THE DISPERSION BEHAVIOUR OF NANOPARTICLES IN ETHANOL-WATER MIXTURE WITH SURFACTANTS

BY

SITI NAJWA BINTI ZAINI

15090

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons.) Chemical

MAY 2014

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

The Dispersion Behaviour of Nanoparticle in Ethanol-Water Mixture with Surfactants

By

Siti Najwa Binti Zaini

15090

A project dissertation submitted to the

Chemical Engineering Programme

Universiti Teknologi PETRONAS

In partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons.)

(CHEMICAL)

Approved by,

____

(Dr. Rajashekhar Pendyala)

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and the acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SITI NAJWA BINTI ZAINI

ABSTRACT

The study on stability of nanofluids is of utmost importance in order to be able to fully utilize its potentials especially the enhanced thermodynamic properties of the nanofluids. Nanofluids stability can be related to the density of charge on the surface of the particles (electrokinetic properties). High surface charge density generates strong repulsive force between particles, and thus, increasing the stability of the suspension due to less agglomeration of particles. One of the highly effective ways to increase the particles surface charge density is by the addition of surface active agents (surfactants) which increases the value of zeta potential of the nanofluid suspension, hence, increasing the repulsive force between the particles.

This study focuses on achieving the stability of nanofluids by the addition of surfactants, which are Sodium Dodecyl Sulfate (SDS) and Triton X-100 (TX-100) into the suspension of Alumina (Al_2O_3) nanoparticles in ethanol-water mixture. Sedimentation studies on the nanofluid suspensions with different concentration of nanoparticles (0.5, 1.0, and 3.0 wt. %) and base fluid (10, 30, 50, 70, 100 wt. % ethanol in water) with and without surfactants are to be carried out to compare the stability of the suspension before and after the addition of surfactants.

ACKNOWLEDGEMENT

بسم الله الرحمن الرحيم

Alhamdulillah, praise be to ALLAH S.W.T for with His guidance and blessings, I am able to complete the final Dissertation Report for May 2014 semester. May peace be upon His servant and Messenger Muhammad and upon his family and companions.

I am glad to express my highest gratitude to my FYP supervisor, Dr. Rajashekhar Pendyala, for his guidance and support in the whole conduction of the project. My utmost special thanks also goes to Mr. Suhaib Umer Ilyas, without whom I might not have been able to even start the project let alone finish it up to this stage. Your guidance and advises throughout the project is very highly appreciated.

I would also like to express my gratitude to Universiti Teknologi PETRONAS for the opportunity to conduct this project as partial fulfillment of my degree requirement. Also to other lecturers, graduate assistants, laboratory technicians, and fellow final year students who have been directly or indirectly involved in the completion of this project, I cannot thank you enough.

And surely, last but not least, to my family – this is for you.

Table of Contents

List of Figures

List of Tables

CHAPTER 1

INTRODUCTION

1.1 Background

Nanofluids are a new class of dilute liquid suspensions which are obtained by the dispersion of nanometer sized particles into base fluids, thus, making it a two-phase system, with one phase (solid) in the other (liquid). From previous studies, it has been found that nanofluids possess enhanced thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficient [1]. It has also been reported that nanofluids can act as smart fluids where the heat transfer can be reduced or increased at will [2]. Therefore, an increasing number of studies are conducted recently to understand the behavior of the nanofluids so that their potential can be fully utilized since the enhancement in heat transfer is of essential in various industrial applications as well as transportation and biomedical applications. One of the scopes of study regarding nanofluids that are gaining a lot of interest lately is the study on the stability of nanofluid suspensions. As proposed by many researchers and developers, one of the methods that can be used to stabilize a nanofluid suspension is by the addition of surfactants into the fluid mixture.

1.2 Problem statement

Since nanofluid is the suspension of nanoparticles in base fluids, gravity naturally affects the settling of the nanoparticles after a certain period of time. During the process of settling, nanoparticles coagulate easily due to its high surface energy and thus, become difficult to disperse in the base fluid. According to Li *et al*. [1] the amount and the charge of nanoparticles in the nanofluid, and the interaction between the particles and the dispersant directly affect the stability of the suspension.

Therefore, in order to reduce the coagulation of nanoparticles in the nanofluid, surfactants are added. Surfactants are surface active agents that act to lower the surface tension between two liquids or between a liquid and a solid. The adsorption of ionic surfactants is a mechanism for most substances to acquire a surface electric charge when in contact with a polar medium such as water [3]. Thus, surfactants are commonly used to stabilize the colloidal dispersion of particles by increasing the electrostatic repulsive force.

Hence, the use of surfactants has been chosen to achieve the stability of nanofluids in this study.

1.3 Objectives

- To observe the settling characteristics of Alumina nanoparticles in ethanol-water mixture with respect to the different concentrations of the nanoparticles and base fluid.
- To study the effects of different types of surfactants on the nanofluid.

1.4 Scope of Study

An experiment will be conducted to attain the objectives of the project. The nanoparticles Al_2O_3 will be dispersed into ethanol-water mixture. A non-ionic surfactant, Triton X-100, and an anionic surfactant SDS (Sodium Dodecyl Sulfate) will be added to the mixture.

The focus of the study is to achieve the stability of nanofluid by addition of surfactants only and not varying the sonication time.

Table 1: List of controlled, dependent and independent variables of the experiment.

Variables	Parameters
Controlled Variables	Sonication frequency Sonication time

	Concentration of surfactants
Independent Variable	Types of surfactants and nanoparticles pH value Concentration of ethanol in water Weight percent of nanoparticles in ethanol-water mixture.
Dependent Variables	Sedimentation height of the nanoparticles in nanofluids Effect of pH on the Zeta potential

CHAPTER 2

LITERATURE REVIEW

2.1 Applications of nanofluids

Nanofluids are dilute suspensions of nanoparticles with at least one of their principal dimensions smaller than 100 nm [2]. From various studies and experimentations, it was proven that nanofluids clearly exhibit enhanced thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients.

Wong and De Leon [2] in their review article discussed the heat transfer applications of nanofluids with reference to a project by J. Routbort in 2008 which applied the use of nanofluids as industrial cooling. The project could result in great energy savings and reduce the resulting emissions from the industry. If the cooling and heating water for the U.S industry were to be replaced with nanofluids, it has the potential to conserve 1 trillion Btu of energy [2].

Besides that, the nanofluids have also been shown to play a role as a smart fluid in the smart technological handling of energetic resources such as the widely used battery operated devices. Studies have shown that a particular class of nanofluids can be used as a smart material that works as a heat valve to control the flow of heat [2]. However, more researches will have to be conducted to demonstrate a more stable operating system of the smart fluids before it can be fully utilized.

The enhanced heat transfer properties of the nanofluids have also placed them in various applications such as automotive, electronic, and biomedical applications. Nevertheless, more researches need to be done so as to explore the effects of certain factors such as particle size, agitation, and addition of surfactants on the thermal conductivity of the nanofluids.

2.2 Method of preparation of nanofluid

There are two known methods from which the nanofluids can be prepared; the one-step method and the two-step mehod.

