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Abrasion, Wear, and Viscosity Analysis of Nano Fe_3O_4 Based Pongamia Bio-Oil

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Nanolubricants are nanofluids used to lubricate a machine. They are especially used as lubricants in the automotive industry because of their excellent friction-reducing properties. The friction, wear, and viscosity of Fe_3O_4 nanoparticles mixed with pongamia oil at 0, 0.5, and 1 wt. % concentrations are investigated in this research. Fe_3O_4 magnetic nanoparticles show excellent friction-reducing properties when they are used as additives to the base oil, and the results also confirm the same as the coefficient of friction decreases as the content of Fe_3O_4 nanoparticles increases in the base oil. The nanofluid prepared by adding Fe_3O_4 nanoparticles to the pongamia oil mixture shows Newtonian behavior, i.e., the viscosity of the fluid will remain constant irrespective of the amount of shear stress applied. However, with the rise in temperature, the viscosity of the nanofluid decreases, when it varies from 40 to 80 °C.

Keywords: Wear, Friction, Viscosity, Nanoparticle.

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1. INTRODUCTION

Lubrication is the method of using a fluid to minimize friction and wear and tear when two surfaces come into contact. The lubricant forms a layer between the two surfaces, isolating them and avoiding direct contact between metal surfaces. Since the lubricant absorbs the frictional heat generated between the two parts, it acts as a coolant, decreasing power loss by lowering frictional forces. Several methods have been used by humans. Lubricants can further be distinguished as solids, liquids, and semisolids (greases) [1].

Graphite, talc, French powder, etc. come under this category. When an oil film cannot develop due to excessive temperature or pressure, solid lubricants are utilized. They are used in the form of powder. For example, on carom board surfaces French powder is commonly used which helps the striker to move around freely.

Refining crude petroleum yields liquid lubricants, which are widely utilized in industrial applications. They can adhere to a variety of surfaces. They can stick to several different surfaces. Due to their high viscosity and fluidity, they are used in high-speed machinery and engine parts, as well as transmission systems that require high circulation. Mineral oil, synthetic oils, whale oil, and others are examples of liquid lubricants.

Grease is a semi-liquid lubricant. It is made by mixing a petroleum product with a soapy combination. It has a high viscosity and therefore it can adhere to whatever surface it is applied. Semi-liquid lubricants are good for machine components that have a lot of space between two parts that are in touch. When it is observed that the operating temperature is extremely high, grease can be applied. It can be utilized when there is a lot of pressure between two parts and maintaining an oil coating between the surfaces to be lubricated is challenging. Grease can be used in gear drives and chain drives, for example.

This refers to the lubricant's ability to evaporate at a specific temperature. When the temperature in the machine's working environment is high, the lubrication begins to evaporate, worsening the lubricant's qualities. The volatility of a good lubricant should always be low.

The majority of lubricants can attach to metal surfaces and keep them apart. A good lubricant must stick to the surface. When a lubricant is subjected to high pressure, a film of oil forms between two moving metal surfaces. Even at high pressure, good lubricating oil can stick to the surface. When lubricating oil is exposed to a flame, it reaches a temperature, at which it releases enough vapors to burn spontaneously. A good lubricant's flash point should be high.

This refers to the ability of a lubricant to form bubbles on the upper surface due to cohesive forces. Bubbles should not form in a good lubricant. The seeds of the millettia pinnata tree, a native of Asia, are used to produce pongamia oil. It is extracted from the seeds using different methods. It has a high content of triglycerides [2]. Pongamia pinnata plant has medicinal properties and it also fixes nitrogen in the soil.

Sankaran Nair et al., 2020, studied the rheological and tribological properties and oxidative stability of pongamia oil. Tert-butyl hydroquinone (TBHQ) was blended with pongamia oil to improve oxidative stability, and to improve the tribological properties, SiO_2 nanoparticles were added to pongamia oil. An improvement in the viscosity and wear properties of pongamia oil is observed after conducting the experiments [3].

