# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

## OPTIMIZATION ON THE NANOPARTICLE STABILITY IN LIQUID PHASED CONDITION BY USING TAGUCHI ANALYSIS

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.

By

**AIMANEZMIR BIN OTHMAN**

**B071410070**

**920319-04-5393**

FACULTY OF ENGINEERING TECHNOLOGY

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# DECLARATION

I hereby, declared this report entitled "Optimization on the Nanoparticle Stability in Liquid Phased Condition by Using Taguchi Analysis" is the results of my own research except as cited in references.

Signature :
Name : **AIMANEZMIR BIN OTHMAN**
Date :

# APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours. The member of the supervisory is as follow:

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(Project Supervisor)

# ABSTRAK

Peningkatan masalah aplikasi nanofluid adalah kerana nanopartikel yang lebih cenderung untuk menggumpal. Struktur penggumpalan ini memberi kesan terhadap keadaan cecair nano dan prestasi pemindahan haba berkenaan. Penumpuan dan pemendapan adalah fenomena kritikal yang memberi kesan pada kestabilan nanofluid. Objektif kajian ini adalah untuk mengkaji kesan perbezaan penggunaan agen surfaktan dan masa yang ditetapkan terhadap kestabilan nanopartikel (SAE 15W 40). Dalam kajian ini, minyak-nano telah disediakan dengan menyelerakkan nanopartikel dengan komposisi yang optimum iaitu 0.5 graphite vol.% 70 nm , $Al_2O_3$ dan $ZrO_2$ dalam minyak enjin konvensional gred (SAE 15W 40) menggunakan homogenizer ultrasonik selama 10-30 minit. Untuk menentukan kestabilan penyelerakkan, asid oleik, garam SDBS dan natrium klorida telah digunakan sebagai agen surfaktan dengan komposisi optimum 0.3 vol.%. Ujian kestabilan telah dijalankan dengan menggunakan UV-Vis spektrometer. Ujian kualitatif nanofluid juga telah dilakukan melalui pemerhatian pemendapan dengan menggunakan kaedah tradisional. Data yang diperolehi telah dianalisis dengan menggunakan kaedah Taguchi untuk menentukan nilai optimum kestabilan nanopartikel. Nilai keserapan minyak nano telah diukur dengan menggunakan UV-Vis spektrometer sebagai keputusan kuantitatif dan data akan disahkan dengan menggunakan analisis Taguchi. Sampel ini juga telah diperhatikan secara berkala dengan mengambil imej minyak-nano sebagai keputusan yang kualitatif. Keputusan melalui analisis taguchi menunjukkan bahawa nanopartikel zirkonia dengan ejen SDBS adalah paling stabil berbanding sampel lain. Sebaliknya, analisis taguchi telah menganalisis nanopartikel alumina dengan agen asid oleik adalah sampel yang kurang stabil.

# ABSTRACT

The problem arises from the application of nanofluid is that the nanoparticles tend to agglomerate. The agglomeration gives impacts to the properties of nanofluid and the heat transfer performance. Agglomeration and sedimentation are the critical phenomena that affect the stability of nanofluid. The aim of the study is to investigate the effect of different surfactant agents and homogenize time on the stability of nanoparticle (SAE 15W 40). In this study, the nano-oil was prepared by dispersing the nanoparticles with an optimal composition of 0.5 vol.% 70 nm graphite, $Al_2O_3$ and $ZrO_2$ in conventional engine oil (SAE 15W 40) grade by using ultrasonic homogenizer for 10-30 minutes. In order to determine the stability of the dispersion, Oleic Acid, SDBS Salt, and Sodium chloride were utilized as a surfactant agent with an optimal composition of 0.3 vol.%. The stability test was conducted using UV-spectrometer. The qualitative test of nanofluid was also being performed through the observation of sedimentation by using the traditional method. The collected data was analyzed by using the Taguchi method to determine the optimum value of nanoparticle stability. The absorbance value of nano-oil was measured using UV-Vis spectrometer as quantitative results and the data was verified by using Taguchi analysis. The sample was also being observed periodically by capturing the image of the nano-oil as qualitative results. The results of Taguchi analysis show that the zirconia nanoparticle with SDBS agent is most stable compared with another sample. Unfortunately, Taguchi analysis analyzed the alumina nanoparticle with the oleic acid agent is a less stable sample.

# DEDICATIONS

To my beloved parents, Othman Bin Hamza and Fauziah Binti Gani.
To my respected supervisor, Dr. Muhammad Ilman Hakimi Chua Bin Abdullah.
To my helpful friends.