In the one-step method, the process of making and dispersing of the particles are done simultaneously. As mentioned by Yu and Xie [4] in their review article, the one-step process is able to disperse nanoparticles uniformly and thus, become stably suspended in the base fluid [4]. However, there are many drawbacks of the one-step method, the most important one being the leftover of residual reactant in the nanofluids due to incomplete reaction or stabilization as well as the fact that the cost is high and the nanofluids cannot be systhesised in large scales.

On the other hand, the two-step method of nanofluid preparation, or also known as the dispersion method, is more widely used. In this method, dry nanopowder is dispersed into the base fluid by application of one or many dispersion techniques [5]. As compared to the one-step method, this method is more cost-effective due to the low cost of nanopowders. However, the nanofluids prepared by using this method often encounters stability problem, a hitch that researchers are widely studying and finding solutions of.

2.3 Evaluation of the stability of the nanofluids

One of the most common and simple method to evaluate the stability of nanofluids is by sedimentation method. In this method, nanoparticles in nanofluid suspensions are left to settle by gravity and the sedimentation height is observed by photographic technique. The sediment weight or volume of nanoparticles in nanofluid under an external force field is an indication of stability of the nanofluid [4].

The stability of nanofluid is also commonly evaluated by Zeta potential analysis in which the influence of pH is used to study the dispersion behavior of the nanoparticles suspension. Li *et al*. [1], conducted an experiment to evaluate the dispersion behavior of aqueous copper nano-suspensions with varying pH under three different dispersants [1]. From the study, it was found that at low pH value, the Zeta potential is at minimum and thus, the force of electrostatic repulsion is not sufficient to overcome the force of attraction between particles. As pH increases until the value of 9.5, the Zeta potential of the particle surface increases, so the electrostatic repulsion force between particles becomes sufficient to overcome the force of attraction and collision between particles. However, as the pH further increases beyond 9.5, the Zeta potential becomes lower and resulted in poorer dispersion [1].

2.4 The use of surfactant to enhance nanofluid stability

Surfactants are surface active agents that act to lower the surface tension between two liquids or between a liquid and a solid. In a nanofluid suspension, the nanoparticles possess high surface energy making it easier to coagulate and difficult to disperse in water [1]. Therefore, the addition of surfactant into nanofluid suspension can help to increase the electrostatic repulsive force between the particles, thus, preventing it from coagulating.

A study conducted by Li *et al*. [1] uses different types of surfactants (non-ionic, cationic and anionic) with varying concentrations under the constant pH value of 9.5 for aqueous copper nano-suspension. From the study, it was found that the cationic (CATB) and anionic (SDBS) surfactants used had significantly increased the absolute value of Zeta potential of the particle surfaces, and the non-ionic surfactant (TX-10) formed a good hydration layer around the particle surfaces, leading to the enhancement of stability of the suspensions.

2.5 The effect of pH on nanofluid stability

A study conducted by Liu *et al*. [6] which involved the pH influence on the stability of different types of nanoparticles showed that the maximum aggregation of the particles (lowest stability) occurred at a pH value that is identical to the point of zero charge [6]. For all three nanoparticles used (TiO_2, TNs and TNs-TiO_2 in Na^+ solution), it was found that the zeta potential continuously decreases with the increase in pH and even a reversal of electric charge from positive to negative occurs as shown in Figure 1(a). This can be explain with the fact that as the pH increases, the OH^- ions in the solution tend to bond with the H^+ ions on the surface of the nanoparticles, causing the decrease of zeta potential [6].

As for the particle size, Liu *et al*. [6] found that for all three types on nanoparticles used, the particle size increases with the increase in pH up to a certain point and decreases afterwards (Figure 1(b)). The reduction of particle size after the pH of 4 (for TNs and TNs-TiO_2) is due to the large electrostatic repulsion force that is resulted from the increase in the amount of electric charge [6]. The pH at which the particle size is the largest is the pH at which the zeta potential shifted from positive to negative charge. This proves that the maximum aggregation of the nanoparticles occurs at a pH value that is identical to the point of zero charge.

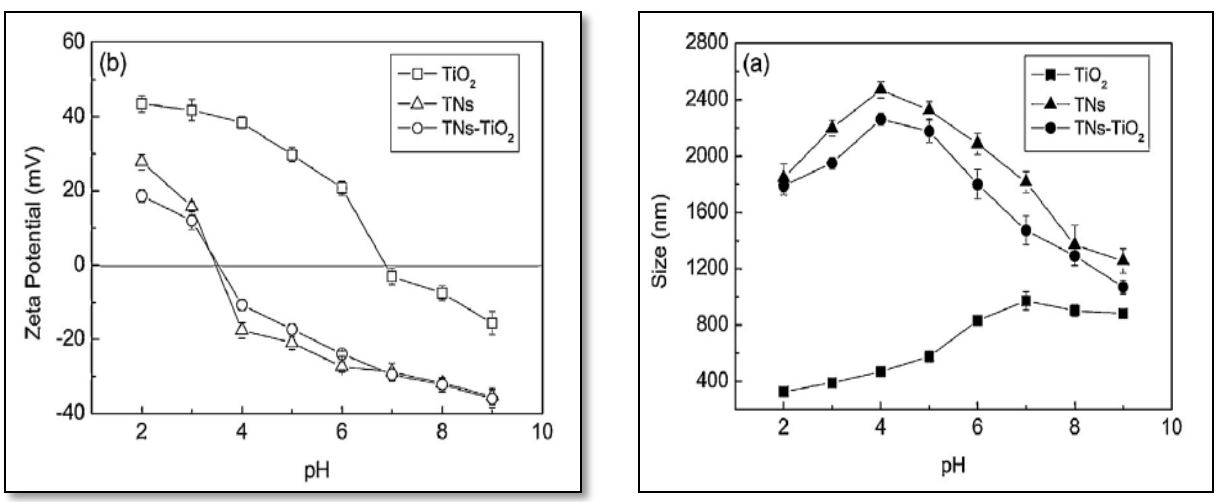


Figure 1 (a) and (b): Effect of pH on the Zeta Potential and the particles size of the different nanoparticles in Na+ solution [6]

Table 2: List of previous researches involving the use of surfactants for nanofluid stabilization