K.V. et al., 2014, used pongamia oil as a raw material to produce biodiesel. The use of ou alors pongamia pinnata biodiesel mixed with diesel for diesel engines was investigated in various concentrations such as 10, 20, 30 %, etc. The oil is blended with petrodiesel. By varying certain parameters like compression ratio, injection pressure, and load or by using additives, one can find out the most suitable combinations of the mixture for a compression ignition (CI) engine. The author concluded that a 20 % mixture of pongamia oil with diesel provides the maximum efficiency for biodiesel operation [4].

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Jason et al., 2021, examined the viscosity studies of pongamia oil with graphene nanoplatelets (GNP) as additives. As a result of the experiments, it was concluded that the addition of 0.05 wt. % GNP to pongamia oil shows a decrease in friction by 17.5 % and a decrease in wear by 11.96 %. It was also found that the viscosity of nanolubricant increases upon the addition of nanoparticles. The viscosity increases by increasing the concentration of nanoparticles, however after a certain concentration the viscosity starts decreasing because of the agglomeration of nanoparticles [5].

Birleanu et al., 2022, examined the properties of engine oil mixed with TiO_2 in different volume concentrations of 0.01, 0.025, 0.050, and 0.075 %. The tribological test was performed by using the four-ball tribometer. It was found that the coefficient of friction reduces when 0.075 % volume concentration of TiO_2 nanoparticles is added to the base oil at a temperature of 75 °C [6].

2. METHODOLOGY

The phase of the crystal is identified by using an X-ray diffractogram. Structure, composition, and physical properties are also studied. In XRD, an X-ray beam is made to fall on the sample at a certain angle of incidence, the sample used must be homogeneous and reduced to fine particles. X-rays then scatter which causes interference, this interference is both constructive and destructive which results in a pattern of lower and higher intensities. To identify the phase, the obtained XRD pattern is matched with the JCPDS data.

UV-Vis is a technique that measures the amount of light absorbed or transmitted by a material. The device used for this experiment is the spectrophotometer. It consists of two cuvettes, one is the reference cuvette and the other is a sample cuvette. There are two slots in the spectrophotometer, one slot is for the reference cuvette and the other is for the sample cuvette. Both cuvettes should be placed in such a way that the light is incident on the transparent part of the cuvette. The reference cuvette contains the solvent in which nanoparticles are to be dissolved and the sample cuvette contains nanoparticles mixed with the solvent. First, the cuvette containing the solvent is placed inside the spectrophotometer in both slots to calibrate the instrument. Now the sample is placed inside the sample slot and the reference cuvette is still kept in the reference slot. A graph between the absorbance and wavelength is obtained which gives the value of the maximum wavelength [7, 8].

Photoluminescence is a phenomenon wherein photons of visible wavelength strike the specimen placed in a glass cube. When the energy of an incident photon matches the excitation energy of electrons, then the electron gets excited to a higher energy level. When the electron returns to a lower energy level due to the natural tendency of occupying a lower energy level, it releases energy in the form of photons which are absorbed.

Zetasizer is a device that is mainly used to measure the particle size by using the dynamic light scattering (DLS) technique. It can also analyze the particle charge also known as the zeta potential using electrophoretic light scattering (ELS) [2, 8].

3. RESULTS AND DISCUSSION

3.1 Particle Characterization

The obtained XRD graph of Fe_3O_4 nanoparticles in Fig. 1 is compared with the standard diffraction pattern for Fe_3O_4 nanoparticles. The diffraction peaks were detected at $2\theta = 30.1°$, $35.7°$, $43.3°$, $57.5°$, and $63.0°$ which correspond to Miller indices of (220), (311), (400), (511), (440), etc. Miller indices for the peaks can be calculated by using Bragg's law. The data agrees with standard X-ray diffraction patterns of Fe_3O_4 nanoparticles (JCPDS file no. 00-003-0863) [9-11].