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# LIST OF SYMBOL AND ABBREVIATIONS

| | | |
|---|---|---|
| % | - | Percent |
| $Al_2O_3$ | - | Alumina |
| API | - | Petroleum American Institute |
| ASTM | - | American Society Testing and Material |
| Au | - | Gold |
| COF | - | Coefficient of Friction |
| CNT | - | Carbon Nanotubes |
| CuO | - | Copper Oxide |
| ° C | - | Degree Celcius |
| DOE | - | Design Of Experiment |
| DOF | - | Degree Of Freedom |
| g | - | Gram |
| $g/cm^3$ | - | Gram per Cubic Metre |
| hBN | - | Hexagonal Boron Nitride |
| HCl | - | Hydrochloric Acid |
| KOH | - | Potassium Hydroxide |
| NaCl | - | Sodium Chloride |
| NaOH | - | Sodium Hydroxide |
| mg | - | Miligram |
| ml | - | Mililiter |
| mm | - | Milimeter |
| $M_oS_2$ | - | Molybdenum Dissulfide |
| MSDS | - | Material Specific Data Sheet |
| nm | - | Nanometer |
| PAO | - | Polyalphaolefins |
| PTFE | - | Polytetrafluorocthylene |
| SAE | - | Society Automotive Engineers |
| SDS | - | Sodium dodecyl sulfate |
| SDBS | - | Sodium Dodecyl Benzene Sulphonate |

| | | |
|---|---|---|
| SN | - | Signal Noise |
| TBN | - | Total Based Number |
| $TiO_2$ | - | Titanium Dioxide |
| UV | - | Ultra Violet |
| Vol.% | - | Volume Percent |
| Wt.% | - | Weight Percent |
| $ZrO_2$ | - | Zirconia |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Nanoparticles as an additive in lubricants are found to give better performance in tribological properties and increment of heat transfer. Lubricants are the substances utilized to decrease the effect of friction between the two moving sliding surfaces. Generally, lubricants can be classified based on their physical states such as a solid lubricant, semi-solid lubricant, and liquid lubricant. Utilizing nanoparticles as an added substance in fluids to expand thermal performance of fluids has already began in 1990s. The lubricant is vital in any industry because it helps to reduce the frictional resistance, wear, surface deformation, provide protection against corrosion, and also improve the efficiency of engine component. Besides, lubricant with nanoparticle enhanced the load-carrying capacity, friction reduction properties and anti-wear. Kong et al., (2017) found that the mechanism of lubricant may be accessible when nanoparticles were utilized as additives in lubricant such as polishing effect, rolling of nanospheres, self-repairing effect and tribochemcial.

Nanoparticle as an additive in the lubricant is called a nanofluid. According to Khairul et al., (2016), the mixtures of base fluid and nanoparticles have produced the nanofluid without the chemical reaction between these two components. The existence of nanoparticles in the lubricants contributes to better flow combination and excellent thermal conductivity compared to pure fluid. The typical size of producing nanofluid usually below 100 nm by the dispersion of metallic or nonmetallic nanoparticles into the mixture (Ghadimi et al., 2011; Sidik et al., 2014). Nanofluids have superior thermo physical properties over the base fluids in terms of thermal conductivity, viscosity, thermal diffusivity and convective heat transfer coefficients. The high surface area of nanoparticles improves thermal conductivity of nanofluids from the heat transfer takes place on the particle surface. The number of atoms existing on the nanoparticles surface is bigger compared with the interior. In addition, the nanoparticle may reduce erosion and clog due the smaller size which contributed to the stability of the nanoparticles (Das et al., 2007; Ramakoteswaa et al., 2014).

Generally, one of the fundamental prerequisites of nanofluid features is the long term stability generated through nanoparticles dispersion. The stability of nanofluid is crucial to ensure the nanofluid is in good condition. Yu and Xie (2012) stated that the stability was indicated by those particles which do not aggregate at a significant rate. The nanoparticle aggregation rate is determined by the frequency of collision caused by the probability of cohesion during the collision and Brownian motion. Nanoparticles tend to aggregate because of the high surface region and surface movement (Kong et al., 2017). Nanofluids stability is determined through the amount of van der Waals forces and electrostatic repulsion force between nanoparticles dispersed living in nanofluids. When the electrostatic repulsion force is greater than the forces of attraction then the stability will be achieved. According to Amiruddin et al., (2015), the repulsion force from the repel of particles forms van der Waals which leads to agglomeration and this is when stabilization has been reached through the permeation of stable particle on the surface of the pigment. In order to increase the repulsion force between nanoparticles, two mechanisms are used like steric mechanism and electrostatic mechanism. Nevertheless, the field of this study focuses only on the steric mechanism.

