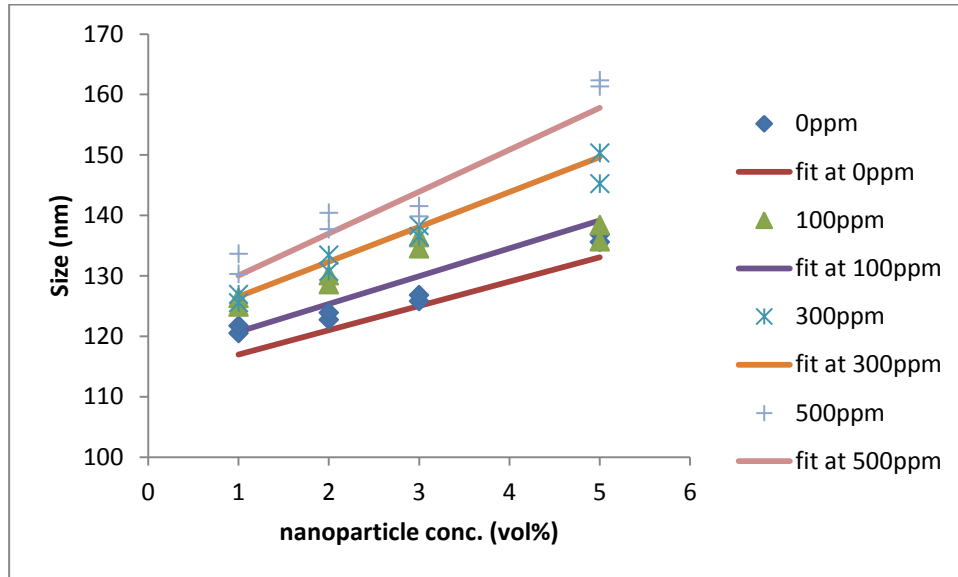


Figure 5.3: Size of nanoparticle agglomerate as a function of nanoparticle concentration at different salt concentrations at pH 5.

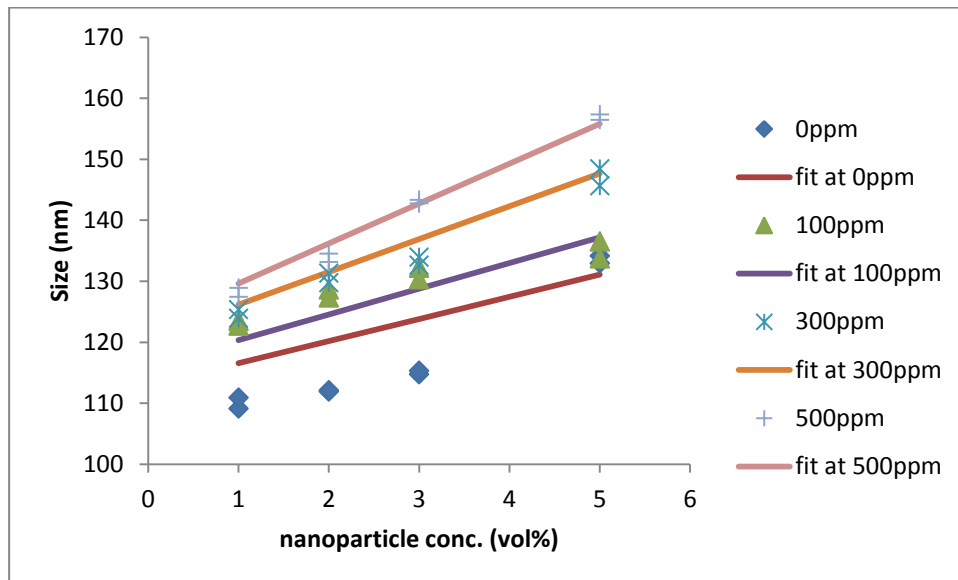


Figure 5.4: Size of nanoparticle agglomerate as a function of nanoparticle concentration at different salt concentrations at pH 3.

5.1.2 Size as a Function of Nanoparticle Concentration for pH Values at Different salt Concentrations

Figures 5.5, 5.6, 5.7 and 5.8 illustrate the effect of pH at different nanoparticle concentrations, with each figure depicting different concentrations of salt (0, 100, 300 and 500 ppm). In Figure 5.5, because there is no added salt, there is no salt effect; thus, the only variable besides nanoparticle concentration is pH. This figure shows the relationship of size of nanoparticle agglomerate as a function of the volume fraction of alumina at different pH values; 9, 7, 5 and 3. The results show that the size of nanoparticle agglomerate is greater at 5, 7 and 9 than at 3, as can be seen in Figure 5.5. Therefore, the size of nanoparticle agglomerate of nanoparticles is smallest at all concentrations of nanoparticles in the absence of salt in base fluid. Moreover, there is an increase in size of nanoparticle agglomerate with the increasing volume fraction of nanoparticle concentration. From that, the effect of pH at different nanoparticles concentration can be observed without the addition of NaCl salt at this point

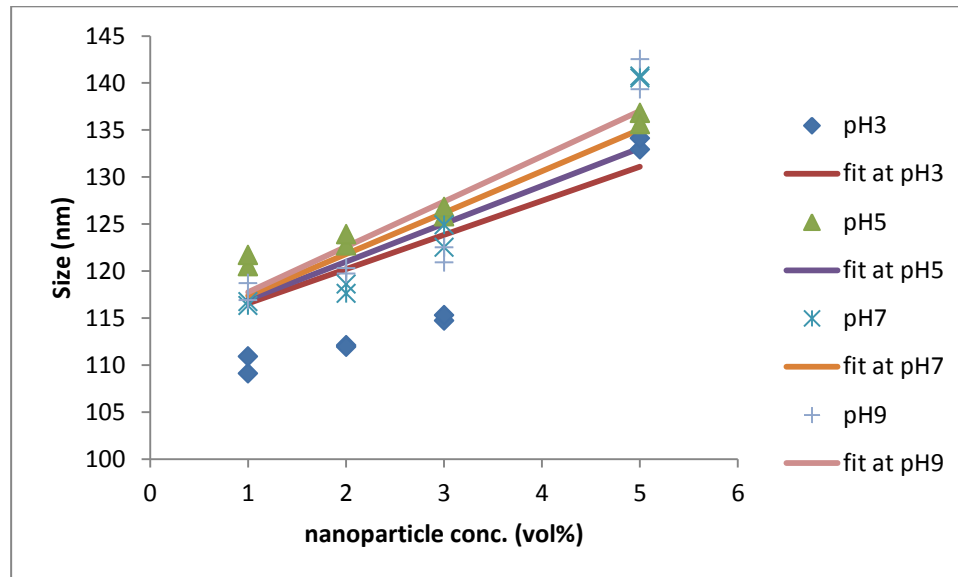


Figure 5.5: Size of nanoparticle agglomerate as a function of nanoparticle concentration at different pH values at 0 ppm

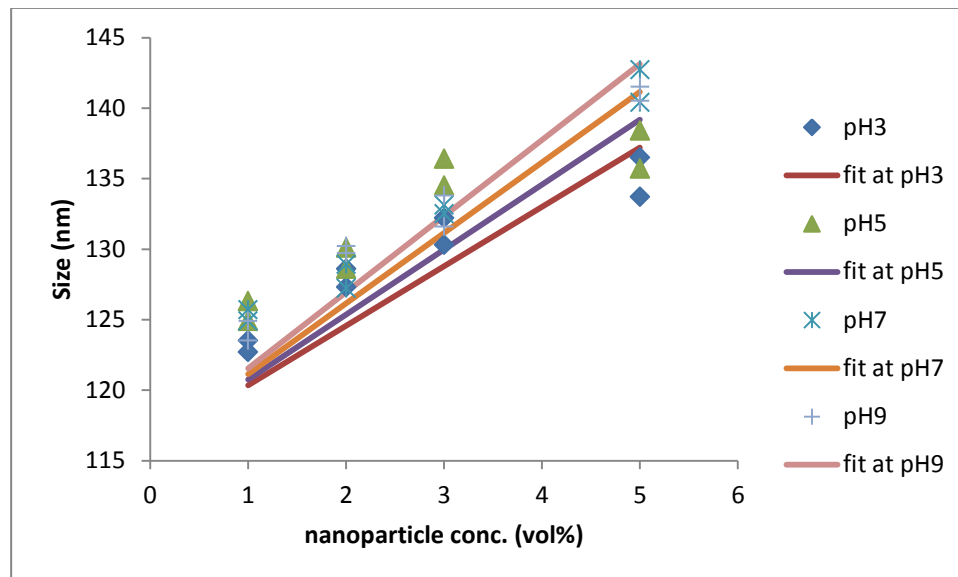


Figure 5.6: Size of nanoparticle agglomerate as a function of nanoparticle concentration at different pH values of 100 ppm

Figures 5.6, 5.7, and 5.8 show size of nanoparticle agglomerate as a function of alumina nanoparticle concentration in the presence of salt, with each line representing different pH values. From this, we can see there is no highly significant effect of pH in the presence of NaCl. Moreover, the effect of nanoparticle concentration is significant on the size of nanoparticle agglomerate. However, the only effect of pH was at zero salt where the size of nanoparticle agglomerate was noticeable smallest at pH 3, it was around 110nm at 1 vol % and 112 nm at 2 vol % of nanoparticle concentration. The only apparent reason, that the amount of acid was added to base fluid for changing the pH was caused increases in ions. The ions of hydrogen may have an impact on the stability of the solution, as the salts have a negative effect on the size of nanoparticle agglomerate.