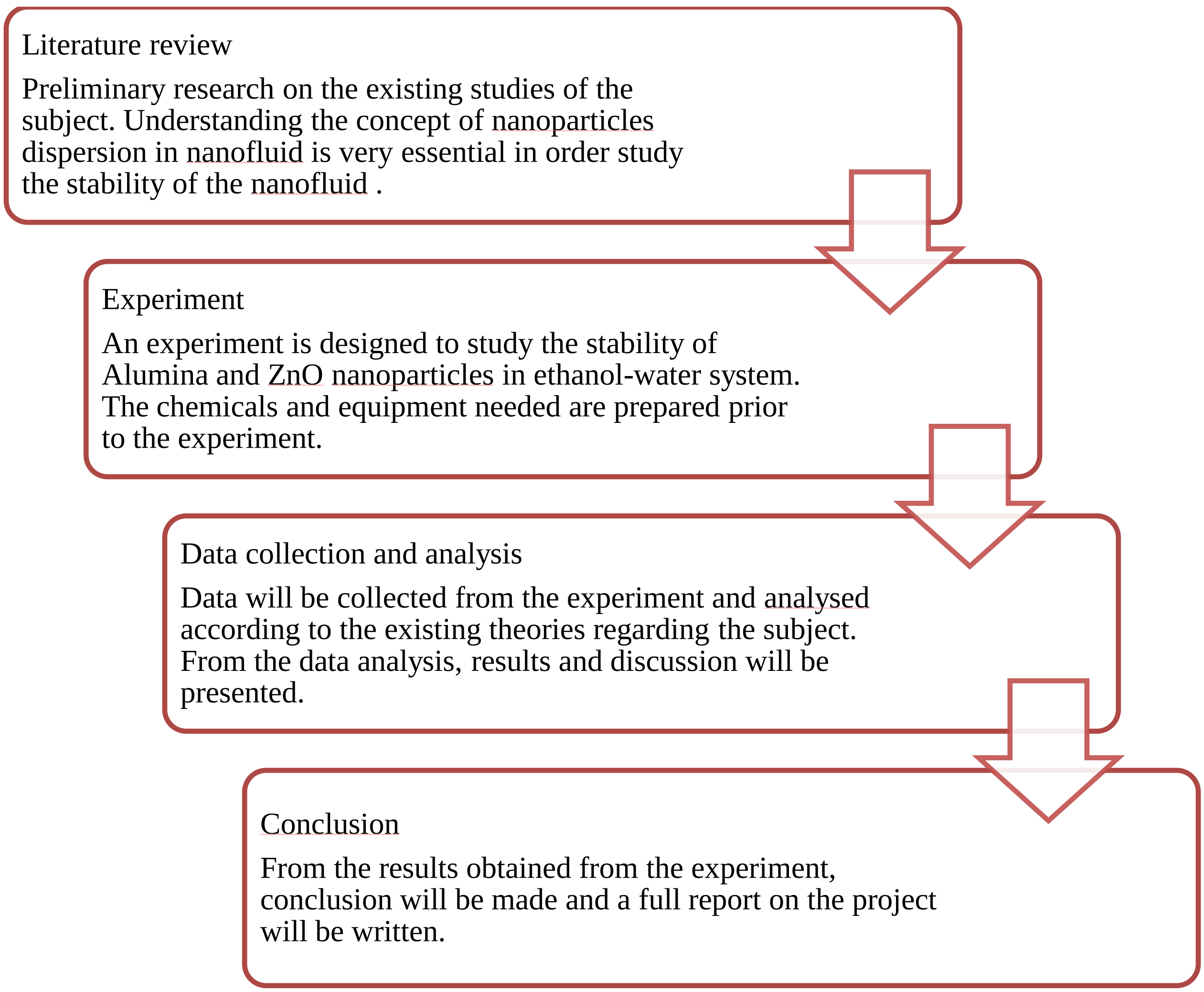
No.	Author	Year	Nanoparticle	Base fluid	Surfactant	Remarks
1	Liu *et al*. (2013) [6]	2013	- titanium dioxide - titanate nanotubes - titanate nanotubes-TiO_2	Na^+ and Ca^{2+} solution	Humic acid	Increase in humic acid concentration resulted in decrease in zeta potential and particle size in Na+ and Ca2+ solutions.
2	Witharana *et al*. (2013) [5]	2013	ZnO Al_2O_3 TiO_2	- propylene glycol - ethylene glycol - water	Hydopalat 5040 Anti-terra 250 Dispebyk-190 Gum Arabic Disponil A 1580 Hypermer LP1 Aerosol TR-70 Aerosol TR-70HG Aerosol OT-70PG	Only TiO_2 is used for surfactant study. The only stable suspensions were the 1% TiO_2-WEG in the presence of Aerosol TR-70, Aerosol TR-70HG and Aerosol OT-70PG.
3	Li *et al.* (2007) [1]	2007	copper	water	CATB SDBS TX-10	CATB and SDBS can significantly increase the value of zeta potential of particle surface by electrostatic repulsion. TX-10 can form a good hydration layer around the particle by steric interference and enhance the stability of the suspension.
4	Manjula *et al*. (2005) [7]	2005	Alumina	water	- Darvan C - JBR215 (bio surfactant)	The suspension in the presence of Darvan C is stable in a wider range of pH. In presence of JBR215, alkaline pH facilitates the stabilizing agent, while in acidic pH range, it is not effective.

5	Vékás *et al*. (2006) [8]	2006	Fe^{3+} and Fe^{2+}	water oil	- DBSA - lauric acid - myristic acid - oleic acid	Short chain length surfactants proved to ensure high colloidal stability of nanofluid sample.
6	Drzazga *et al*. (2012) [9]	2012	copper (II) oxide	water	- Rokanol K7 - Rokacet O7	Small concentration of surfactant had no influence on the particle size distribution. The zeta potential remains constant for surfactant doses below 200ppm and reduced in higher doses.
7	Hu *et al.* (2003) [10]	2003	Alumina (microparticle)	-	- DDA hydrochloride - SDS	SDS and DDA made the alumina surface hydrophobic at pH 3.5 and 10 respectively.
8	Fedele *et al.* (2011) [11]	2011	single wall carbon nanohorns (SWCNHs), titanium dioxide (TiO_2) and copper oxide (CuO)	Water	- n-dodecyl sulphate - polyethylene glycol	The addition of n-dodecyl sulphate and polyethylene glycol, respectively in SWCNHs-water and TiO2-water nanofluids, improved the nanofluid stability.

CHAPTER 3

METHODOLOGY

3.1 Project flow



3.2 Gantt Chart

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	First meeting with coordinator	x																											
2	First meeting with supervisor		x																										
3	Preliminary research work and preparing proposal																												
4	Submission of extended proposal							x																					
5	Proposal defense								x																				
6	Experiment on settling charecteristic for nanofluid without surfactant																												
7	Submission of interim draft report													x															
8	Submission of final interim report														x														
9	Experiment on settling charecteristic for nanofluid with surfactant																												
10	TEM and Zeta Potential analyses																												
11	Submission of progress report																						x						
12	Compilation and analysis of data																												
13	Pre-SEDEX																									x			
14	Submission of draft report																										x		
15	Submission of dissertation (soft bound)																										x		
16	Submission of technical paper																										x		
17	Oral presentation																											x	
18	Submission of dissertation (hard bound)																												x

3.3 Experimental methodology

The experiment will be using sedimentation technique, in which the nanofluid suspensions will be placed in test tubes and will be left to settle for a period of time. Photographs will be taken at certain intervals to depict the changes in the dispersion of the nanoparticles in the nanofluid by measuring the height of the suspended particles inside the test tubes at every time interval.

Respectively, Alumina nanoparticles, will be mixed into ethanol-water mixture of different concentrations varying from 0% to 100% of ethanol in water. Surfactants (SDS and TX-100, respectively) of unvarying concentration will then be added to the mixture which is later sonicated for 30 minutes to one hour by Sonicator. Then, the mixture will be left to settle under the influence of gravity and photographs will be taken at a time interval (5 to 60 minutes) depending on the settling characteristics of the mixture.

Figure 2 shows the procedures of the experiment in a simplified flow chart.