Instability of the nanofluid can influence its thermo physical properties such as viscosity, density, and thermal conductivity. Hence, the advantages of nanofluid in heat transfer will decrease due to the instability of nanofluids. The potential benefit of nanofluids will drop off since thermal conductivity is directly or indirectly decreased due to its instability. To obtain better concentration and stability of the nanofluid, physical or chemical treatment has been conducted in which surfactant agent is added into the lubricant. The utilization of surfactants is the imperative strategy to upgrade the stability of nanoparticles in liquids condition. The usefulness of the surfactants under high temperature is another major concern, particularly for high-temperature applications. In addition, a homogenizer is utilized in this investigation as a mechanism to stabilize the nanofluids with surfactant agents. The intermolecular interactions between particles can be disrupted by sonication while the agglomeration in the nanofluid can be decreased by homogenization processes. In this research, the effect of difference surfactant agents and homogenize time on the nanoparticle stability (SAE 15W 40) were optimized to investigate the nanoparticle stability parameter in liquid phased condition.

## 1.2 Problem Statement

The problem arises when nanoparticles tend to agglomerate from a nanofluid application in advanced lubricant. Sukarno, (2017) found that the agglomeration gives impacts to the properties of nanofluid and the heat transfer performance. Amiruddin et al., (2015) shows that the molecules on the pigment surface are stabilized through the absorption reaction, it will prevent repulsive forces of different particles from approaching close sufficient for the appealing van der Waals forces to bring about agglomeration. Proportionality of the Van der Waals forces acting on nanoparticles is higher than microparticles compared to another force. The agglomerates framed could have various sizes and configurations and it can change every time. Hence, it will be difficult to control the agglomeration effects to the stability of nanofluid.

Furthermore, the suspension of nanoparticles aggregates regularly and it is not homogeneous due to the relatively strong impact of Van der Waals interactions in between the nanoparticles (Ramakoteswaa et al., 2014). According to Ilyas et al., (2014), the primary reason for a faster settling of nanofluid is due to the aggregation of nanoparticles in the liquid, which have high surface free energy and also the reduced conductivity of whole effective thermal. Sedimentation is also one of the phenomena that are critical to the stability of nanofluid. The sedimentation of nanoparticles would decrease the thermal conductivity of nanofluids significantly. As point out by Ganguly and Chakraborty (2011), the sedimentation and nonhomogeneous dispersion of particles within the resulting suspension as a result of the high surface energy of nanoparticles which is causes coagulation of tiny particles produce huge aggregation. To overcome the sedimentation and agglomeration, the surfactant agent must be added into the lubricant to rectify the particle surface properties.

## 1.3 Objective

i. To optimize on the nanoparticle stability parameter in liquid phased condition.
ii. To investigate the effect of difference surfactant agents and homogenize time.

## 1.4 Scope

i. Optimizing on the nanoparticle stability parameter in liquid phased condition by using Taguchi method.
ii. Investigating the effect of difference surfactant agents and homogenize time on the nanoparticle stability by using $L_9$ Orthogonal arrays.

# CHAPTER 2

## LITERATURE REVIEW

### 2.1 Introduction

Lubrication plays a major role in successful many potential applications like an automotive industry. Nowadays, a lubricant is improved with nanoparticles alternative of oil soluble additives to enhance the tribological properties. A mixture both of additives and dispersion agent can give stability to the oil phase. Lubricants with additives have better tribological properties such as increase resistance to friction, better anti-wear characteristics, improved load carrying capacity and the ability to absorb heat better (Prabu et al., 2016). The stability of nanofluids is essential to give a better performance in their applications. Hence, the surfactant is a better mechanism to stabilize the nanofluids. This formula is crucial in developing a new lubricant.

### 2.2 Classification of Modern Lubricant

Modern lubricants are developed from various base fluids and chemical additives. The liquid base has various function, especially it is a lubricant that provides a fluid layer separating the moving surfaces and wear particles with minimum friction. Many lubricating properties are improved or created by the addition of a special chemical additive to liquid foundation (Mortier and Orszulik, 1992). Additives of lubricant continue to develop to provide improved properties and performance to a modern lubricant. Nowadays, better lubricants are needed for more complex machine. Present of modern lubricant today is to improve the performance of the current lubricant.

### 2.2.1 Latest Solid Lubricant

Solid lubricants are thought to be any solid material that has the ability to decrease friction and interactions of mechanical between surfaces in relative motion opposed to the action of a load (Rudnick, 2009). A solid lubricant has superior features, such as good heat resistance, high chemical stability, and high-pressure resistance. Solid lubricants are commonly utilized as a dry film or an added substance in a liquid to give improved lubrication to a wide range of applications. Solid lubricants are typically utilized in anti-seize compounds and threading compounds, to provide a sealing function and friction reduction for threaded pipe fitting. The applications of the solid lubricant include low sliding speeds and high contact loads, for example, gear lubrication. The solid lubricant successfully gives the required wear protection and load bearing performance essential from gear oil, particularly capable when utilized with lower viscosity base oils.

