An Extensive Review On Tribology and Lubrication

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Abstract - Tribology is the "ology" or science of "tribein". The word comes from the same greek root as "tribulation". A faithful translation defines tribology as the study of rubbing or sliding. The modern and broadest meaning is the study of friction, lubrication and wears. According to the modern dictionary and handbook, "The branch of science and technology concerned with interacting surfaces in relative motion and with associated matters as friction, wear, lubrication and the design of bearings is Tribology". Tribology is the art of applying operational analysis to problems of great economic significance, namely, reliability, maintenance and wear of technical equipment, ranging from spacecraft to household appliances. The understanding of the underlying mechanism requires a combination of knowledge from the fields as varied as physics, chemistry, materials science, mechanical engineering and mathematics and makes tribology all the more interesting. Tribology is crucial to modern machinery, which uses in sliding and rolling surfaces. The role of lubrication is an important part in the field of tribology. Lubrication is simply the use of material to improve the smoothness of movement of one surface over another, and the material, which is used in this way called a lubricant. Lubricants are commonly used for lubrication to reduce the friction and wear of interacting surfaces and provides smooth running and a satisfactory life for machine elements. Most lubricants are liquids (such as mineral oils, synthetic oil, silicon fluids, water, etc.), but they may be solids (such as polytetrafluoroethylene, or PTFE) for use in dry bearings, greases for use in rolling element bearings or gases (such as air) for use in gas bearings. The physical and chemical interactions between the lubricant and the lubricating surfaces must be understood in order to provide the machine elements with satisfactory life.

Keywords- Tribology, Polyalphaolefin (PAO), perfluoropolyether (PFPE), lubricants.

I. INTRODUCTION

Low temperature fluidity is another important property in lubricant rheology. The pour point is an indicating parameter of low temperature fluidity, which is defined in ASTM-D-97-39 as the lowest temperature at which the oil will pour or flow when it is chilled without disturbance under definite prescribed conditions. Bondi reports that a large number of oils show glassy solidification due to higher viscosity at the pour point. Viscoelastic solid transition temperature TVE also represents the low temperature fluidity of lubricating oil. The physical and practical significance of viscoelastic solid transition temperature is much better than the pour point. Sound velocity in the lubricating oil can be measured as like the other lubricant properties. Sound is a molecular disturbance and the disturbance is caused by vibration. It depends on the nature of the medium through which it travels and also the gap between the molecules. Sound velocity depends on the molecular structure of any substance. Sound velocity in the liquid is lower than that of solid. So, it directly related to the bulk modulus or modulus of elasticity of the substances. Adiabatic bulk modulus, which is an important parameter of lubricating oil, can calculate from the measured sound velocity. The bulk modulus of a substance measures the substance's resistance to uniform compression. It is defined as the pressure increase needed to cause a given relative decrease in volume.

Pressure-viscosity coefficient, Viscoelastic solid transition temperature and other properties of lubricating oils are measured experimentally. There are many correlations to predict the lubricant properties also. Pressure-viscosity coefficient a can be directly determined by measuring the viscosity at various pressures. Many correlations exist to predict a, but most of them suffer from disadvantages of containing complex equation forms, requiring data difficult to access and providing low accuracy. In this research, author proposed a simple correlation to predict pressure-viscosity coefficient a. The relation emphasized on adiabatic bulk modulus K, which was calculated from the sound velocity in the lubricating oil. K is related to the intermolecular force and high-pressure physical properties, which depends on free volume. If sound velocity can measure in high accuracy then accurate bulk modulus can be easily calculated. Then anyone can easily predict the pressure-viscosity coefficient of lubricating oil. Again, viscoelastic solid transition temperature at atmospheric pressure TVEO can be measured experimentally from the occurrence of photo elastic effect by lowering the temperature using liquid nitrogen. The measurement is quite difficult and requires low temperature apparatus for handling the liquid nitrogen. Since TVEO is related with the free volume of the substances, it has

a relation with the sound velocity of the substances. Upon this basis, a relation has found between the sound velocity and the low temperature fluidity.