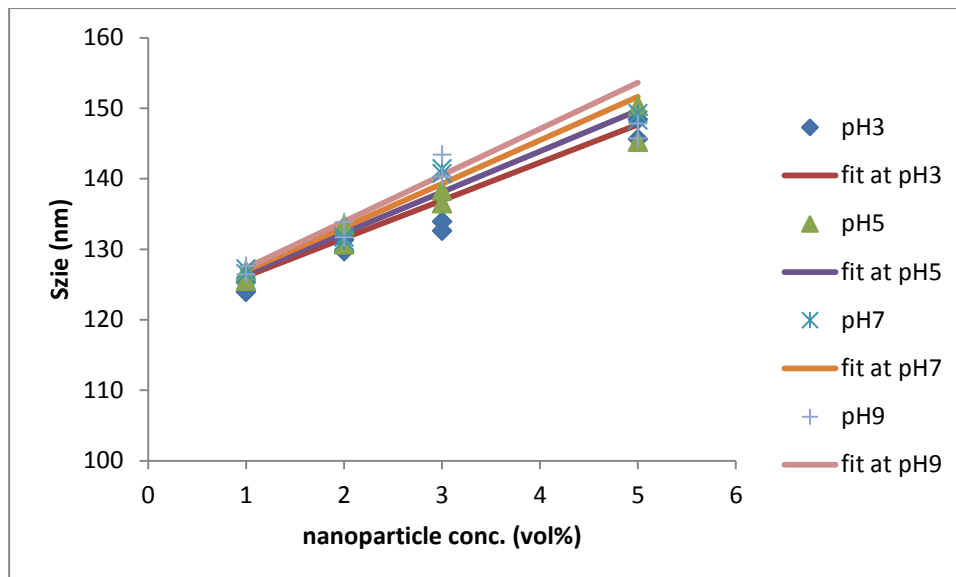


Figure 5.7: Size of nanoparticle agglomerate as function of nanoparticle concentration at different pH values at 300 ppm

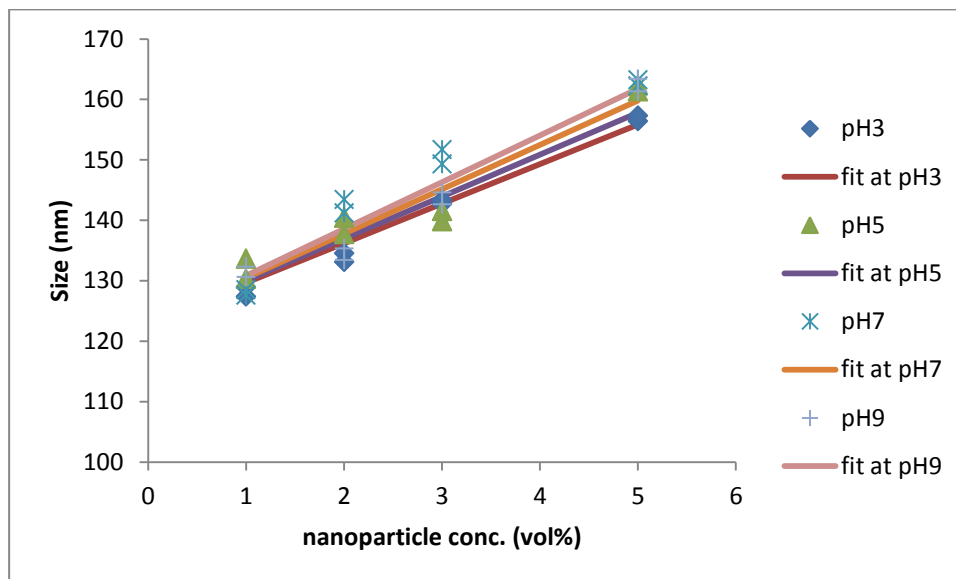


Figure 5.8: Size of nanoparticle agglomerate as a function of nanoparticle concentration at different pH values at 500 ppm

5.1.3 Size as a Function of Salt Concentration for pH Values at Different Nanoparticle Concentrations

Figures 5.9, 5.10, 5.11, and 5.12 below show the relationship of size of nanoparticle agglomerate as a function of salt concentration at different values of pH (3, 5, 7 and 9). Each figure represents one concentration of nanoparticles at 1, 2, 3 and 5%. From the figures, we can see there is no linear relationship between the size of nanoparticle agglomerate and NaCl salt at any pH values used.

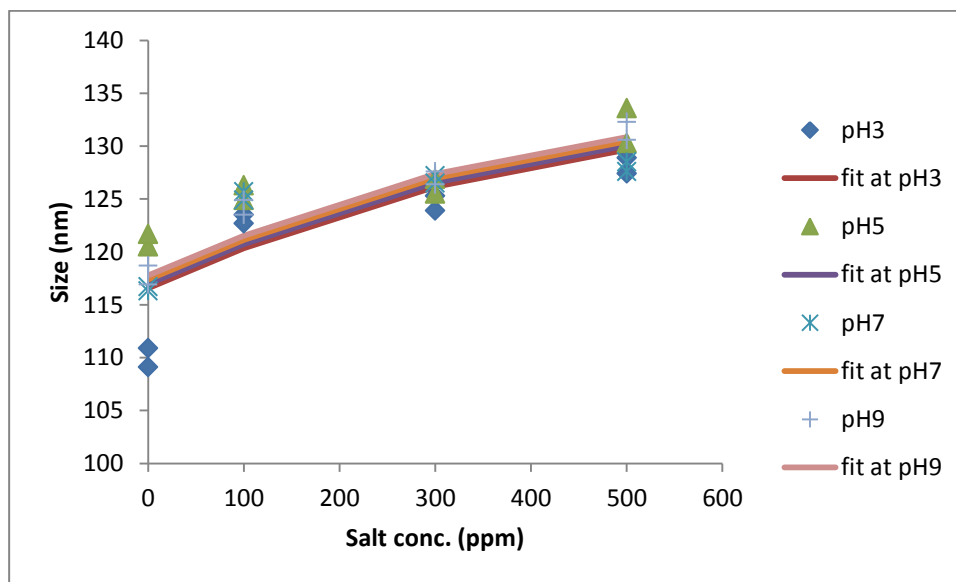


Figure 5.9: Size of nanoparticle agglomerate as a function of NaCl concentration at different pH values at 1% of nanoparticles

Figure 5.9 shows a high effect of salt on the size of nanoparticle agglomerate; especially at pH 3 and 0 ppm salt concentration, the size of nanoparticle agglomerate increases rapidly. This effect diminishes between 100 ppm and 500 ppm for pH 3. However, for other pH values the changing in size of nanoparticle agglomerate is not significant between 0 ppm to 100 ppm as was done for pH 3. The growth of size of nanoparticle agglomerate as results of effect of salt is clear in this figure.

It was noticed that the size of nanoparticle agglomerate at 0 ppm for pH 3 was the smallest one at any concentration of salt or different volume fraction of nanoparticles.

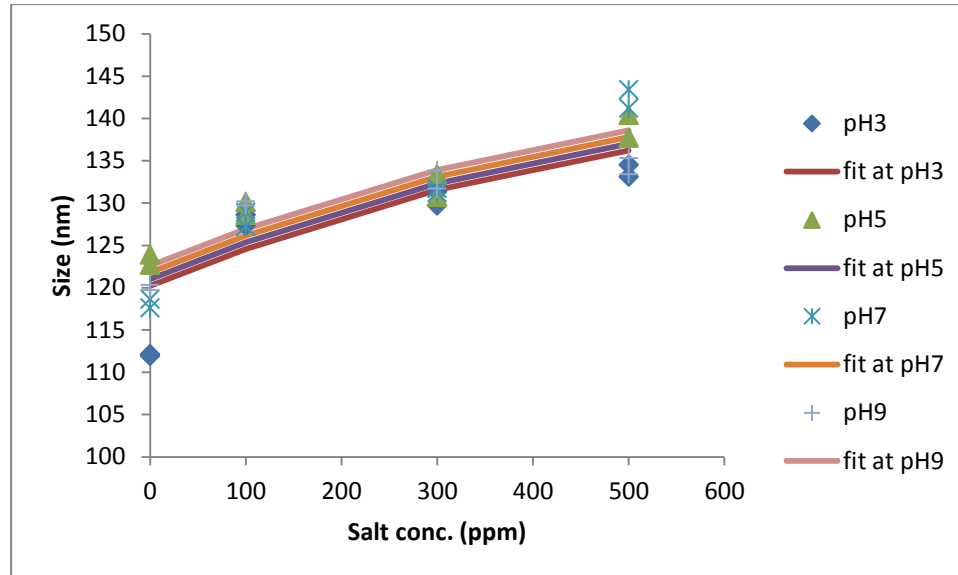


Figure 5.10: Size of nanoparticle agglomerate as a function of NaCl concentration at different pH values at 2% of nanoparticles

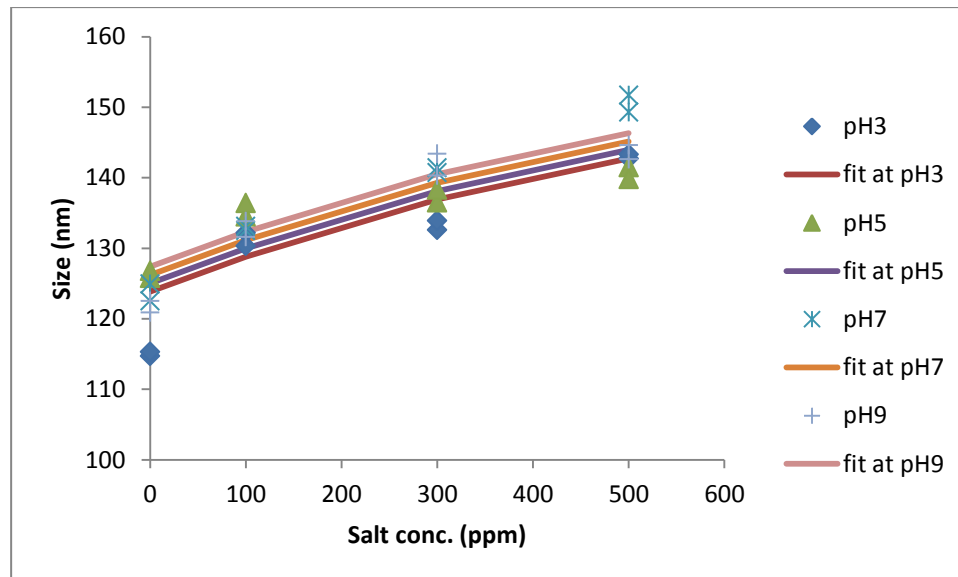


Figure 5.11: Size of nanoparticle agglomerate as a function of NaCl concentration at different pH values at 3% of nanoparticles

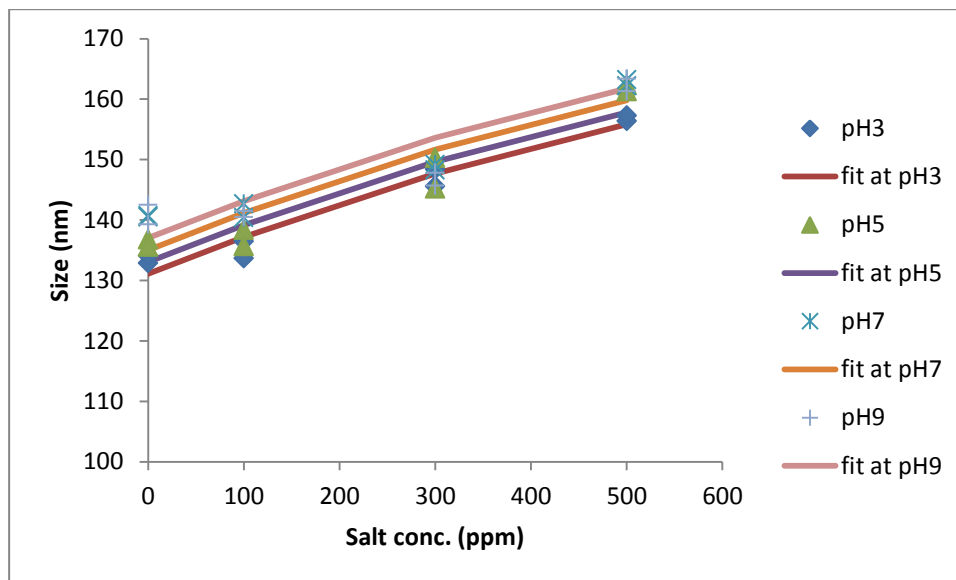


Figure 5.12: Size of nanoparticle agglomerate as a function of NaCl concentration at different pH values at 5% of nanoparticles

The size of nanoparticle agglomerate increases with increase in volume fraction of nanoparticles, where the size of nanoparticle agglomerate is increased dramatically as concentration of nanoparticles is increased in different previous figures.