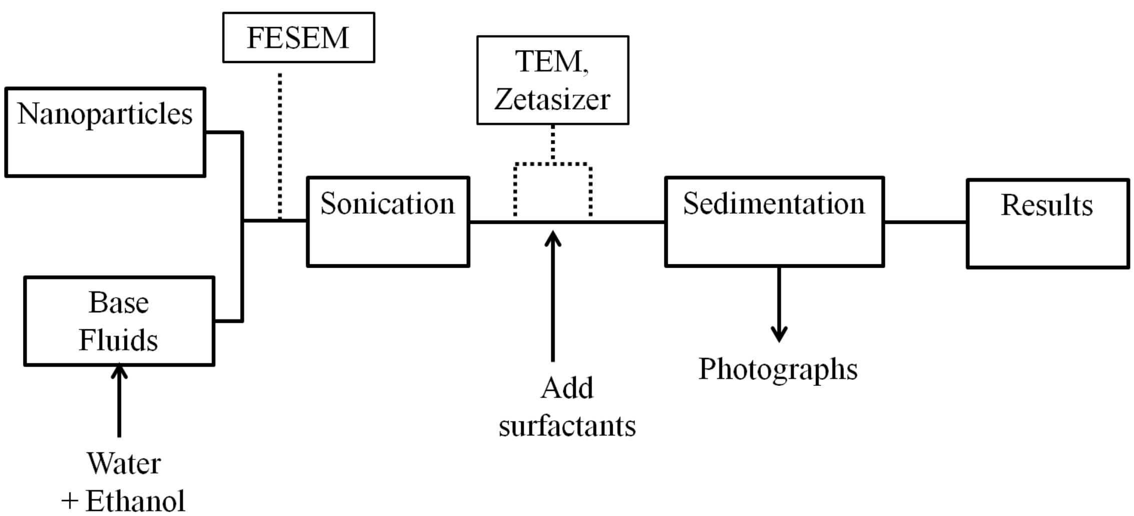


Figure 2: Flow of experimental procedure

The experiment was conducted under room temperature ($23^oC \pm 0.02^oC$). The effect of wall hindrance due to cohesive force in the test tube is neglected.

Table 3: List of experiment parameters and the details

Parameters	Details
Nanoparticles	Alumina (AL_2O_3)
Base fluids	Ethanol (C_2H_5OH) + Water (H_2O)
Nanoparticles concentration (%)	0.5, 1.0, 3.0
Ethanol concentration in water (%)	0 - 100
Surfactants	Sodium Dodecyl Sulfate (SDS), Triton X-100 (TX-100)
Surfactants %	0.1, 0.5, 1.0
Sonication time	30 min

3.4 Chemicals

- Aumina (Al_2O_3) nanoparticles
- Ethanol (C_2H_5OH)
- Sodium Dodecyl Sulfate, SDS ($C_{12}H_{25}O_4S.Na$)
- Triton X 100 ($(C_2H_4O)nC_{14}H_{22}O$)

3.5 Equipments

In the experiment, for the sonication process of the samples, the probe sonicator or ultrasonic homogenizer was used instead of the bath sonicator. This is due to the higher effectiveness of the sonication by the probe sonicator as compared to that of the bath sonicator.

Several characterization techniques were also used to analyze and clarify the stability of the suspensions. The nanofluid samples with addition of surfactant and had undergone sonication, were examined by TEM (Transmission Electron Microscopy) for imaging of the nanoparticles suspensions and the Zetasizer for the determination of the particles size distribution as well as the effect of pH on the Zeta potential of the suspensions.

Figure 3: Ultrasonic homogenizer, Biologics Model 150 V/T

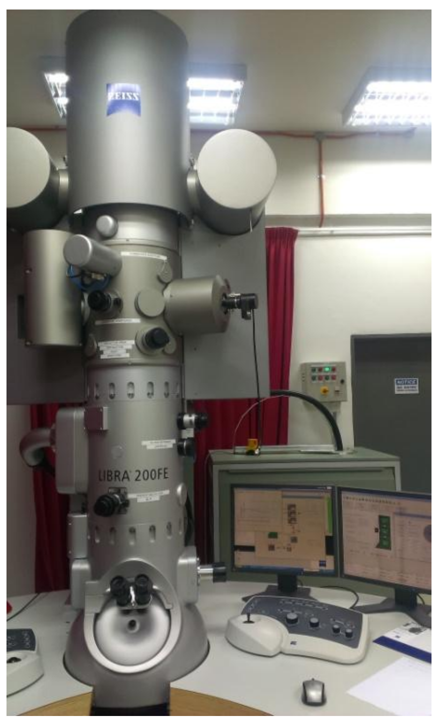


Figure 4: Transmission Electron Microscope (TEM) Model: Zeiss Libra 200 from the Centralized Analytical Laboratory Universiti Teknologi PETRONAS.

3.6 Experimental Procedure

The experiment was conducted in room temperature.

1. Al_2O_3 in solid form is dried in the oven to remove any water molecule.
2. Sample of nanofluids are prepared using the two-step method with different concentration of ethanol-water mixture and different weight fraction of nanoparticles.
3. All samples are sonicated using the Probe Sonicator for 10 minutes each.
4. Surfactants are added to the sonicated samples with respect to the different concentrations required.
5. The samples are then placed in test tubes and arranged properly at the set-up workstation that has dark screen backdrop with a ruler at the side to measure the height of sedimentation.
6. Pictures are taken using digital camera to observe the sedimentation height of the nanofluids.
7. The size of Al_2O_3 particles are measured using TEM.
8. The particle size distribution and the value of zeta potential are determined using Zetasizer.
9. All data are recorded and analyzed.

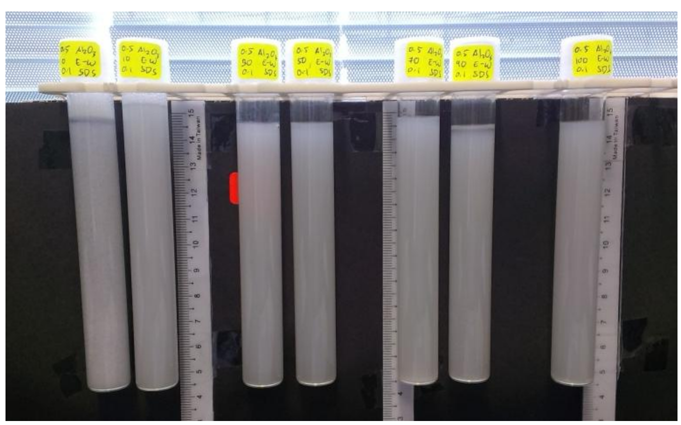


Figure 5: An example of the sedimentation set-up

CHAPTER 4

RESULT AND DISCUSSION

4.1 Experiment results

The sedimentation results for the experiment were obtained by the method of photographing the sedimentation process at designated time intervals and extracting the measurement of the sedimentation height from the photos by technical calibration with a 1cm scale. Figure 6 shows an example of how the height of the sedimentation is measured while ensuring its accuracy.