Testing lubricating oils were considered on group basis, such as traction oil, polyalphaolefin (PAO) oil, paraffinic mineral oil, perfluoropolyether (PFPE) oil, Ester oil, Vegetable oil and Glycerol. PAO and paraffinic mineral oil can also named as Hydrocarbon oil. Molecular structure of these groups is different compare to each other. Measured sound velocity also shown different value as the group basis. At this instant, author found the effect of sound velocity on the molecular structure of lubricating oils. To clarify this effect, density and surface tension of testing oils were measured by conventional method. Some times measurement of sound velocity in lubricating oil became difficult. Considering this difficulty, author found a relation to estimate sound velocity. Since, sound velocity is related with the molecular structure and the lubricant property: surface tension and density are also related with molecular behavior of the lubricant, it can estimate the sound velocity of lubricating oil from the surface tension and its density.

II. FLUID LUBRICATION

a brief overview of fluid lubrication, an introduction of the application and development of pure ionic liquids as lubricants and a literature review of the application of nanoparticles in fluid lubricants.

A. Tribology

The word “tribology” is derived from Greek word “tribos”, which means “rubbing”. Nowadays, in the study of friction and lubrication engineering, tribology is defined as the science and technology of interacting surfaces in relative motion and of related subjects and practice. The definition of tribology integrates individual technology into engineering related to friction, so tribology generates interdisciplinary fields ranging from fundamental research to industrial applications such as nanotechnology and surface sciences. From an economic viewpoint, the study of tribology in practice is important, UK scientist H. Peter Jost estimated in his famous “Jost Report” to British government that the appropriate application of tribological principles and practices in industry can result in the savings of 1.0% to 1.4% of a country’ gross national product (GNP).

B. History and Overview of Oil Lubricants

The use of lubricating oils can be traced back to ancient Egypt. At that time, people have been aware that certain liquids between surfaces in relative motion could reduce friction [3]. In the middle of the 19th century, with the discovery of petroleum, the petroleum-based lubricants, also called mineral oils, have been used and developed for various machines after the Industrial Revolution. However, with the development of rocket motors and space vehicles, as well as the discovery of the gas turbine in World War II, people found that at condition of extreme temperature, mineral oil lubricants were not suitable for applications in the harsh condition. For example, mineral oil lubricants were easy to oxidize at temperatures above 100°C and it would become very viscous or gelatinous at temperatures below -20°C. Because of the disadvantages of mineral oil lubricants, synthetic lubricants and lubrication additives intended for extreme conditions, such as higher loads, extreme temperature and vacuum, became also available.

C. Fluid lubrication mechanisms and Types

In practice, various kinds of devices and machines need lubricants for sliding pairs. Lubricants can be divided into three kinds: fluid lubricants such as water or mineral oils, greases, and solid lubricants (self-lubricating materials) such as graphite. In the three categories, fluid lubricants are most commonly used in practices. Fluid lubricants have a series of advantages compared to greases and solid lubricants, such as long term endurance, low mechanical noise, promotion of thermal conductance and very low friction in the elastohydrodynamic regime as illustrated in Figure 2.1. Regime (1) is the regime for hydrodynamic lubrication. In this regime, the viscous liquid is introduced between the surfaces and a stable liquid film is formed. The applied load is completely supported by the liquid film and the two surfaces never come into direct contact so that the friction is reduced between the friction surfaces. Moreover, in this regime, the lubricant performances are decided by the viscosity of the lubricant, applied loads to the contact and sliding velocity. Regime (2) is the elastohydrodynamic lubrication (EHL) regime. In this regime, the thickness of the lubrication liquid film is obviously much lower than that found in hydrodynamic lubrication.