5.1.4 Size as a Function of pH for Different Salt Concentrations at Different Nanoparticle Concentrations

Figures 5.13-5.16 show the relationship of size of nanoparticle agglomerate as a function of pH values at different salt concentrations. Each figure represents one nanoparticle concentration. The size of nanoparticle agglomerate at pH 3 is the smallest at 0 ppm while at other salt concentrate are bigger. The Figures 5.13-5.15 show the same trend where the size of nanoparticle agglomerate is a smallest at pH 3 where each figure represents different percentage of nanoparticle. The effect of NaCl salt is stronger than the effect of pH. However, the presence of nanoparticles in Figure 5.16 reduces the difference in size of nanoparticle agglomerate between the salts at 0 and 100 ppm as result of nanoparticles concentration which was 5%.

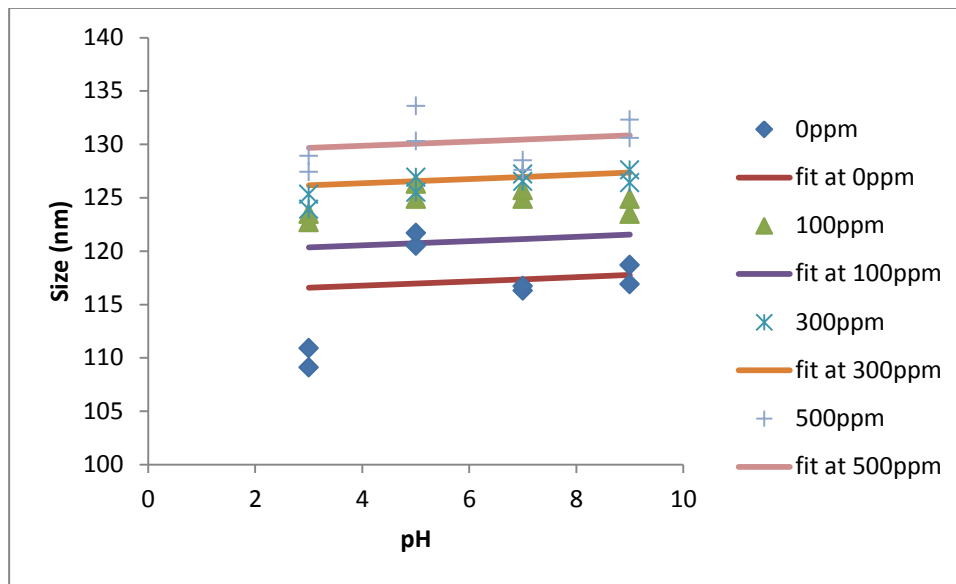


Figure 5.13: Size of nanoparticle agglomerate as a function of pH values for NaCl concentrations at different NaCl concentrations at 1% of nanoparticles

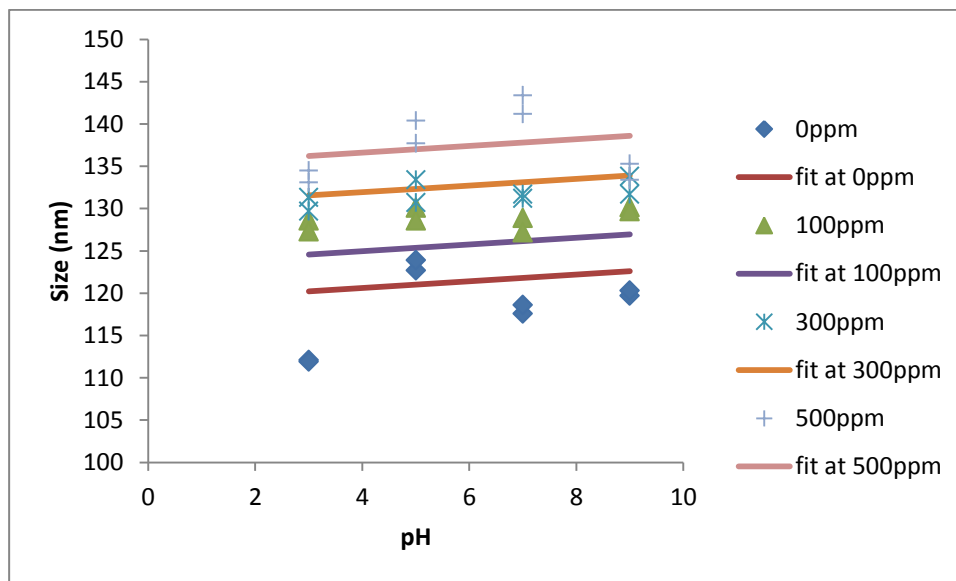


Figure 5.14: Size of nanoparticle agglomerate as a function of pH values of NaCl concentrations for different NaCl concentrations at 2% of nanoparticles.

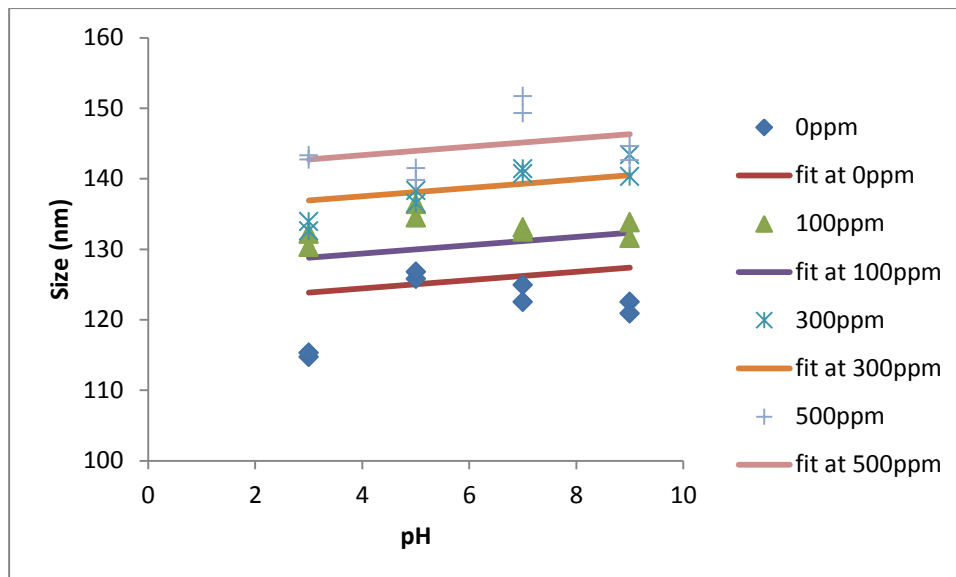


Figure 5.15: Size of nanoparticle agglomerate as a function of pH values of NaCl concentrations for different NaCl concentrations at 3% of nanoparticles.

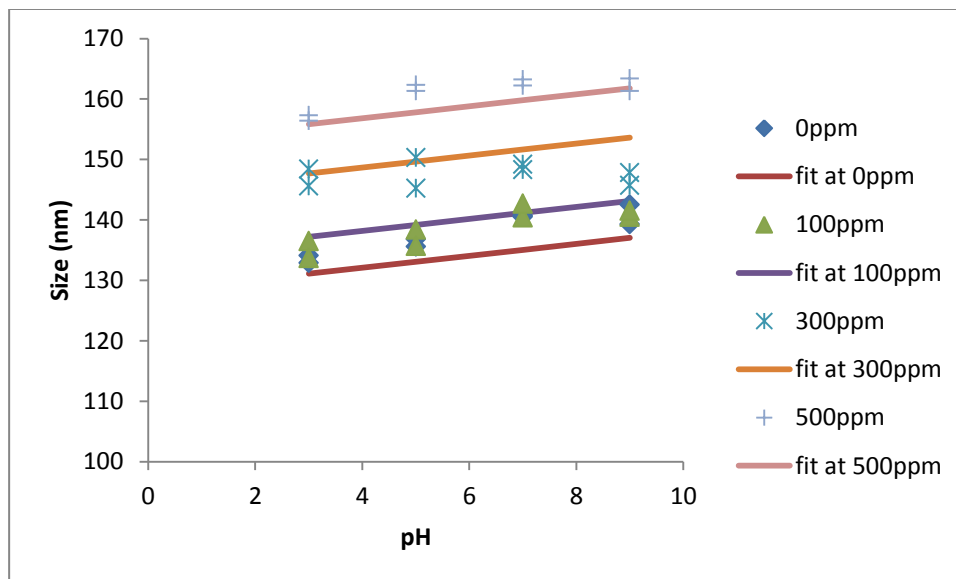


Figure 5.16: Size of nanoparticle agglomerate as a function of pH values of NaCl concentrations for different NaCl concentrations at 5% of nanoparticles

5.2 Electrical Conductivity

5.2.1 Electrical Conductivity as Function of Nanoparticles Concentration for Different Salt Concentration at Different pH Values

Figures 5.17, 5.18, 5.19 and 5.20 represent the data in Tables in appendix. Each figure illustrates various pH values, and each line indicates the predicted electrical conductivity by using the derived model. The points show the measurements electrical conductivity of nanofluid with various salt concentrations. All figures in this subsection show the relationship of electrical conductivity as a function of nanoparticle concentration. Also show the effect of different salt concentrations and different pH values on electrical conductivity of nanofluids. From all figures (5.17-5.20) it can be that the electrical conductivity of nanofluids shows enhancement with an increase in the concentration of nanoparticles. Moreover, electrical conductivity shows greater enhancement in the presence of NaCl salt. The enhancement was 64046% at 5 vol% of alumina nanoparticle for pH 7 for 100ppm, since the enhancement was calculated by getting the difference between the electrical conductivity of a nanofluid and the electrical conductivity of the base fluid ($0.75 \mu\text{S}/\text{cm}$). Even though there also increase in electrical conductivity is present due to the effect of nanoparticles in presence of NaCl salt. For example at any salt concentrations it can be seen the effect of volume fractions of nanoparticles. The electrical conductivity at 500ppm for pH 9 was increase from $1566 \mu\text{S}/\text{cm}$ to $1831 \mu\text{S}/\text{cm}$ at 1 vol % and 5 vol % of alumina nanoparticle concentration, respectively.