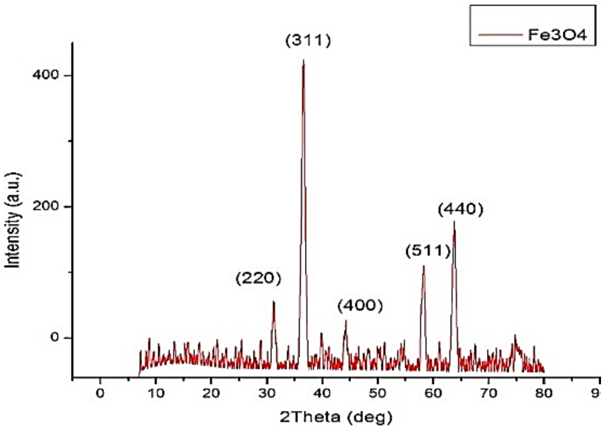

Fig. 1 – X-ray pattern

3.1.2 Ultraviolet-Visible Spectroscopy (UV-Vis)

The maximum absorbance intensity was found to be at 455 nm, after which the absorbance is found to decrease as the wavelength increases (Fig. 2).

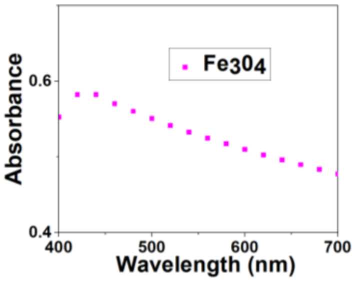

Fig. 2 – UV-vis absorption

3.1.3 Photoluminescence

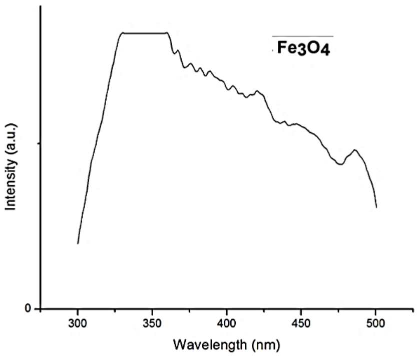

Fig. 3 – Photoluminescence

Fig. 3 shows the graph between intensity and wavelength for Fe_3O_4 nanoparticles. The intensity is found to increase first and it reaches a maximum at a wavelength of about 560 nm. After reaching the maximum, the intensity begins to decrease.

3.1.4 Zetasizer

Fig. 4 shows the variation of intensity with size for Fe_3O_4 nanoparticles. The average particle size was found to be 45 nm.

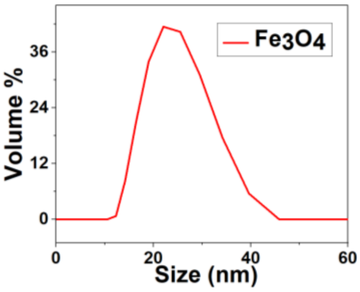

Fig. 4 – Zetasizer

3.1.5 Rheology

Fig. 5 shows the graph of viscosity vs temperature. It is observed from the graph that the viscosity of Fe_3O_4-based nanolubricant decreases as the temperature increases and the trend is similar for all three concentrations of Fe_3O_4 nanoparticles. This is because the kinetic energy of molecules increases and the intermolecular force of attraction becomes weak as the temperature increases. The viscosity is maximum at 30 °C and the lowest at 80 °C. At initial temperatures, the change in viscosity is abrupt [12].

