Vol. 02, Iss. 4 (2024) 273-278, DOI: 10.61552/JME.2024.04.005

JME

Journal of Materials and Engineering

www.jme.aspur.rs

Research article

Study of Variation in Physicochemical Properties of a Worm Gearbox Lubricant by Blending Castor Oil in the Base Lubricant

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Keywords:

TAN
TBN
Castor oil
Worm gear box

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Received: 3 March 2024
Revised: 19 April 2024
Accepted: 21 May 2024

A B S T R A C T

In both industrial & heavy-duty applications, oil analysis can be a very effective strategy for preventing gearbox failure, cutting downtime, and managing maintenance costs. In any application, gearboxes are essential to production, the unplanned downtime and the resulting productivity losses can prove to be extremely expensive. Used oil analysis is a preventative maintenance procedure that can point out and pinpoint mechanical breakdown inside the system before it gets serious or becomes too expensive to fix. A thorough oil examination can identify wear, corrosion, and other changes that could be harmful to the health and durability of the machinery.

To reduce machine wear, prevent contamination, or optimize working conditions in challenging environments, lubricants are carefully formulated by mixing additives in the base oil. A lubricant with a high acid content can cause varnish and sludge to accumulate, which can clog oil filters and cause machine parts to corrode. When a lubricant degrades, acidic byproducts are produced because of the base stock and additives' process of decomposition in the presence of heat and air.

To assess the presence of acidic constituents in the oil or its acid concentration, Total Acid Number (TAN) oil testing is employed.

The present work studies the effects on Total Acid Number (TAN) and Total Base Number (TBN) properties of commercial lubricant (EP 90) when castor oil is mixed in percentage concentration in it. The findings of this research have unveiled that the acidic characteristics of the base lubricant (EP90 commercial gear oil) increases as the percentage of castor oil additive is increased in the base lubricant oil.

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1. INTRODUCTION

Since a few decades ago, environmental concerns have been taken seriously, and lubricating oils play a significant role in this because they are essential components of modern life. For the disposal of used, contaminated lubricating oils, strict legislation are being studied, thought about, and developed around the world. Due to its adverse impact on the environment, including reduced biodegradability and increased toxicity, there has been a continuous rise in the demand for biodegradable and environmentally friendly lubricating oils. The rising expenses associated with synthetic mineral oils have prompted industries to seek alternative solutions in order to satisfy the increasing demand. Compared to currently available commercial lubricants, used bio-oils degrade quickly and naturally with no adverse effects on human health. Bio-oil mist has no adverse impact on human respiratory systems and exhibits non-reactive properties when it comes into contact with human skin.

When gearboxes make use of lubricating oils, they frequently encounter challenging conditions characterized by high temperatures and fluctuating oxidation levels. These environmental factors can lead to modifications in the characteristics of the lubricants, such as their viscosity, carbon residue, sludge content, acidity, and alkalinity. Consequently, these changes can impact various machinery components and lead to the deterioration of the lubricant itself.

The major reasons for the early gearbox failure are incorrect application selection, improper installation, gear oil contamination and impact loads. Failures of the gear box can be avoided well before they occur by monitoring the responses like vibration and temperature. Increased vibrations and an unusual rise in temperature are the first signs of gear box failure. The present work studies the effects on TAN and TBN properties of commercial lubricant (EP 90) when castor oil is added in percentage concentration in it.

2. LITERATURE REVIEW

Many different types of acidic compounds can lead to a rise in the TAN value, oxidation products are major contributor in it. Since the TAN value only assesses the acid concentration and not the precise amounts of the different acidic compounds present in the sample, it cannot be used to predict how corrosive the lubricants will be. TAN value's rate of change is more significant than the absolute value. With degradation, oxidation, and impurities formation the TAN rate change shows major increase. There are several factors that can cause a rapid increase, including excessive degradation or a change in the fuel's Sulphur content.

The higher TBN means the oil has good acid neutralizing properties but with high TBN values solid by-products (ashes) gets generated in the lubricants. In general, industrial practices, when TBN values reduces to 50 percent of the new oil value then the lubricant is changed. If the TBN value decreases, this might mean that during the oil's time in the machine, acids were neutralized. Evaluating the quality of lubricating oil involves assessing various performance parameters, which encompass factors such as TAN, TBN, viscosity, and particle count. These parameters serve as indicators of both the lubricant's performance and its degree of deterioration. Among these indicators, viscosity emerges as a crucial and objective measure for detecting oil degradation.