Graphite and molybdenum disulfide ($MoS_2$) are the main materials used as a solid lubricant. Figure 2.1 showed crystal structure of graphite. As a result of the solid and crystalline nature of pigments, graphite and $MoS_2$ show good resistance to high temperature and oxidizing atmosphere environments, though fluid greases ordinarily will structure.

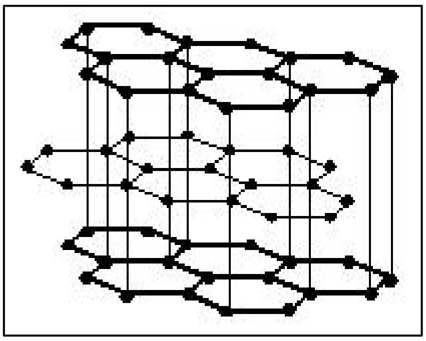

Figure 2.1: Crystal structure of graphite
(http://www.tribology-abc.com/abc/solidlub.htm)

This feature makes graphite and molybdenum disulfide lubricant vital for procedures including extreme temperatures or excessive contact pressure. There are also other compounds which are helpful solid lubricants, including cerium fluoride, boron nitride, polytetrafluoroethylene (PTFE), calcium fluoride, and tungsten disulfide. The characteristics of commonly used solid lubricants are showed in table 2.1.

Table 2.1: Characteristics of common solid lubricants (Shizhu and Ping, 2012).

| Lubricant Type | Temperature Limit °C | Typical Coefficient of Friction | Usage |
|---|---|---|---|
| 1. Layered solid Molybdenum disulfide | 350 (in air) | 0.1 | Powder, adhesive film, or cathodic vacuum coating |
| Graphite | 500 (in air) | 0.2 | Powder |
| Tungsten disulfide | 440 (in air) | 0.1 | Powder |
| Calcium fluoride | 1000 | | Melt coating |
| Graphite fluoride | | 0.1 | Brush or cathodic vacuum coating |
| Talc | | 0.1 | Powder |
| 2. Febrile material PTFE (unfilled) | 280 | 0.1 | Powder, solid block, or adhesive film |
| Nylon 66 | 100 | 0.25 | Solid block |
| Polyimide | 260 | 0.5 | Solid block |
| Acetal | 175 | 0.2 | Solid block |
| Polyphenylene sulfide (filled) | 230 | 0.1 | Solid block or coating |
| Polyurethane | 100 | 0.2 | Solid block |
| Polytetrafluoroethylene (Fill) | 300 | 0.1 | Solid block |
| Nylon tip 66 (Fill) | 200 | 0.25 | Solid block |
| 3. Others A1203 | 800 | | Powder |
| Phthalocyanin | 380 | | Powder |
| Lead | 200 | | Brush or cathodic vacuum coating |

### 2.2.2 Advanced Semi-Solid Lubricant

Grease is a semi-solid lubricant produced by the dispersion of thickening agents in mineral oil or synthetic liquid base that may contain other ingredients that impart special properties (Rudnick, 2009). The main advantage of choosing the grease over conventional lubricating oil in certain applications because of the ability of grease to stay in contact with the surface is required to move. Grease is generally not leaked from the time of application. Thickeners in grease designed to minimize any migration due to gravity, pressure centrifugal action (Bhushan, 2013). Thickening agents are the most common metal soaps with aluminum, calcium, sodium, barium or lithium. Oils are liked to grease since they are better coolants and are simpler to deal with and apply. However, the preferred grease for applications where it is important that the oil did not run or drip for higher.

The greater part of greases is made out of petroleum and synthetic oil thickened with metal soaps and other agents, for example, silica, clay, and polytetrafluoroethylene. Most lubricant greases utilized as a part of industry have petroleum oils as their fluid base. However, practically every greasing up fluid can present with a reasonable to make grease. The petroleum oil based grease can be utilized at a temperature up to 175 °C relying upon the thickener and synthetic oil based greases may utilize at higher temperatures. Silicone thickened with ammeline and silica is the best materials in the greases and it can be utilized at temperatures up to 300 °C.

Today, the requirement of advanced lubricants such as low friction characteristic, thermal conductivity, heat transfer or cooling, environmental impact, and additive compatibility is essential. These requirements are needed to improve energy efficiency and mechanical durability. The latest creation of grease is also one of the most advanced lubricants. The use of grease is a mechanism to reduce friction. Laurentis et al., (2016) study the effect composition containing grease on friction in rolling or sliding contact concentrated. The experimental results show at the high-speed region, the friction administered by the viscosity and type of the base oil. To a certain viscosity, synthetic grease base oil showed lower friction and friction are