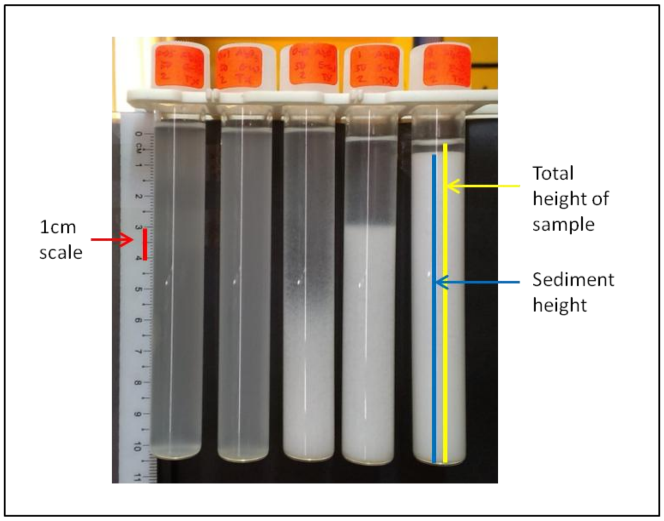


Figure 6: Measurement of sediment height from photo with 1cm scale

From the height of sediment obtained, sedimentation ratio can be calculated by;

$$\text{Sedimentation ratio} = \frac{\text{Sediment height}}{\text{Total height}}$$

4.1.1 The effect of different concentration of ethanol

In order to observe the effect of the ethanol-water concentration on the sedimentation ratio, a sedimentation study has been conducted for a constant concentration of alumina (0.5 wt%) in varying ethanol-water concentration (0%, 10%, 30%, 50%, 70%, 90%, 100%) which are subjected to 30 minutes sonication time without the addition of surfactant.

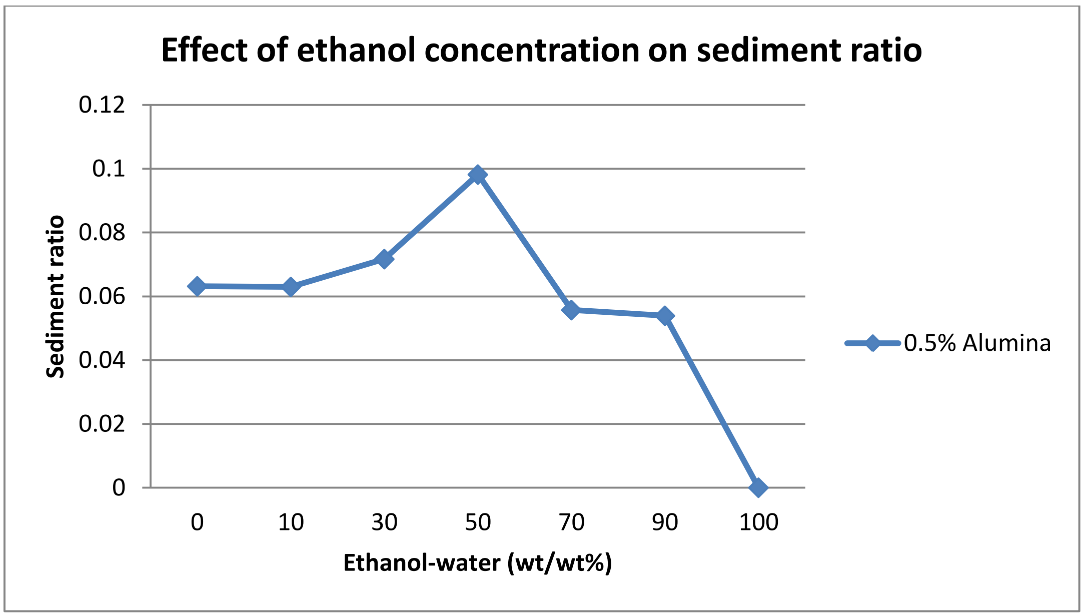


Figure 7: The effect of ethanol-water concentration on the sedimentation ratio of the nanofluid suspension observed after 2 hours

From the experiment, it is observed that the ratio of sedimentation increases with the increase in ethanol-water concentration until 50 wt% concentration as shown in Figure 7. As the ethanol-water concentration is further increased to higher concentrations, the ratio of sedimentation is reduced. This is due to the difference in viscosity of the solution which may have affected the interactions with nanoparticles.

4.1.2 The effect of different surfactant added

The types of surfactants used for this experiment are the Sodium Dodecyl Sulfate (SDS) and Triton X-100 (TX-100). SDS is an anionic surfactant whereas TX-100 is a non-ionic one. The samples consist of 0.5% Alumina in 50% ethanol-water solution and are subjected to 30 minutes sonication time. The effect of both surfactants on the sediment ratio against time are shown in Figure 8 and 9.

i) Addition of SDS

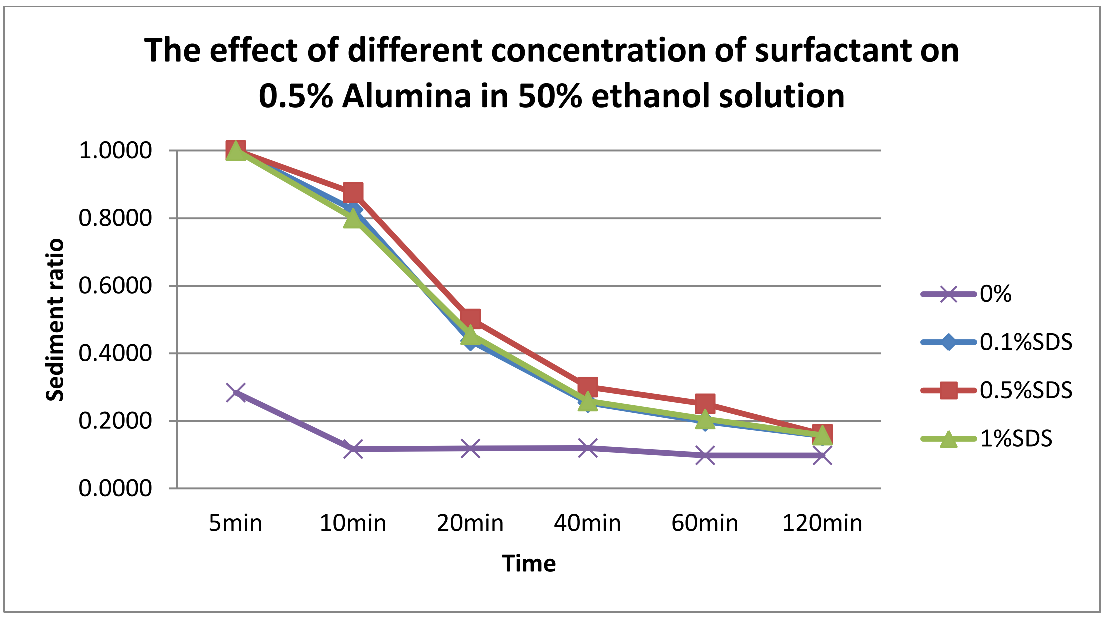


Figure 8: The effect of different concentration of SDS surfactant on 0.5% Alumina in 50% ethanol solution.