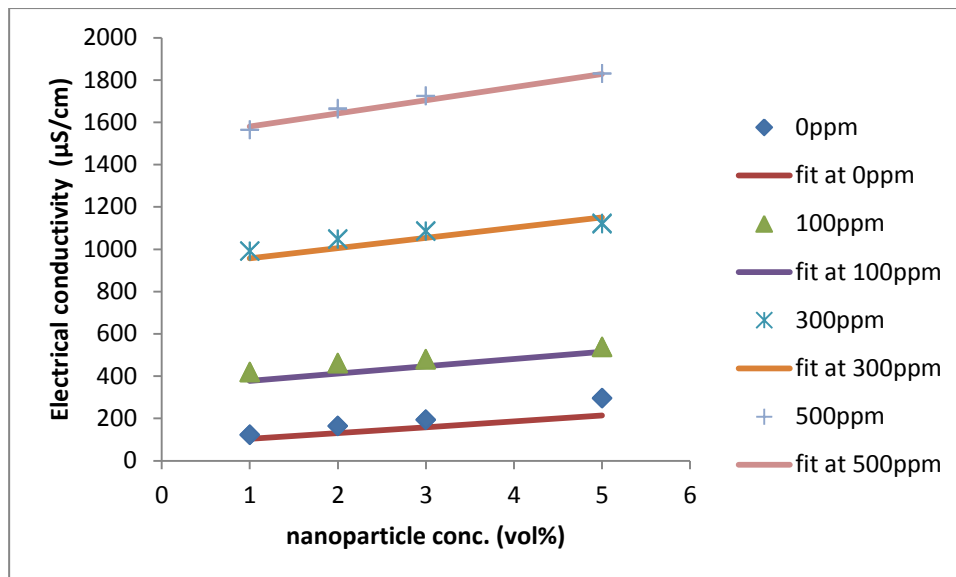


Figure 5.17: Electrical conductivity as a function of nanoparticle concentration at different salt concentrations at pH 9.

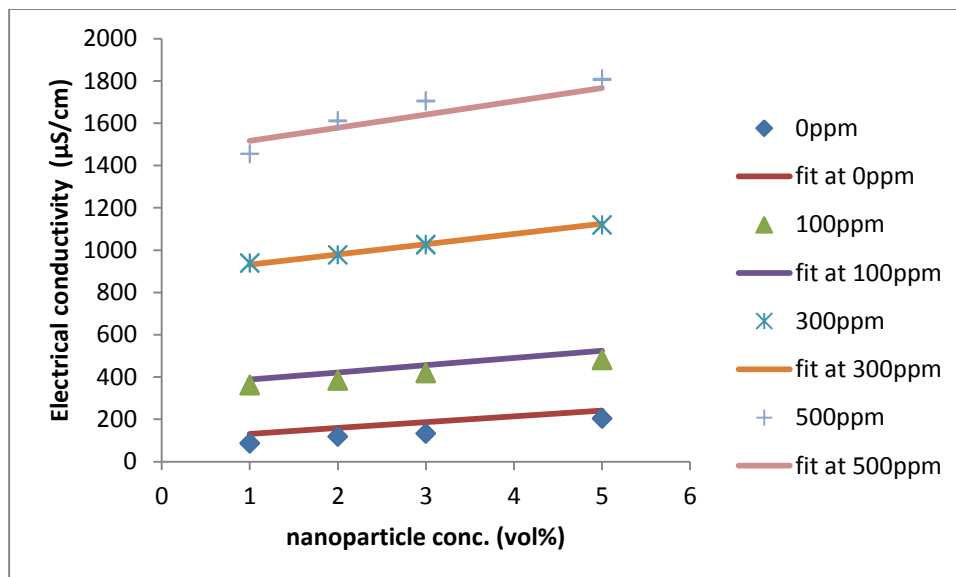


Figure 5.18: Electrical conductivity as a function of nanoparticle concentration at different salt concentrations at pH 7.

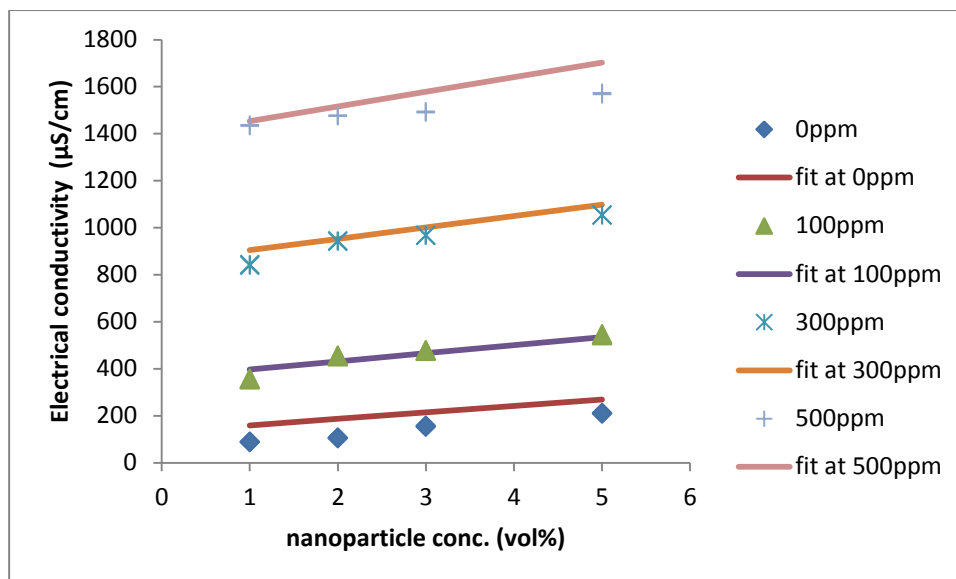


Figure 5.19: Electrical conductivity as a function of nanoparticle concentration at different salt concentrations at pH 5.

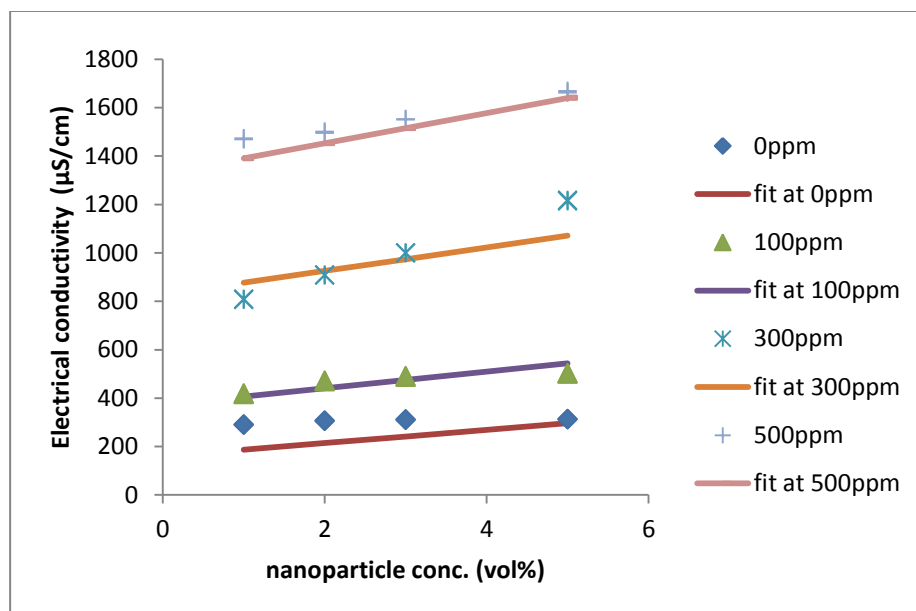


Figure 5.20: Electrical conductivity as a function of nanoparticle concentration at different salt concentrations at pH 3.

In Figure 5.20, the electrical conductivity at 0 ppm at pH 3 is higher than, another salt concentration at a different pH value. The electrical conductivity at pH 3 for 5vol% at

00ppm is 312.7 $\mu\text{S}/\text{cm}$, while the other at same condition less than that. However, it is due to of the amount of HCl that was added to change the pH value.

By comparing the results of this part with the result in the literature review (Ganguly et al., 2009), it can be seen the electrical conductivity increases with an increase in nanoparticle concentrations. The number of studies on the electrical conductivity of nanofluids is still few compared to the number of investigations on the thermal conductivity of nanofluids. The previous published literature has focused on two parameters, the concentration of nanoparticles and temperature. The electrical conductivity in previous study is 60, 160 and 200 $\mu\text{S}/\text{cm}$ at 1, 2 and 3 vol% of alumina nanofluids. In this study, the values was measured at same condition are 87.9, 118.3 and 133.6. $\mu\text{S}/\text{cm}$.

5.2.2 Electrical Conductivity as Function of Nanoparticles Concentration for pH Values at Different Salt Concentration

In Figure 5.21 it can be observed that the electrical conductivity increases with any increase in the nanoparticle concentration. In this figure, there is no salt added; it is just DI water at different pH values. This demonstrates the relationship of electrical conductivity of nanofluid as function of nanoparticle concentration at different pH values. The largest value of electrical conductivity was at pH 3 as a result of the amount of HCl. Here, the model is fitted on all pH values, except pH 3, where it does not share the same approach as other pH values 9, 7 and 5.