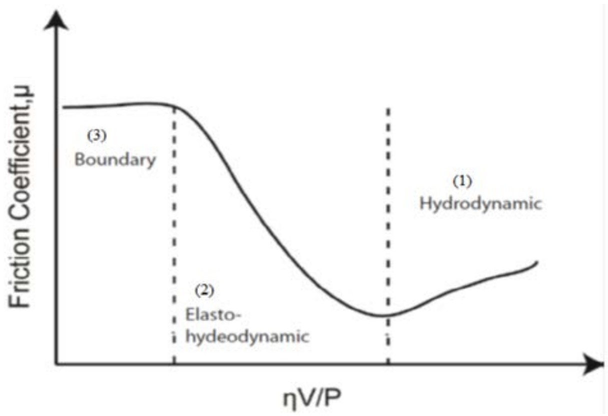

Figure 2.1 Fluid lubrication regimes illustrated by Stribeck curve.

Where g is the fiction coefficient, n is the dynamic viscosity of the lubricant, V is the sliding velocity and P is the applied load.

III. LITERATURE REVIEW

Sound is a travelling wave which is an oscillation of pressure transmitted through a solid, liquid, or gas, composed of frequencies within the range of hearing and of a level sufficiently strong to be heard, or the sensation stimulated in organs of hearing by such vibrations. Sound velocity is the rate of travel of a sound wave through an elastic medeum. Sound travels faster in solid than in liquid, and faster in liquid than it does in gases. Sound velocity depends of the medium's compressibility and density. Calculating adiabatic compressibility or adiabatic bulk modulus from sound velocity measurement is a well-established practice. Molecular compressibility was determined from Wood equation. The compressibility and density are combined using the Urick equation , which is based on an idea suggested by Wood.

The measurement of sound velocity in fluid systems is the subject of numerous research studies. There are many studies concerned with single-phase fluids and the fluid systems composed of two or more different fluid phases, such as liquid and gas. Nichita et al. proposed a method to calculate the isentropic compressibility and the sound velocity in both single-phase and two-phase states for various mixtures. The thermodynamic limits for compressibility and sound velocity were the subject of their study, correspond to a regime of slowly varying pressures and/or small gas domains in the liquid: the liquid and gas phases were considered to be in thermodynamic equilibrium at any instant. Okazaki presented a universal method for describing the speed of sound from the perspective of physicochemical reaction kinetics. He shown that the speed of sound changes with temperature according to a thermodynamically derived formula and that the motion and propagation phenomena of sound energy can also be regarded as chemical reaction. Povey et al. [15] studied on the relationship between the sound velocity and chain length. They used Cygnus UVM1 ultrasound velocity meter to measured sound velocity. They derived a model from the detailed analysis of the mechanisms involved. That model can give very precise estimations of the composition of pure liquid. They envisage that the ultrasound velocity method, with the mentioned units ease of use and in-line capability, can provide a powerful new method of characterizing polymetric fluids, as well as contributing to understanding of fluid compressibility and of the propagation of sound in terms of specific intermolecular and intramolecular physicochemical behavior. The weaker molecular forces involved are difficult to probe by other methods but they hope that their method will offer new perspectives on the molecular basis of the liquid state, leading to practical applications where identification and/or purity are issues.

There are many literatures on the lubricant properties. The pressure-viscosity characteristics of liquids are important in understanding the behavior of lubrication and hydraulic system. Bell and Kannel and Cheng studied on the elastohydrodynamic theory and suggested that the lubricant film thickness under a bearing is governed largely by the pressure-viscosity effect in the low-pressure region. As long ago as 1893, Barus established an empirical equation to describe the isothermal pressure-viscosity relationship for a given liquid. Based on the concept that the mobility of the molecules in a liquid is governed by their free volume, different models were later derived to describe molecular transport phenomena, such as viscous flow and diffusion. The basic concept underlying free volume theories implies that each molecule in a liquid is confined to a cage bounded by its immediate neighbors. Therefore, knowledge of pressure-viscosity relationship of lubricants is important for the design and construction of the lubrication elements, such as rolling bearings, valve cams and gear. Pressure-viscosity coefficient a is the parameter of pressure-viscosity relationship.