Referring to Figure 8, the results obtained showed that the ratio of sedimentation for all samples decreases with time except for the sample without addition of SDS which ratio becomes almost constant after 10 minutes sedimentation. All samples that have been added with SDS showed higher stability as compared to the sample without SDS addition as shown in Figure 8 where all the samples have higher ratio of sedimentation throughout the 2 hour period of observation. Among all the samples with SDS addition, it is found that the sample containing 0.5 wt% SDS has the highest stability as the ratio of sedimentation is the highest among the 3 samples.

ii) Addition of TX-100

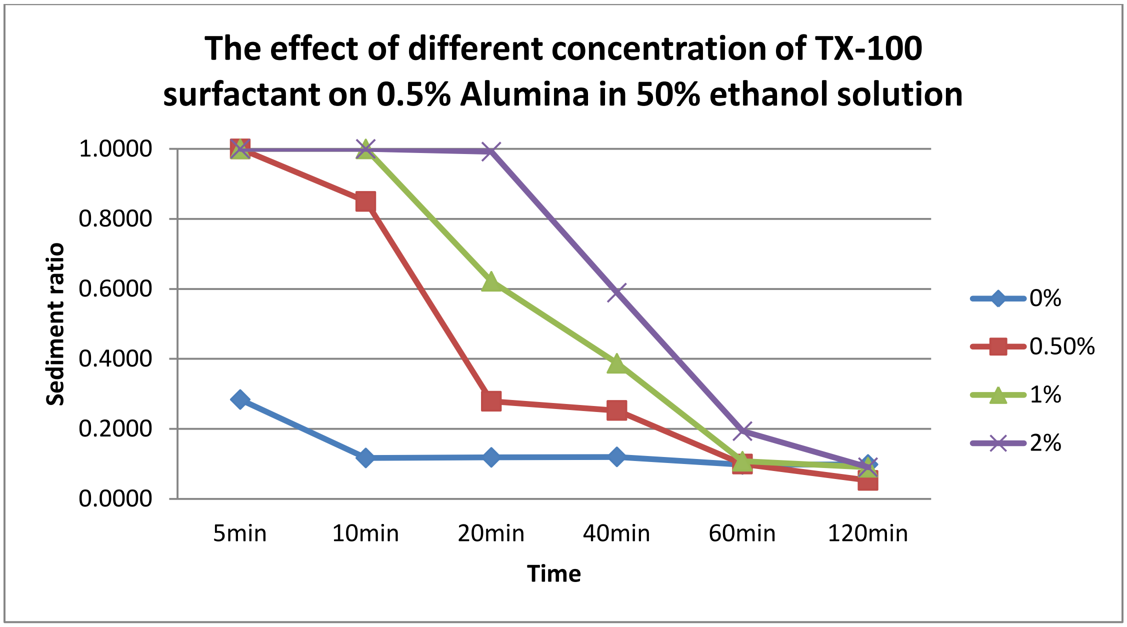


Figure 9: The effect of different concentration of TX-100 surfactant on 0.5% Alumina in 50% ethanol solution.

Figure 9 shows the effect of different concentration of TX-100 on the ratio of sedimentation over time for 0.5% Alumina in 50% ethanol solution. From the data collected, it is observed that the ratio of sedimentation for all samples decreases with time except for the sample without addition of TX-100 which ratio becomes almost constant after 10 minutes sedimentation. All samples that have been added with TX-100 showed higher stability as compared to the sample without surfactant addition where all the samples have higher ratio of sedimentation throughout the first hour of the observation period. The sediment ratio for samples with TX-100 falls below that of the sample without TX-100 after 2 hours. From the results, it can be said that the samples with higher concentration of TX-100 have higher stability. Thus, the sample with highest stability is the one with 2 wt% of TX-100.

iii) Comparison between the effect of SDS and TX-100 surfactant

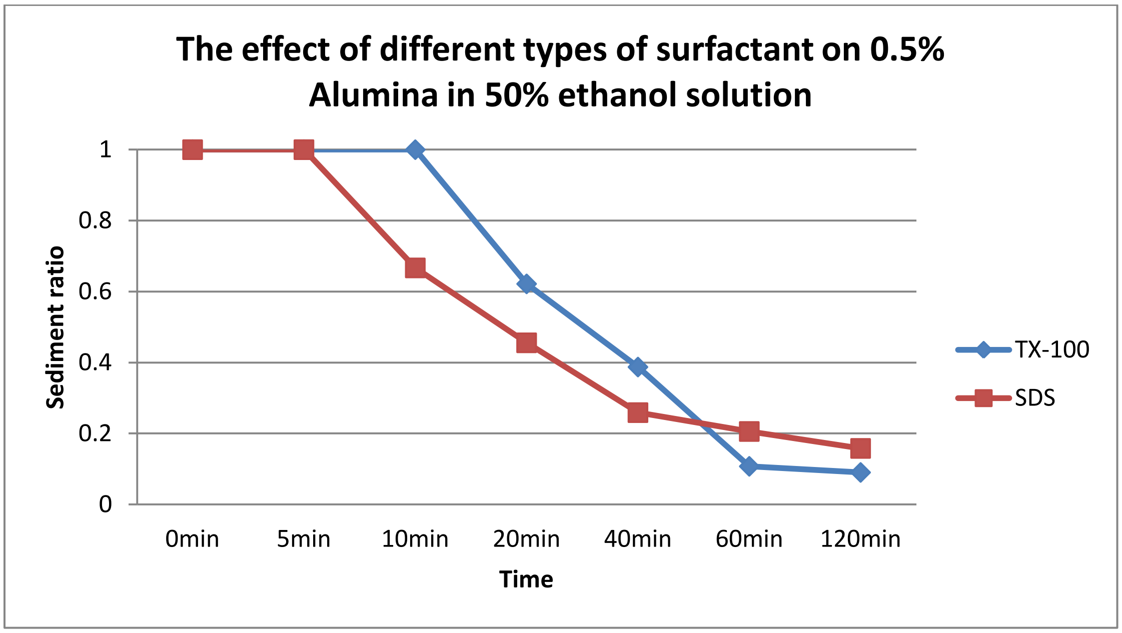


Figure 10: The effect of 1% TX-100 surfactant and 1% SDS on 0.5% Alumina in 50% ethanol solution.

Based on the results from the experiment, it is observed that the samples with TX-100 surfactant have higher stability than the samples with SDS surfactant as shown in Figure 10 where the TX-100 samples have higher ratio of sedimentation. This may be due to the behaviour of the TX-100 surfactant which has non-ionic properties that might have affected the forces of attraction between the particles in the suspension due to its influence to the surface characteristics of the Alumina nanoparticles in the ethanol-water solution.

Figure 11 (a) and (b) show the results of sedimentation for 0.5% Alumina in 50% ethanol-water with addition of SDS and TX-100 surfactant respectively. From the sedimentation photographs, it can be clearly seen that the samples with TX-100 surfactant achieved higher stability than that of the samples with SDS surfactant as the suspension are observed to be stable for a longer period of time.