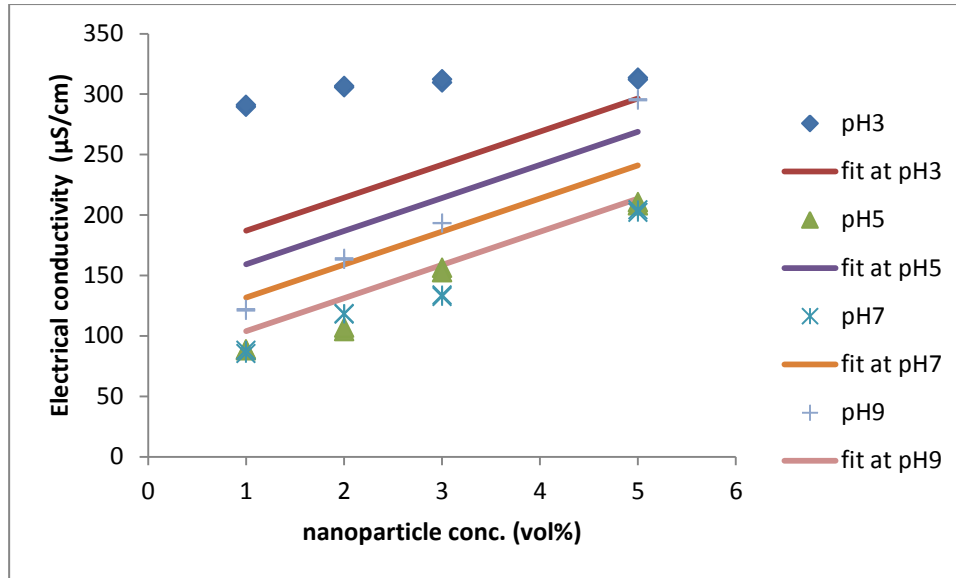


Figure 5.21: Electrical conductivity as a function of nanoparticle concentration at different pH values at 0 ppm

In Figure 5.21, the strange trend is the electrical conductivity of pH 3. There is no effect of nanoparticles concentrations as the rest of the results. The reason for that, the HCl has a high electrical conductivity. since a big amount was added to base fluid. Therefore, adding the nanoparticles to base fluid does not effect on electrical conductivity, where the electrical conductivity of high concentration of nanoparticles at others pH is still less than the smallest concentrations at pH 3. Moreover, in Figure 5.29, it can be seen that the electrical conductivity at pH 3 is high and the following value is for pH 9. This mean the electrical conductivity effect by pH, the amount was added to change pH from 7 to 3 is greater than the amount was added to increase the pH to 9.

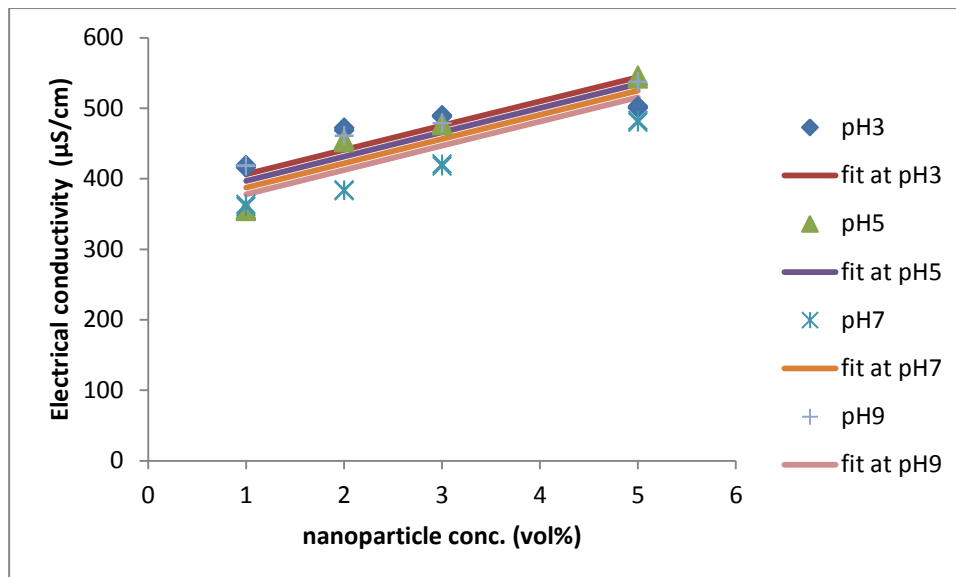


Figure 5.22: Electrical conductivity as a function of nanoparticle concentration at different pH values at 100 ppm.

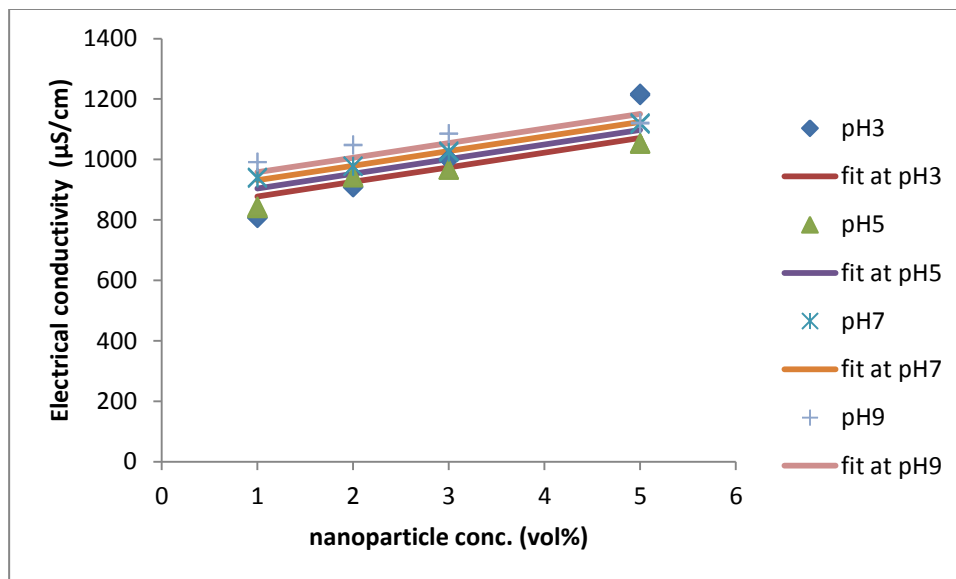


Figure 5.23: Electrical conductivity as a function of nanoparticle concentration at different pH values at 300 ppm.

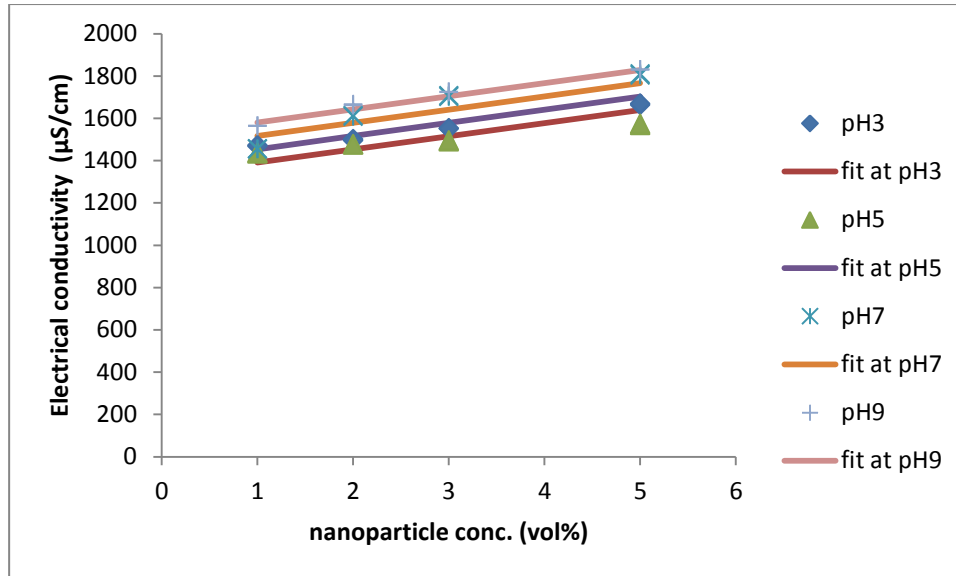


Figure 5.24: Electrical conductivity as a function of nanoparticle concentration at different pH values at 500 ppm.

It can be seen that the model lines deviate with the increase in salt concentrations in figure 5.21. In following figure, where the concentrations of salt are increased, the model lines are increased in dispersions. Moreover, considering the pH effects on electrical conductivity beside the salt concentrations, it can be concluded that the adding of salt concentrations is more effective on a high pH value. The electrical conductivity at pH 3 for 0ppm and 100ppm are different, the electrical conductivity at 100ppm is 502.5 while at 0ppm is 313.5 $\mu\text{S}/\text{cm}$. It can be seen that the electrical conductivity of pH 7 and 9 are increased with an increase in salt concentrations. The highest values of electrical conductivity are 1830 and 1807 $\mu\text{S}/\text{cm}$, these values measured at pH 9 and pH7.

5.2.3 Electrical Conductivity as Function of Salt Concentration for pH Values at Different Nanoparticles Concentration

Figures 5.25-5.28 show the relationship of electrical conductivity as function of salt concentration at different pH values. Each figure represents a different concentration of nanoparticles. It can be concluded that there is great enhancement in the electrical conductivity of nanofluid as a result of using a salty base fluid.

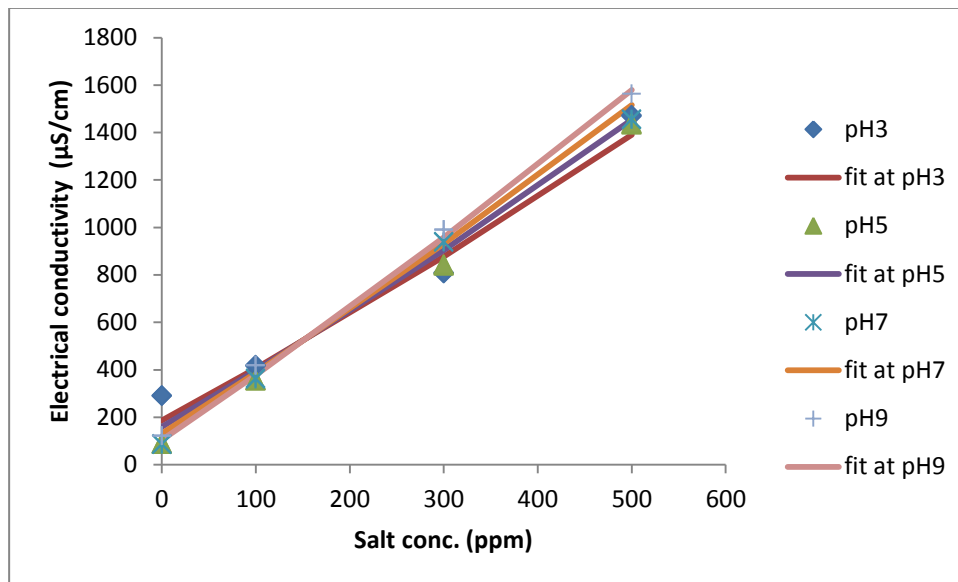


Figure 5.25: Electrical conductivity as a function of NaCl concentration at different pH values at 1% of nanoparticles