Many correlations were proposed to predict pressure-viscosity coefficient a, but most of them suffer from the disadvantages of containing complex equation forms, requiring data difficult to access and providing low accuracy. Most of all, as pointed out by Johnston these correlations are entirely empirical and not related to the fundamental liquid theories. At the same time, Johnson has derived an equation to relate a to the bulk properties of liquids based on Eyring's thermal activation energy model for viscous flow. However, his result gives a low level of precision when it was compared to the experimental data of some oil samples. So and Klaus proposed a viscosity-pressure correlation of liquids. The parameters used for this correlation were the atmospheric viscosity and density at the temperature of interest and the constant which indicates the atmospheric viscosity-temperature property m0. This equation has a rather complex form, but it only requires physical properties which are very easy to measure. In 1989, Wu et al. developed a method for the prediction of pressure-viscosity coefficients of lubricating oils based on free volume theory. The accuracy of this method was only compared to So's method. The failure of this method to predict the pressure behavior of some synthetic hydrocarbons and non-hydrocarbons appears to be related to the unusual high, or low bulk moduli of these fluids. Bair and Kottke concluded their research as numerical simulations of elastohydrodynamic lubrication have generally failed to accurately describe pressure-viscosity response and a complete pressure viscosity curve can be accurately represented piecewise by well-known empirical equations. They also mentioned that free volume theory could be used to arrive at accurate expressions although these may be complicated. Leeuwen describes a method to deduct pressure-viscosity coefficient through an accurate film thickness measurements. In this research, he compared eleven film thickness approximation formulas related in the film thickness of a test fluid. Among those, the Roelands pressure-viscosity equation is most popular in EHL work. Bair discussed about the missing of Roelands equation in one of his research. He also described clearly the effect of pressure, viscosity and temperature of lubricant in his several researches. In the EHL, film thickness also can be measured using the pressure-viscosity coefficient of lubricating oil. From the above studies, there is no doubt that pressure- viscosity coefficient is an important parameter of lubricating oil.

IV. EXPERIMENTAL TECHNIQUES

Various material characterization equipment were used to analyze the characterization of OTS functionalized SiO_2 nanoparticles formed in this research project, the tribological and rheological properties of mixtures of nanoparticles (NPs) in ionic liquids (ILs). Specifically, Fourier transform infrared spectroscopy (FTIR), thermal gravimetric analysis (TGA), dynamic light scattering (DLS), Nanotribometry, scanning electron microscopy (SEM) and rheological measurements were used. The following sections will give a brief description of how each equipment works.

A. Fourier transforms infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FTIR) was used to examine the surface of tested substance to provide quantitative and qualitative information in the range from 10cm-1 to 12,800cm-1. Molecular vibrational states of tested substance are different and the difference in vibrational states may cause adsorption, emission, or reflection of photons. In this method, IR radiation results in the transitions between different molecular vibrational states because IR photons have the same order of magnitude when the energy difference between molecular vibrational states exists.

B. Thermal gravimetric analysis (TGA)

Thermal gravimetric analysis is a method to measurement of sample mass loss according to decomposition, oxidation, or loss of volatiles with the change of temperature, and the mass loss is the function of temperature. In the measurement, the temperature is raised linearly and the sample mass is recorded. At certain temperature, there will be a sharp decrease in mass because of chemical decomposition or boiling. If the boiling or decomposition point of each component in a compound is known, the percentage of different components may be determine by tracking the mass loss with the change of temperature.