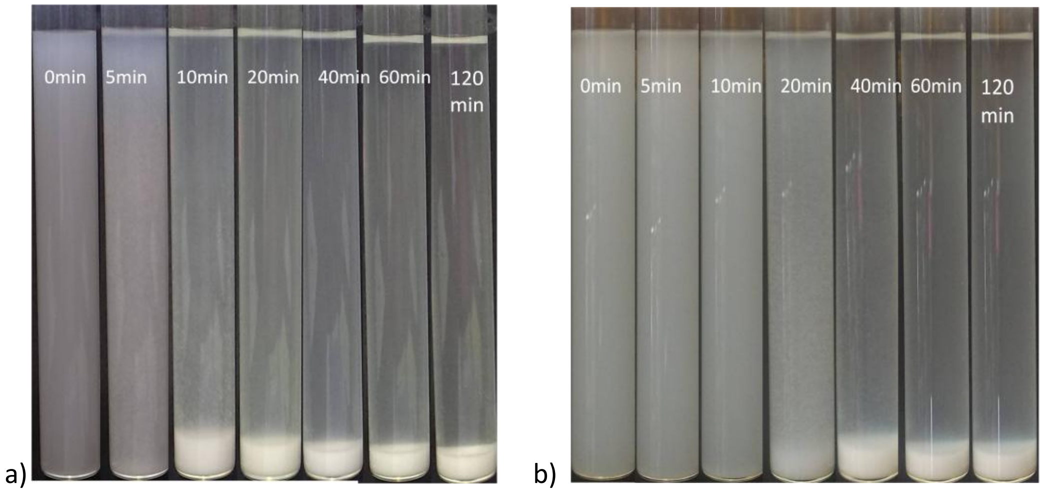


Figure 11 (a) and (b): a) The sedimentation result of 0.5% Alumina in 50% ethanol-water with 1% SDS; b) 1% TX-100

Despite the clear differences between the sedimentation results for samples of Alumina in ethanol-water suspension with addition of both surfactants, the TEM imaging results showed that both samples obtain almost the same agglomerates of nanoparticles which indicated the instability of the suspension. The images are shown in Figure 12 (a) and (b).

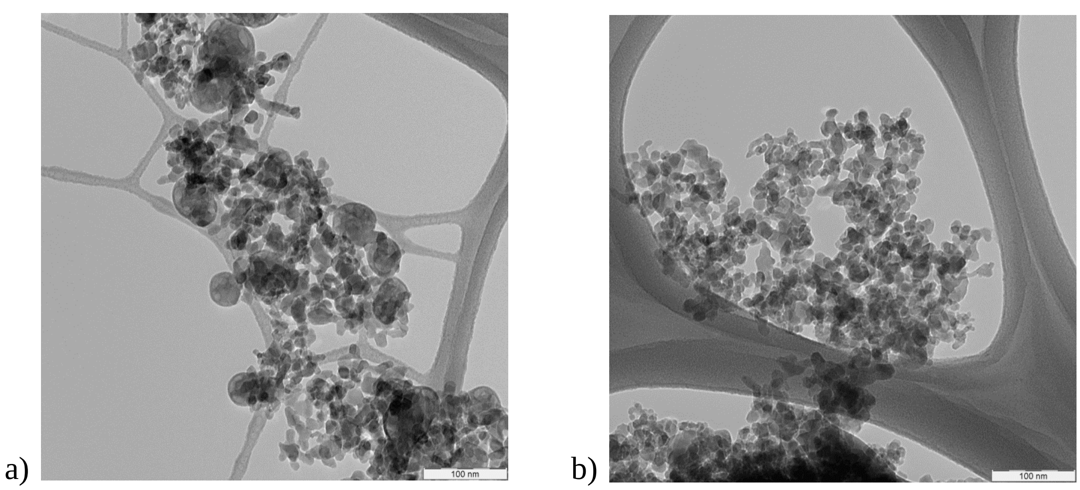


Figure 12 (a) and (b): a) TEM image of 0.5% Alumina in 50% ethanol-water with 1% SDS; b) TEM image of 0.5% Alumina in 50% ethanol-water with 1% TX-100

4.1.3 The effect of different concentration of Alumina

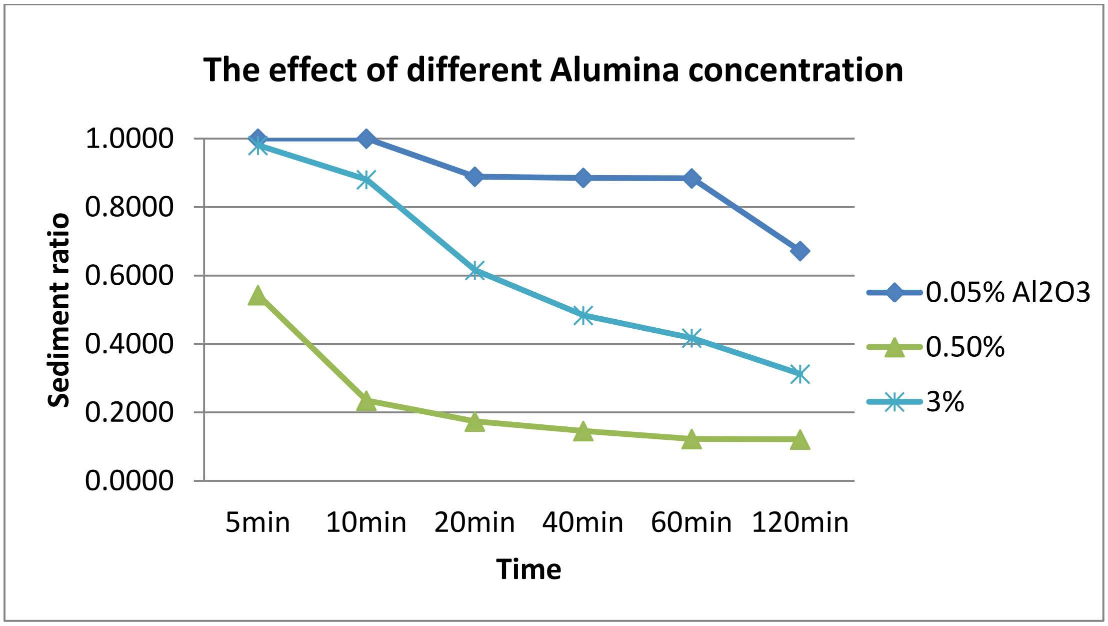


Figure 13: The effect of different concentration of Alumina nanoparticles in 50% ethanol with 1% addition of TX-100

The study on the effect of different concentration of Alumina in 50% ethanol-water with 1% TX-100 shows that the highest stability is obtained in suspension with very low concentration of Alumina. At a slightly higher concentration of Alumina, which is 0.5%, the stability of the suspension decreased tremendously; and increased again in samples with 3% Alumina concentration.

4.2 Limitations and recommendation

During the conduction of the experiment several limitations faced might have occurred and affected the results obtained for the experiment.

4.2.1 Retention time

After the preparation of samples, some might not be able to undergo sonication immediately since the probe sonicator can only sonicate one sample at one time. Therefore, the particles in the sample that have been prepared earlier might already have agglomerated in the meantime. The limited number of probe sonicator available is not helping either. In order to reduce or prevent the retention time effect on the particles, it is the best practice to prepare the sample right before sonication instead of preparing a batch of samples at once. This is to ensure best agitation of nanoparticles during sonication.