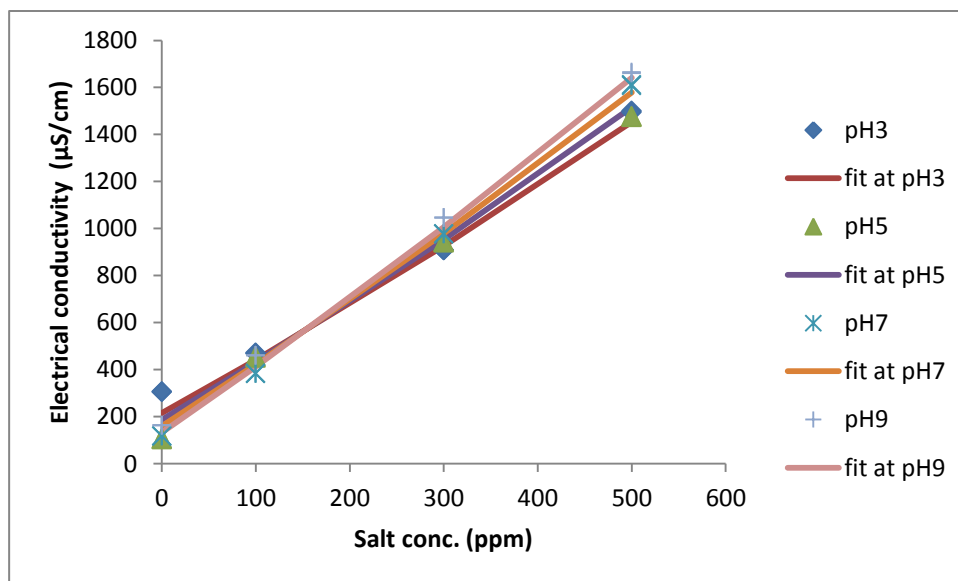


Figure 5.26: Electrical conductivity as a function of NaCl concentration at different pH values at 2% of nanoparticles

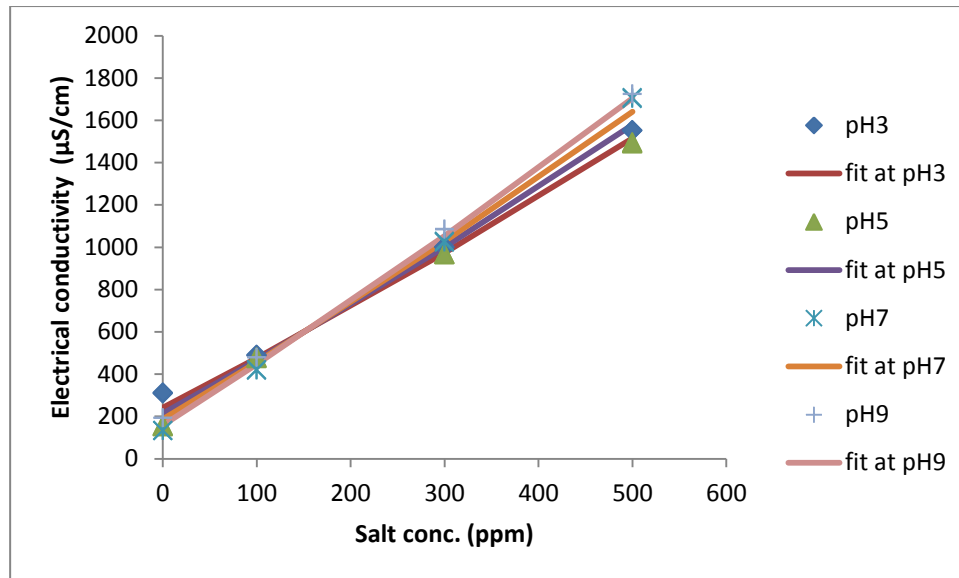


Figure 5.27: Electrical conductivity as a function of NaCl concentration at different pH values at 3% of nanoparticles

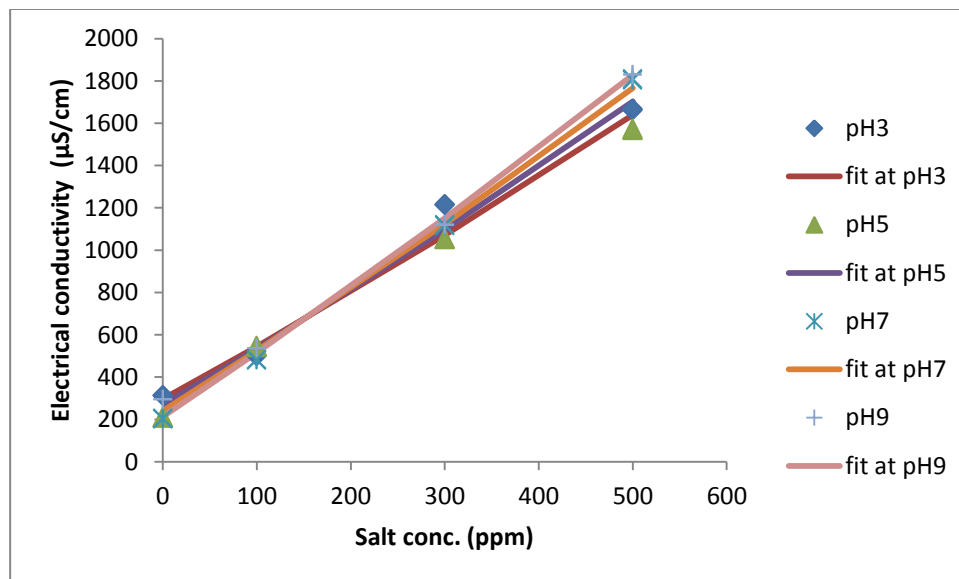


Figure 5.28: Electrical conductivity as a function of NaCl concentration at different pH values at 5% of nanoparticles.

The conclusion of the previous study is that the electrical conductivity of nanofluid was increased with an increase in nanoparticles concentration. The only data it can be

compared with was done by using DI water without any adding of salt. The highest value of electrical conductivity was found at 252 while, in this study, the highest value was found at 312.7 at pH 3 when no salt was added and 5 vol% of alumina nanoparticles. However, the highest value when salt was added was 1807 at pH 7, and the concentration of salt was 500 ppm with 5 vol% of alumina nanoparticles.

5.2.4 Electrical Conductivity as Function of pH for Different Salt Concentration at Different Nanoparticles Concentration

Figures 5.29-5.32 show the relationship between the electrical conductivity of nanofluid and the pH value. The electrical conductivity at pH 3 when there is no salt was added was greater than other pH values for all different nanoparticle concentrations at 0 ppm. However, there is clearly effect of pH on these figures. The effect of pH found different at low and high salt concentration. At high salt concentration 300 and 500ppm the electrical conductivity increases with increase in pH, while at low salt concentration it lightly decreases with increases in pH.

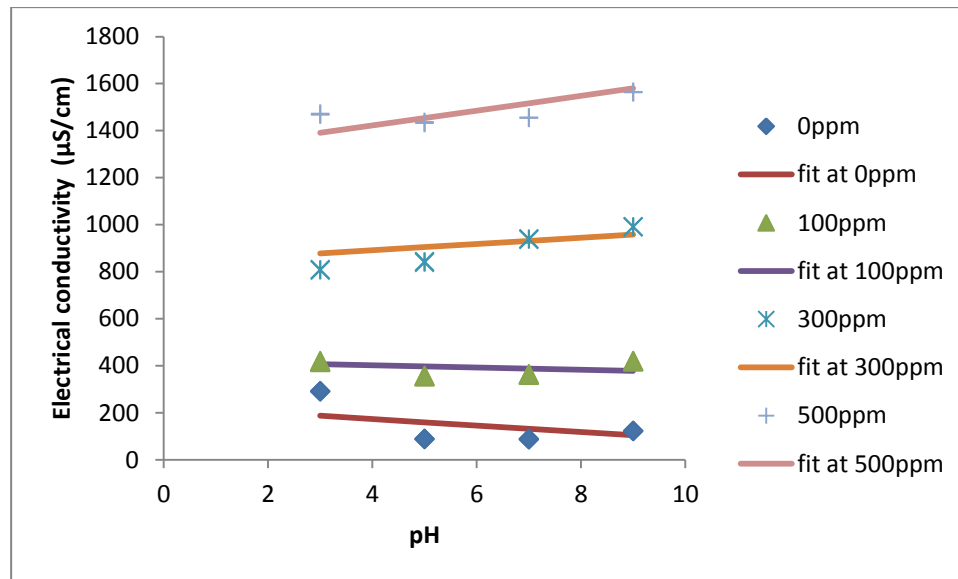


Figure 5.29: Electrical conductivity as a function of pH values for NaCl concentrations at different NaCl concentrations at 1% of nanoparticles

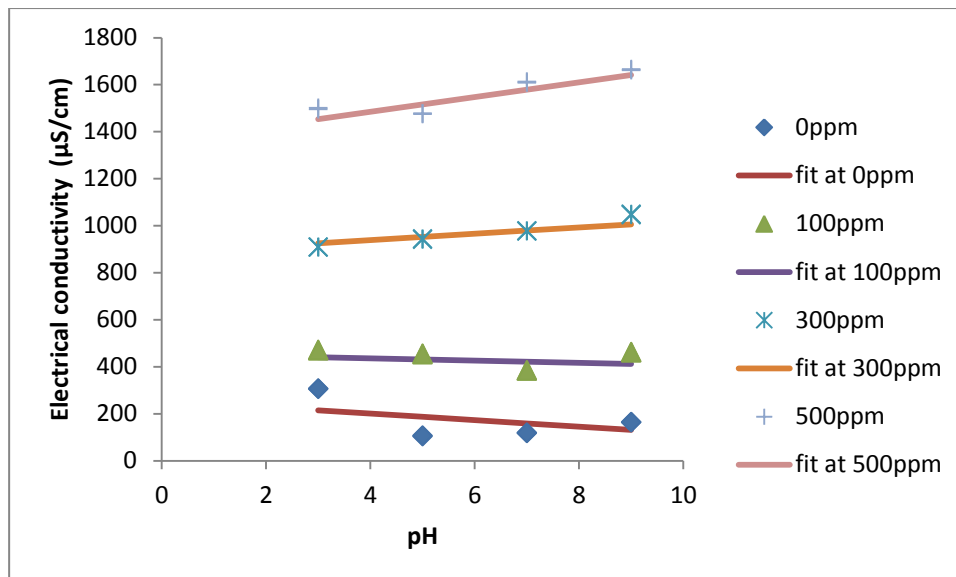


Figure 5.30: Electrical conductivity as a function of pH values for NaCl concentrations at different NaCl concentrations at 2% of nanoparticles

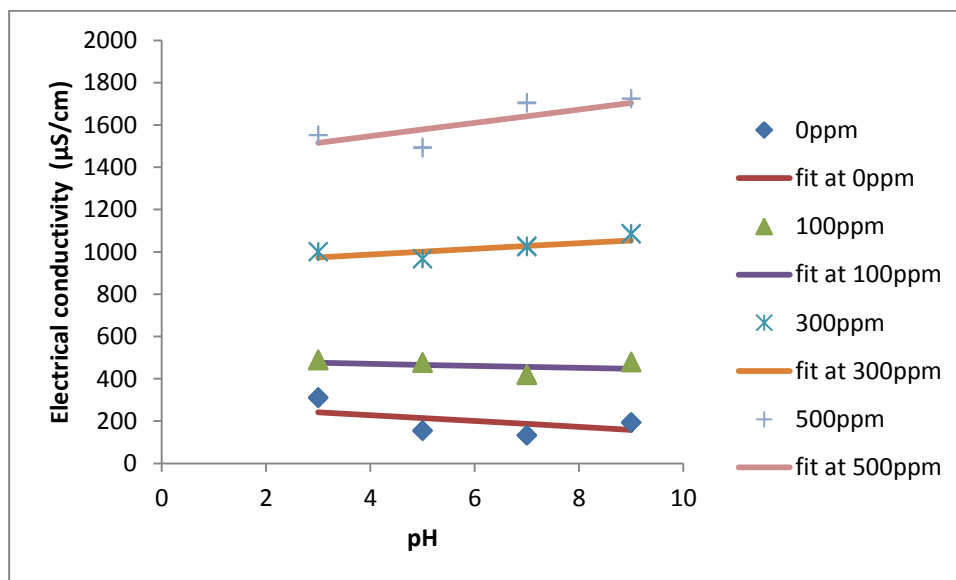


Figure 5.31: Electrical conductivity as a function of pH values for NaCl concentrations at different NaCl concentrations at 3% of nanoparticles.