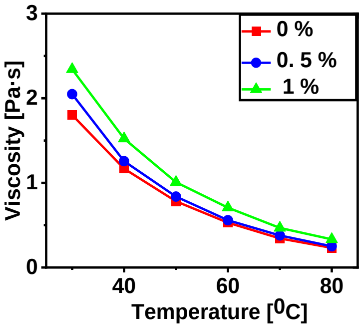

Fig. 5 – Viscosity vs temperature

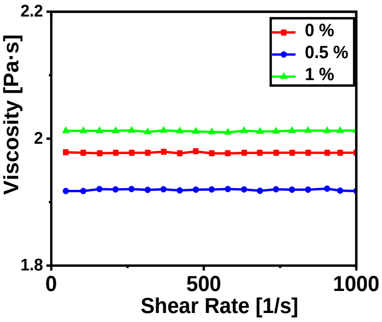

Fig. 6 – Viscosity vs shear rate

The viscosity vs shear rate is shown in Fig. 6 for Fe_3O_4 nanoparticles mixed with pongamia oil at different concentrations. From Fig. 11, it is understood that the viscosity is not dependent on the shear rate. As the shear rate increases, the viscosity remains constant throughout. Hence, this confirms the Newtonian nature of the nanolubricant. It is also observed from the graph that the viscosity increases as the doping of Fe_3O_4 nano-particles increases. A similar trend in the graph was also obtained by Chen and Xie [13].

3.1.6 Tribology

Fig. 7 shows the change in frictional force (FF) with sliding distance at a load of 50 N for all compositions. It is observed from the graph that there is no change in the coefficient of friction with sliding distance. The graph also reveals that FF decreases as the concentration of Fe_3O_4 nanoparticles increases in the base oil. This decrease in the FF with increasing concentration was also observed by Singh et al., 2016 [9, 14].

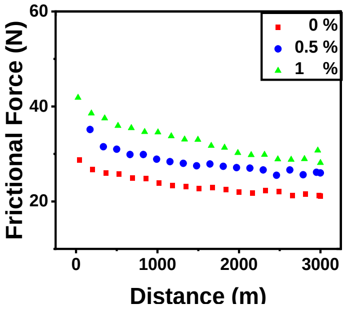

Fig. 7 – Frictional force vs distance

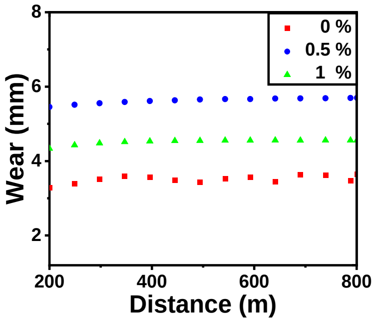

Fig. 8 – Wear vs distance

Fig. 8 represents the graph between wear and distance for different concentrations of Fe_3O_4 nanoparticles in pongamia oil. The wear rate remains constant as the sliding distance increases, as per Fig. 8. However, it is also observed from the graph that the wear rate decreases as the concentration of Fe_3O_4 nanoparticles in the pongamia oil increases [15].

4. CONCLUSIONS

Nanoblended Fe_3O_4 pongamia oil was successfully developed with disbursed particles. The 0.5 % shows excellent properties like low friction and wear. The XRD pattern revealed nanoparticle formation. The viscosity was constant concerning the shear rate. The viscosity showed a Newtonian behavior with temperature. 0.5 % blend can be considered an excellent candidate for mineral oil replacement.

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Аналіз тертя, зношування та в'язкості мастила понгамієвої олії на основі наночастинок Fe_3O_4

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Наномастила – це нанорідини, які використовуються для змащування механізмів. Вони особливо використовуються як мастильні матеріали в автомобільній промисловості через їх відмінні властивості зменшення тертя. У роботі досліджуються тертя, зношування та в'язкість наночастинок Fe_3O_4, змішаних з понгамієвою олією при концентраціях 0, 0,5 та 1 мас. %. Магнітні наночастинки Fe_3O_4 демонструють відмінні властивості зменшення тертя, коли їх використовують як добавки до базової олії, і результати це також підтверджують, оскільки коефіцієнт тертя зменшується зі збільшенням вмісту наночастинок Fe_3O_4 в базовій олії. Нанорідина, отримана шляхом додавання наночастинок Fe_3O_4 до суміші понгамієвої олії, демонструє ньютонівську поведінку, тобто в'язкість рідини залишатиметься постійною незалежно від величини прикладеної напруги зсуву. Однак із підвищенням температури від 40 до 80 °C в'язкість нанорідини зменшується.

Ключові слова: Зношування, Тертя, В'язкість, Наночастинка.