C. Dynamic light scattering (DLS)

Dynamic Light Scattering is the measurement of particle size through measuring the random change in the intensity of light scattered from a suspension or solution. In this method, the intensity of light scattered by the molecules in the sample is a function of time. Because all molecules in solution are not stationary and they diffuse in Brownian motion, the diffusion causes interference (constructive or destructive) and results in a change in light intensity. Dynamic Light Scattering can provide information including the average size, size distribution, and polydispersity of molecules and particles in solution according to the measurement of the time scale of light intensity fluctuations. Moreover, the faster the particles diffuse, the faster the intensity will change. The speed of the intensity change is directly related to the motion of the molecule. The diffusion of the molecules is essentially controlled by the following factors: temperature (the higher the temperature the faster the molecules will move), viscosity of the solvent (the more viscous the solvent the slower the molecules move) and the size of the molecules (bigger the molecules, the slower they move). Assuming that temperature and solvent are constant, the variation in the intensity of the scattered light is directly related to the size of the molecule.

D. Nanotribometry

A nanotribometer is an instrument designed to study the tribological properties between surfaces in contact under dry and lubricated conditions. A large variety of tribometers exist including pin-on-disk, four-ball, block-on-ring, to name a few. In this work, the primary focus will be on a pin-on-disk tribometer the schematic of which is shown in Figure 4.1. The tribometer used in this study consists of a linear reciprocating module and a cantilever spring assembly. The cantilever spring assembly consists of a spring with a known spring constant at the tip of which a ball holder is located. In addition to the ball holder, two mirrors are located on top of the spring: one mirror is flush with the spring surface and the other perpendicular to it. Each mirror is faced by an optical sensor to allow the detection of normal and lateral deflections. Given the spring constant, and the deflection of the spring, forces can be obtained using Hooke's law.

E. Scanning electron microscopy (SEM)

A scanning electron microscope is the measurement of the sample's surface topography and composition by scanning the sample with a focused spot of electrons. The focused spot of electron is about 2-3 nm in diameter. If the resolution of SEM is 2.5 nm, the images can be magnified up to 100,000 times. When the SEM works with the electrons scanning the sample's surface, three types of electrons are released including secondary, backscattered, and transmitted electrons. Backscattered electrons are those that enter the specimen and leave in the direction it came from without affecting the electrons in the electron shell. Secondary electrons are generated during inelastic collision whereby an electron from the beam knocks out an electron from the inner shell. Because secondary electrons have low energy and have a very slight negative charge, the secondary electrons may be collected by a detector with a positive charge to generate a 3-D image.

F. Rheological Properties Measurements

Rheological properties measurement can provide more detailed information about the microstructure of the nanoparticles because flow behavior is responsive to properties such molecular weight and molecular weight distribution.

Generally, the rheological properties of suspension system can be measured by the rheometer, Most rheometer models belong to three specific categories: rotational, capillary, or extensional. The most commonly used of these is the rotational rheometer, which is also called a stress/strain rheometer, followed by the capillary type.

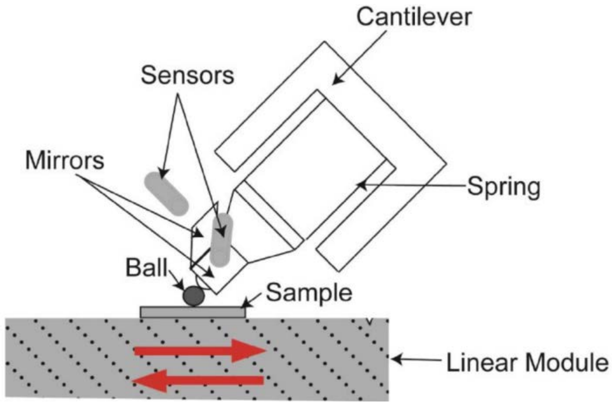

Figure 4.1; Schematic illustration of the operating principle of a nanotribometer.