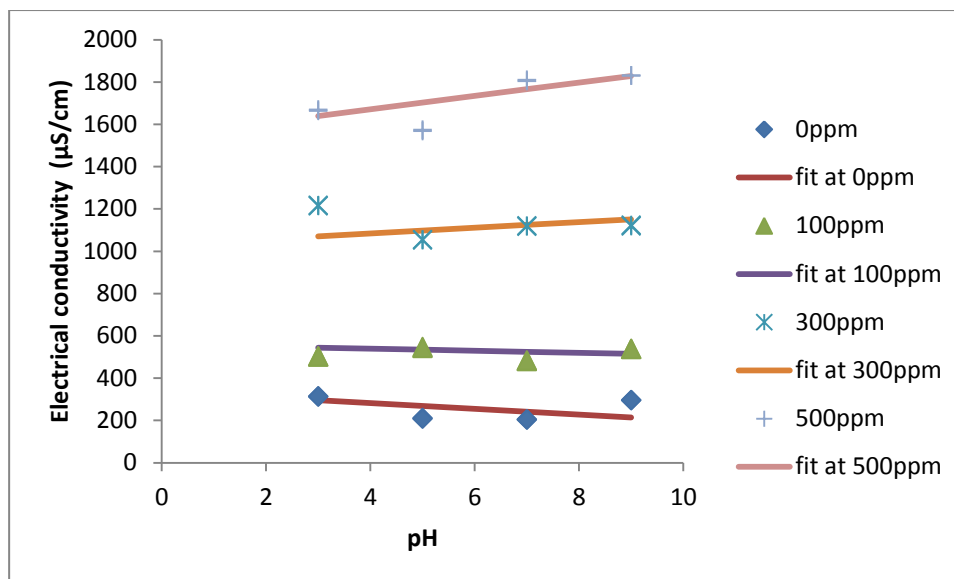


Figure 5.32: Electrical conductivity as a function of pH values for NaCl concentrations at different NaCl concentrations at 5% of nanoparticles.

5.3 The Relationship between Electrical Conductivity and Size of Nanoparticles

In this part, the relationship between electrical conductivity and size of nanoparticle agglomerate discusses since both are impacted by same parameters. The electrical conductivity of alumina and size of alumina nanoparticle agglomerate have effect by volume fraction of alumina nanoparticle, pH and NaCl concentration. Here, trying to determine if the size of nanoparticle agglomerate has an effect on electrical conductivity. Figure 5.33 shows the electrical conductivity as a function of size for different pH values at 100 ppm. In this relationship, it can be seen that the electrical conductivity of nanofluids increases with increase in size of nanoparticle agglomerate. Also, it can see that also in Figure 5.34. The electrical conductivity of nanofluids increases with increase in size of nanoparticle agglomerate. In reality, the size of nanoparticle agglomerate and the electrical conductivity was increased with increase in volume fraction of nanoparticle and salt concentration. The size of nanoparticle agglomerate may affect the electrical conductivity, where the surface area decreases when the nanoparticle agglomerates.

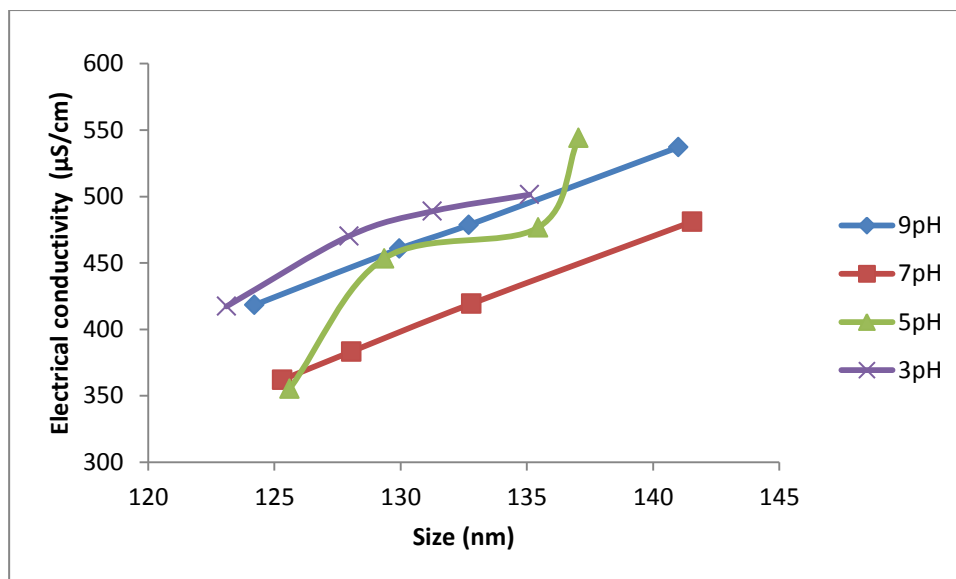


Figure 5.33: The electrical conductivity as a function of size of nanoparticle for different pH values at 100 ppm

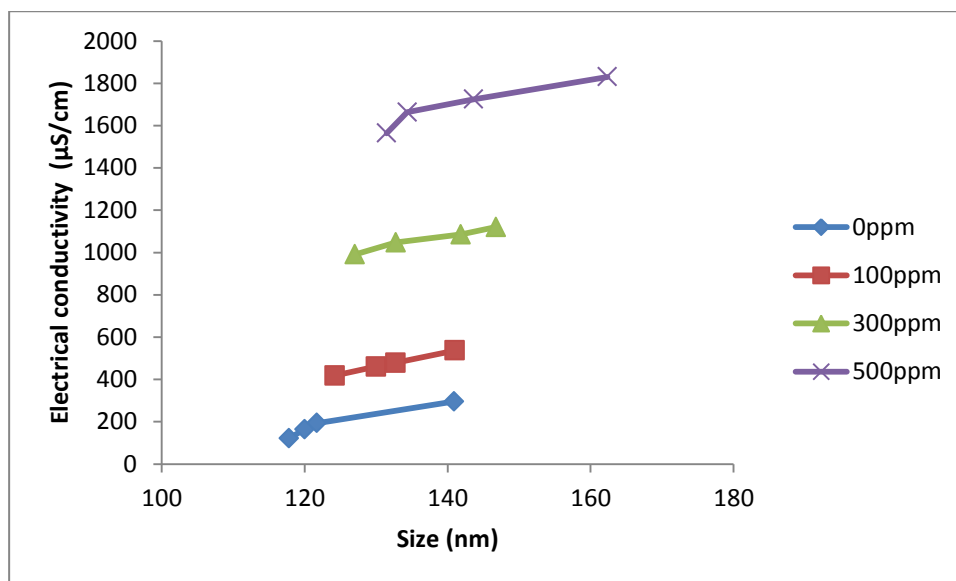


Figure 5.34 : The electrical conductivity as a function of size of nanoparticle for different salt concentration at pH 9.

5.4 Zeta Potential

The zeta potential was measured at 1 vol% of alumina nanoparticles. Various concentrations of NaCl were used. The zeta potential was measured as a function of pH values as in Figure 5.35. The results demonstrated that zeta potential effect by pH, where zeta potential was high at 3 pH while was decreased with an increase in pH until around 7

pH and then it increased at 9 pH, even though it is still less than 3 pH. This corresponds with previous results, where the smallest size was found at 3 pH. Moreover, the charge of zeta potential was found to be positive. However, the zeta potential was increased with an increase in NaCl concentration, which does not match with the result in the size part. In other words, a high zeta potential means high stability and less agglomeration, but in the case of the increasing of NaCl it was expected that zeta potential was decreased with an increase in NaCl loading.

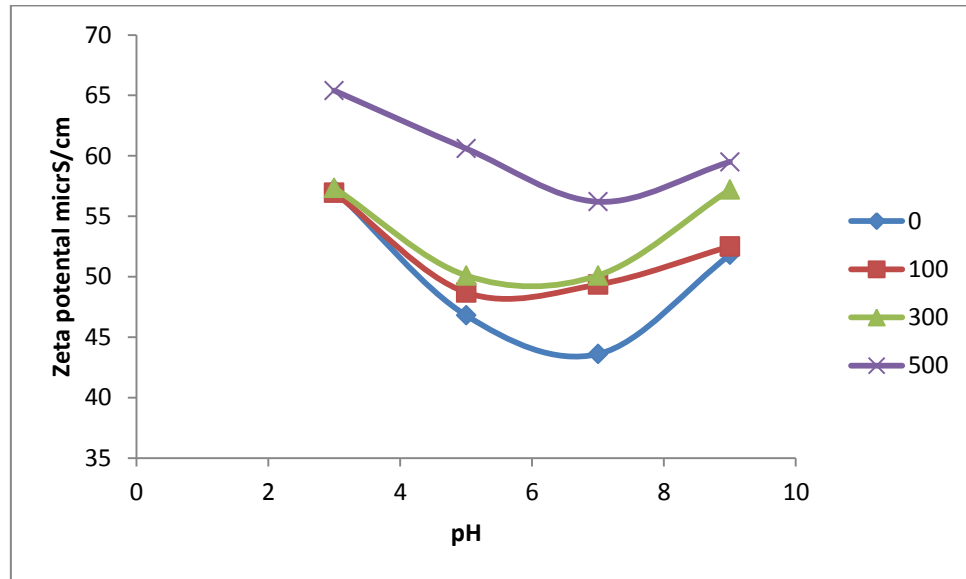


Figure 5.35: Zeta potential as a function of pH values for NaCl concentrations at 1% of nanoparticles

There is not much data that can be compared with the results of this work the only study which has measured the zeta potential of alumina nanofluids was done by Wang et al., (2009). Their results show that the charge zeta potential was negative while the neutral charge of alumina is positive; the reason for changing the charge is because a surfactant was added during the preparation of the nanofluids, which was not added here. Also, the value of the zeta potential is not the same; it could be affected by the surfactant.