4.2.2 Temperature factor

According to Patel et al (2006), the difference in surrounding temperature may affect the stability of the nanofluid suspension. [12] In the process of sonication of the Alumina in ethanol-water suspension, the power introduced to the samples is quite high and thus, leads to the increase in temperature of the suspension. The effect of the temperature change was neglected in the experiment though it might have been a contributing factor in the difference in stability of the suspension at various concentrations. Therefore, in order to fully be able to neglect the effect of temperature on the nanofluid stability, a temperature control mechanism should be introduced during the sonication process.

CHAPTER 5

CONCLUSION

The study focused on the stability of nanofluids by the addition of surfactants. An experiment has been designed to observe the settling characteristics of the Al_2O_3 and ZnO nanoparticles in ethanol-water mixture. Sedimentation study, which is one of the most common and effective ways to evaluate the stability of nanofluid suspension has been chosen as the method to observe the settling results for this project. The dispersion behavior of the nanoparticles can be understood by analyzing the results from the experiment where the use of surfactants has also been proven to contribute to the stability of Alumina in ethanol-water suspension.

As a conclusion, the stability of the suspension was found to be higher in suspensions that have been added with surfactants (SDS or TX-100) than that of the ones without surfactant. In the study of stability for Alumina in ethanol-water with addition of SDS and TX-100, it was observed that stability of the suspensions is the best in the sample with 0.5% SDS concentration and 2% TX-100 concentration respectively. It was also observed that the samples added with TX-100 have higher stability as compared to that of the SDS.

For the study of the effect of different ethanol-water concentration on the stability of the nanofluid suspension, it was found that the highest ratio of sedimentation was obtained at 50% ethanol-water concentration. In the study to observe the effect of different Alumina concentration on the stability of the suspension, the sample with lowest concentration of Alumina (0.05%) has the highest stability.

REFERENCES

[1] X. Li, D. Zhu, and X. Wang, "Evaluation on dispersion behavior of the aqueous copper nano-suspensions," *Journal of colloid and interface science*, vol. 310, pp. 456-463, 2007.

[2] K. V. Wong and O. De Leon, "Applications of nanofluids: current and future," *Advances in Mechanical Engineering*, vol. 2010, 2010.

[3] L. L. Schramm, E. N. Stasiuk, and D. G. Marangoni, "2Surfactants and their applications," *Annual Reports Section" C"(Physical Chemistry)*, vol. 99, pp. 3-48, 2003.

[4] W. Yu and H. Xie, "A review on nanofluids: preparation, stability mechanisms, and applications," *Journal of Nanomaterials*, vol. 2012, p. 1, 2012.

[5] S. Witharana, I. Palabiyik, Z. Musina, and Y. Ding, "Stability of glycol nanofluids—the theory and experiment," *Powder Technology*, vol. 239, pp. 72-77, 2013.

[6] W. Liu, W. Sun, A. G. Borthwick, and J. Ni, "Comparison on aggregation and sedimentation of titanium dioxide, titanate nanotubes and titanate nanotubes-TiO< sub> 2</sub>: Influence of pH, ionic strength and natural organic matter," *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, vol. 434, pp. 319-328, 2013.

[7] S. Manjula, S. M. Kumar, A. Raichur, G. Madhu, R. Suresh, and M. Raj, "A sedimentation study to optimize the dispersion of alumina nanoparticles in water," *Cerâmica*, vol. 51, pp. 121-127, 2005.

[8] L. Vékás, D. Bica, and O. Marinica, "Magnetic nanofluids stabilized with various chain length surfactants," *Romanian Reports in Physics*, vol. 58, p. 257, 2006.

[9] M. Drzazga, G. Dzido, M. Lemanowicz, and A. Gierczycki, "INFLUENCE OF NONIONIC SURFACTANT ON NANOFLUID PROPERTIES."

[10] Y. Hu and J. Dai, "Hydrophobic aggregation of alumina in surfactant solution," *Minerals engineering*, vol. 16, pp. 1167-1172, 2003.

[11] L. Fedele, L. Colla, S. Bobbo, S. Barison, and F. Agresti, "Experimental stability analysis of different water-based nanofluids," *Nanoscale research letters*, vol. 6, pp. 1-8, 2011.

[12] H. E. Patel, K. Anoop, T. Sundararajan, and S. K. Das, "A micro-convection model for thermal conductivity of nanofluids," in *International Heat Transfer Conference 13*, 2006.

[13] S. U. Ilyas, R. Pendyala, and N. Marneni, "Settling Characteristics of Alumina Nanoparticles in Ethanol-Water Mixtures," *Applied Mechanics and Materials,* vol. 372, pp. 143-148, 2013.

[14] J.-B. Huang, M. Mao, and B.-Y. Zhu, "The surface physico-chemical properties of surfactants in ethanol–water mixtures," *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* vol. 155, pp. 339-348, 1999.

[15] S. Witharana, C. Hodges, D. Xu, X. Lai, and Y. Ding, "Aggregation and settling in aqueous polydisperse alumina nanoparticle suspensions," *Journal of Nanoparticle Research,* vol. 14, pp. 1-11, 2012.

[16] Y. Li, J. e. Zhou, S. Tung, E. Schneider, and S. Xi, "A review on development of nanofluid preparation and characterization," *Powder Technology,* vol. 196, pp. 89-101, 2009.

[17] B. LotfizadehDehkordi, S. Kazi, M. Hamdi, A. Ghadimi, E. Sadeghinezhad, and H. Metselaar, "Investigation of viscosity and thermal conductivity of alumina nanofluids with addition of SDBS," *Heat and Mass Transfer,* vol. 49, pp. 1109-1115, 2013.

[18] Y. Hwang, J. Lee, C. Lee, Y. Jung, S. Cheong, C. Lee*, et al.*, "Stability and thermal conductivity characteristics of nanofluids," *Thermochimica Acta,* vol. 455, pp. 70-74, 2007.

[19] A. Ghadimi, R. Saidur, and H. Metselaar, "A review of nanofluid stability properties and characterization in stationary conditions," *International Journal of Heat and Mass Transfer,* vol. 54, pp. 4051-4068, 2011.

[20] A. Brunelli, G. Pojana, S. Callegaro, and A. Marcomini, "Agglomeration and sedimentation of titanium dioxide nanoparticles (n-TiO2) in synthetic and real waters," *Journal of nanoparticle research,* vol. 15, pp. 1-10, 2013.

[21] Y. Zhang, Y. Chen, P. Westerhoff, K. Hristovski, and J. C. Crittenden, "Stability of commercial metal oxide nanoparticles in water," *Water research,* vol. 42, pp. 2204-2212, 2008.

[22] L. V. Stebounova, E. Guio, and V. H. Grassian, "Silver nanoparticles in simulated biological media: a study of aggregation, sedimentation, and dissolution," *Journal of Nanoparticle Research,* vol. 13, pp. 233-244, 2011.

[23] M. Premalatha and K. S. A. Jeevaraj, "Effect of Concentration and Temperature on the Ultrasonic Parameters of Carbon Nanotube Nanofluids," *Journal of Nanofluids,* vol. 2, pp. 133-139, 2013.

[24] J. Huang, X. Wang, Q. Long, X. Wen, Y. Zhou, and L. Li, "Influence of pH on the stability characteristics of nanofluids," in *Photonics and Optoelectronics, 2009. SOPO 2009. Symposium on*, 2009, pp. 1-4.