V. CONCLUSION

In this paper a brief study of various the tribological properties of two nanoparticle- based lubrication are studied and reviewed . The pressure viscosity coefficient is key property to know the performance of lubricating oil in Elastohydrodynamic and boundary lubrication. Adiabatic bulk modulus was compared with the tribological and rheological properties of lubricating oils. Selection of lubricant is very important. To select an appropriate lubricant, it is necessary to know the properties of lubricant, lubrication system of applied machinery, conditions of machinery, cost of lubricant etc. Common properties of lubricating oil are: viscosity, viscosity index, density, compressibility, surface tension, cloud point, pour point or low temperature property, flash point, friction coefficient, etc. The most important property is its viscosity. Viscosity is a function of temperature and pressure. Relationship between the viscosity with temperature and relationship between viscosity with pressure is also important in lubricant rheology as well as for the life of machine elements. Just as temperature rise reduces the viscosity of lubricating oil, again, an increase in pressure produces a rise in its viscosity.

REFERENCES

[1] Ludema, K. C. (1996), Friction, Wear, Lubrication: a text book in tribology, CRC Press Inc., New York, USA.
[2] Halling, J. (1976), Introduction to Tribology, Wykeham Publications (London) Ltd., London
[3] Bhushan, B. (1999), Principles and Applications of Tribology, John Wiley & Sons, Inc., New York, USA.
[4] Schowalter, W. R. (1978), Mechanics of non-Newtonian Fluids, ISBN-0¬08021778-8.
[5] Lansdown, A. R. (1982), Lubrication: A practical guide to lubricant selection, Pergamon Press Ltd., Oxford, England.

[6] Barus, C. (1893), Isothermal, Isopiestics and Isometrics Relative to Viscosity, American Journal of Science, Vol. 45, pp. 87-96.

[7] Bondi, A. (1951), Physical Chemistry of Lubricating Oils, Reinhold Publishing Corporation, New York, USA.

[8] The American Heritage Dictionary of English Language, Fourth Edition, (2006), Houghton Mifflin Company, Boston, MA, USA.

[9] Strutt, J.W. and Rayleigh, B. (1896), The Theory of Sound, Third Edition, Macmillan, London.

[10] Laplace, P.S. (1816), Analytical Chemistry, Vol. 3, pp. 238-241.

[11] Urick, R.J. (1947), A Sound Velocity Method for Determining the Compressibility of Finely Divided Substances, Journal of Applied Physics, Vol.18, pp. 983-987.

[12] Wood, A.B. (1964), A Text Book of Sound, Third Edition, Bell and Sons, London.

[13] Nichita, D. V., Khalid, P. and Broseta, D. (2010), Calculation of Isentropic Compressibility and Sound Velocity in Two-phase Fluids, Fluid Phase Equilibria, Vol. 291, No. 2, pp. 95-102.

[14] Okazaki, N. (2000), Temperature Rule for the Speed of Sound in Water: A Chemical Kinetics Model, Chem. Eur. Journal, Vol.6, No.18, pp. 3339-3343.

[15] Povey, M. J. W. et al. (2005), Estimating Organic Chain Length through Sound Velocity Measurements, Ultrasonics, Vol. 43, pp. 219-226.

[16] Syed Q. A. Rizvi. 1945, ”A comprehensive review of lubricant chemistry, technology, selection, and design” ISBN 978-0-8031-7000-1

[17] Amit Kumar Singh and P.S. Mukherjee, 2004 “Interrelationship among viscosity, temperature and age of lubricant”

[18] Thomas J. Zolper, Manfred Jungk and Tobin J. Marks, 2006 “Modeling Polysiloxane Volume and Viscosity Variations With Molecular Structure and Thermodynamic State”

[19] Berry, G. and Fox, T. 1968, “The Viscosity of Polymers and Their Concentrated Solutions,” Adv. Polymer Sci., 5, pp. 261–357.

[20] Ewell, R.H. “The reaction rate theory of viscosity and some of its applications.” J. Appl. Phys. 9, 252 (1938).