Chapter 6 Conclusion and Future Work

6.1 Conclusion

The size and electrical conductivity of alumina nanoparticles were measured at different conditions. The primary parameters were pH, nanoparticle concentration and NaCl concentration. Below is a listing of some of the significant conclusions

- The size of the dispersed nanoparticles increased with an increase in alumina nanoparticle concentration for all NaCl concentrations at any pH values. However, the size of nanoparticles increased more in the presence of NaCl at all pH values. Interestingly, the smallest size was found at pH 3 when no salt was added.
- The electrical conductivity increased with an increase in volume fraction of alumina nanoparticles. Also, the electrical conductivity increased rapidly with increase in NaCl concentration. The electrical conductivity at pH 3 at zero salt was very high compared to another pH values.
- The zeta potential was found to be high at low and high pH values in this study 3 and 9. Also, the zeta potential increased with an increase in salt concentration. The charge was found positive charge as natural alumina charge.

6.2 Future work

Some recommendations for further investigation are listed below:

- The effect of temperature on electrical conductivity can be measured at different ranges. Also, other properties can be measured like thermal conductivity, viscosity and diffusivity.
- The electrical conductivity can be measured for different nanoparticles. Also, the effect of size on electrical conductivity could be studied by using one type of nanoparticles with a different size. Moreover, a different type of fluid with different NaCl concentrations can be using as base fluid and measure the electrical conductivity.
- The effect of time on agglomeration, the size, electrical conductivity and zeta potential are measured for several successive days and comparing the results.

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Appendix A



Figure A.1: pH/electrical conductivity

Table A.1: Specifications of Conductivity Meter PC 2700

Conductivity	Specifications
Range	0.050 μ S to 500.0 mS
Resolution	0.01 / 0.1 μ S; 0.001 / 0.01 / 0.1mS
Accuracy	\pm 1% full scale
Cal. Points	Automatic (4 points); Maximum 1 per range Manual (5 points); Maximum 1 per range
Cell Constant	0.010 to 10.000
Coefficient (Per $^{\circ}$ C)	Linear & Pure; 0.000 to 10.000%
Normalization	15.0 to 30.0 $^{\circ}$ C / 59.0 to 86.0 $^{\circ}$ F
Compensation	Automatic with supplied cell or Manual
Temp Compensation	0.0 to 100 $^{\circ}$ C / 32.0 to 212.0 $^{\circ}$ F (0.0 to 80 $^{\circ}$ C / 32.0 to 176.0 $^{\circ}$ F with supplied cell)

Table A.2: Specifications of pH Meter PC 2700

pH	Specifications
Range	-2.000 to 20.000 pH
Resolution	0.1 / 0.01 / 0.001 pH
Accuracy	±0.002 pH + 1 LSD
Cal. Points	Up to 6 preset or 5 custom
Buffer Sets	USA, NIST, DIN, User1, User2, Custom
Slope Display	Yes (with offset)
Temp Compensation	Automatic or Manual (0 to 100 °C / 32 to 212 °F)
Temp Range (Meter)	0.0 to 100.0 °C / 32.0 to 212.0 °F
Inputs	BNC, ATC, Reference (Half-cell)

Table A.3: Values of sizes at different nanoparticle and salt concentrations at pH 9.

Fraction (%)	9pH							
	0 ppm				300 ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
1	116.9	118.7	1.272792	117.8	126.4	127.6	0.848528	127
2	119.7	120.3	0.424264	120	131.7	133.8	1.484924	132.75
3	122.5	120.9	1.131371	121.7	140.3	143.4	2.192031	141.85
5	139.3	142.5	2.262742	140.9	147.8	145.7	1.484924	146.75
Fraction (%)	100 ppm				500 ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
	1	123.5	124.9	0.989949	124.2	130.6	132.3	1.202082
2	130.2	129.7	0.353553	129.95	133.4	135.3	1.343503	134.35
3	133.8	131.6	1.555635	132.7	142.6	144.6	1.414214	143.6
5	140.5	141.5	0.707107	141	163.4	161.3	1.484924	162.35

Table A.4: Values of sizes at different nanoparticle and salt concentrations at pH 7.

fraction	7pH							
	0 ppm				300 ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
1	116.3	116.7	0.282843	116.5	127.2	126.5	0.494975	126.85
2	117.6	118.6	0.707107	118.1	131.2	131.7	0.353553	131.45
3	122.5	124.9	1.697056	123.7	141.4	140.7	0.494975	141.05
5	140.5	140.7	0.141421	140.6	149.2	148.3	0.636396	148.75
fraction	100 ppm				500 ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
	1	124.9	125.7	0.565685	125.3	127.6	128.5	0.636396
2	128.9	127.2	1.202082	128.05	141.2	143.4	1.555635	142.3
3	133.1	132.5	0.424264	132.8	149.3	151.7	1.697056	150.5
5	140.4	142.7	1.626346	141.55	163.2	162.2	0.707107	162.7

Table A.5: Values of sizes at different nanoparticle and salt concentrations at pH 5.

fraction	5pH							
	0 ppm				300 ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
1	120.5	121.7	0.848528	121.1	126.9	125.5	0.989949	126.2
2	122.7	123.9	0.848528	123.3	133.4	130.7	1.909188	132.05
3	125.8	126.8	0.707107	126.3	136.5	138.3	1.272792	137.4
5	136.8	135.6	0.848528	136.2	150.3	145.2	3.606245	147.75
fraction	100 ppm				500 ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
	1	124.9	126.3	0.989949	125.6	130.3	133.6	2.333452
2	130.1	128.6	1.06066	129.35	140.4	137.7	1.909188	139.05
3	134.5	136.4	1.343503	135.45	141.5	139.8	1.202082	140.65
5	138.4	135.7	1.909188	137.05	162.3	161.3	0.707107	161.8

Table A.6: Values of sizes at different nanoparticle and salt concentrations at pH 3.

fraction	3pH							
	0 ppm				300 ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
1	109.1	110.9	1.272792	110	123.9	125.3	0.989949	124.6
2	112.1	111.9	0.141421	112	131.3	129.7	1.131371	130.5
3	114.7	115.3	0.424264	115	132.6	133.9	0.919239	133.25
5	132.9	134.1	0.848528	133.5	148.4	145.6	1.979899	147
fraction	100 ppm				500 ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
	1	123.5	122.7	0.565685	123.1	127.4	128.9	1.06066
2	128.6	127.3	0.919239	127.95	134.5	133.1	0.989949	133.8
3	132.2	130.3	1.343503	131.25	142.7	143.3	0.424264	143
5	136.5	133.7	1.979899	135.1	156.4	157.3	0.636396	156.85

Table A.7: Values of Electrical conductivity at different nanoparticle and salt concentrations at pH 9.

fraction	9pH							
	0ppm				300ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
1	122	120.8	0.848528	121.4	990.1	991.3	0.848528	990.7
2	162.9	164.1	0.848528	163.5	1048	1046	1.414214	1047
3	192.9	193.3	0.282843	193.1	1086	1084	1.414214	1085
5	294.8	295.8	0.707107	295.3	1118	1122	2.828427	1120
fraction	100ppm				500ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
	1	418.9	417.7	0.848528	418.3	1562	1566	2.828427
2	461.1	460.3	0.565685	460.7	1660	1666	4.242641	1663
3	478.9	478.3	0.424264	478.6	1727	1721	4.242641	1724
5	536.8	537.4	0.424264	537.1	1829	1831	1.414214	1830

Table A.8: Values of Electrical conductivity at different nanoparticle and salt concentrations at pH 7.

fraction	7pH							
	0ppm				300ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
1	85.3	87.9	1.838478	86.6	940.1	937.1	2.12132	938.6
2	118.3	117.7	0.424264	118	977.4	976.4	0.707107	976.9
3	132.4	133.6	0.848528	133	1023	1027	2.828427	1025
5	202.1	204.1	1.414214	203.1	1120	1116	2.828427	1118
fraction	100ppm				500ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
	1	363.4	360.6	1.979899	362	1456	1454	1.414214
2	383.9	382.7	0.848528	383.3	1608	1612	2.828427	1610
3	420.9	417.7	2.262742	419.3	1707	1702	2.828427	1704
5	479.8	482.4	1.838478	481.1	1810	1804	4.242641	1807

Table A.9: Values of Electrical conductivity at different nanoparticle and salt concentrations at pH 5.

fraction	5pH							
	0ppm				300ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
1	87.8	88.7	0.636396	88.25	838.4	842.6	2.969848	840.5
2	103.8	106.8	2.12132	105.3	943.8	940.6	2.262742	942.2
3	156.2	152.4	2.687006	154.3	967.2	966.2	0.707107	966.7
5	210.5	207.9	1.838478	209.2	1054	1052	1.414214	1053
fraction	100ppm				500ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
	1	353.9	356.5	1.838478	355.2	1433	1437	2.828427
2	455.3	451.5	2.687006	453.4	1478	1475	1.414214	1476
3	477.9	475.5	1.697056	476.7	1489	1494	2.828427	1492
5	545.9	542.1	2.687006	544	1567	1573	4.242641	1570

Table A.10: Values of Electrical conductivity at different nanoparticle and salt concentrations at pH 3.

fraction	3pH							
	0ppm				300ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
1	289.4	291	1.131371	290.2	805.9	808.5	1.838478	807.2
2	305.5	306.7	0.848528	306.1	907.9	908.7	0.565685	908.3
3	309.4	312.2	1.979899	310.8	1000	999.4	0.424264	999.7
5	313.5	311.9	1.131371	312.7	1213	1217	2.828427	1215
fraction	100ppm				500ppm			
	Test 1	Test 2	STDEV	aver	Test 1	Test 2	STDEV	aver
	1	415.8	418.8	2.12132	417.3	1472	1468	2.828427
2	468.6	471.8	2.262742	470.2	1501	1495	4.242641	1498
3	487.9	489.9	1.414214	488.9	1550	1552	1.414214	1551
5	500.3	502.5	1.555635	501.4	1662	1666	2.828427	1664

Table A.11 : Specifications of ultrasonic

Generator	Specification
Weight	6.8 kg
Dimensions	203mm × 381 mm × 229 mm
Output voltage	1000 V rms (max.)
Output frequency	20 KHz
Converter	Specification
Weight	900 g
Dimensions	183 mm × 63.5 mm
Materials	Aluminum alloy
Standard horn	Specification
Weight	340 g
Dimensions	136 mm × 13 mm
Materials	Titanium Alloy