In accordance with their research findings, Nagy et al. [1] identified a robust association between the longevity of oil service and the levels of TAN (Total Acid Number) and TBN (Total Base Number) values. As outlined by Chawla and Sharma [2], it is recommended to perform an oil change when the Total Base Number (TBN) diminishes to 50% of its initial value. To rapidly examine and monitor used engine oils, Bassbasi et al. [3] proposed using infrared spectroscopy. This technique provides information on the chemical structure of the samples by identifying specific bonds and groups in their IR spectra. In various applications, bio lubricants have the potential to replace conventional lubricants. The fast biodegradability and good viscosity index of the bio lubricant are two of its most useful characteristics. Triacylglycerols are combinations of different types of acids mostly fatty. It constitutes more than 95 percent of the oils extracted from plant and animal origin. In vegetable oils triacylglycerols content is almost 99 percent. The molecules of triacylglycerols have tendency to orient themselves at the solid surface making a close film which is a major desirable quality of a lubricant as discussed by Rudnick [4]. Suarez et al. [5] have concluded that vegetable oil triacylglycerols have a higher orientation tendency than fossil fuels, which accounts for their strong attraction to solid metal surfaces. Kalin et al. [6] have mentioned that the polarity-dependent forces (absorption) that triacylglycerol additive molecules exhibit in natural seed-based oils cause them to get attracted to metal surfaces. In line with Lang et al.'s research [7], it is evident that the elevated viscosity of natural oils plays a crucial role in mitigating the evaporation of the lubricant.

Based on their respective research findings, Joseph et al. [8] determined that among the three natural seed oils under investigation, castor oil exhibited the most consistent thermo-oxidative properties. In a separate study, Kazeemet et al. [9] assessed the physical characteristics of castor oil and reached the conclusion that it presents a viable alternative to traditional lubricants. Furthermore, Kržan et al. [10] conducted field experiments involving nine natural oils and ascertained that castor oil's elevated viscosity makes it a promising candidate for lubrication purposes. Shashidhara et al. [11] also supported this notion by affirming that castor oil possesses the potential to serve as a lubricant in gear applications. Table 1 lists the physical properties as observed by Karmakar et al. [12] of castor oil. Thapliyal and Thakre [13] have established that viscosity plays a substantial role in influencing the performance of lubricants with respect to friction and wear. This viscosity, in turn, is subject to influence based on factors such as density, TAN, and TBN values. The research conducted by Nagy et al. [14] revealed a significant connection between the longevity of oil service and the levels of TAN and TBN in the analyzed samples. They have introduced a straightforward model that relies on a polynomial fitting function for forecasting friction and wear based on TAN and TBN data. Raposo et al. [15] conducted a comprehensive investigation into the process of oil degradation and devised an anticipatory maintenance strategy for extending the lifespan of oil. Artur [16] has proposed a model that relies on variations in the TAN (Total Acid Number) of in-service engine oils, enabling the prediction of the oil's performance throughout its operational life. A Hussain et al. [17] have demonstrated that certain combinations of castor oil with commercial lubricant oils exhibit superior tribological performance in comparison to either commercial lubricant oils or pure castor oil. Hirani et al. [18] have suggested that pH monitoring may be a more accurate indicator of oil degradation.

Table 1. Castor oil properties [12].

Property	Natural Castor oil
Iodine Value	83.0 – 86.0
Pour Point (ºC)	-21.0
Cloud Point (ºC)	-18.0
Kinematic Viscosity at 40 ºC (mm^2/s)	251.0
Viscosity at 100 °C, (cSt)	19.8
Flash Point (ºC)	229.0
Density at 15 ºC (g/cm^3)	0.960

3. EXPERIMENTAL SETUP

To conduct this research, a unique worm gear test rig system was designed and constructed. The key elements comprising the chosen test rig assembly are illustrated in Figure 1. The test rig features a gear box equipped with a half-horsepower motor. A specialized mechanism was developed to exert controlled loads on the output shaft of the gear box, utilizing a hanger bearing setup. All the constituent parts of the test rig were meticulously assembled and securely affixed to a sturdy square base. To prevent any vibrations caused by the test rig being resting unevenly, rubber bushings are provided at each of its four legs.

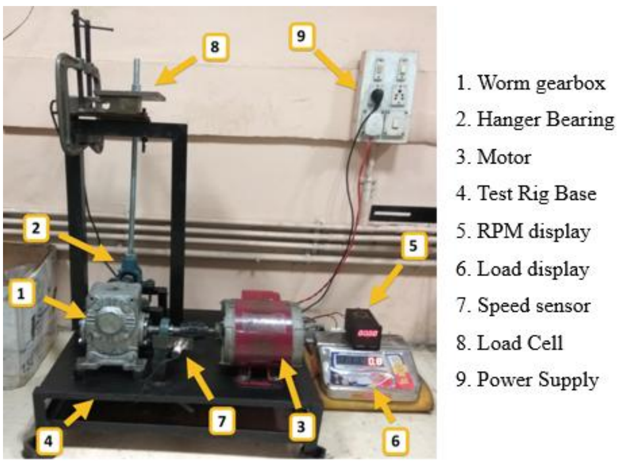

Fig. 1. Experimental setup.

4. EXPERIMENTATION

In this experiment, how the properties of the chosen system (specifically, the alterations in TAN and TBN) are affected when natural castor oil is introduced as a supplement to the base EP90 oil are observed. The experimental procedure involves the application of a consistent 5 Kg load and a 40 Kg load to the output shaft of the gearbox. In this experimentation, oil samples are collected for a fixed interval to check the changes occurring in the physicochemical properties of the oil during gearbox operation. Total 3 different oil blends are selected for the experiment. A total of nine samples were gathered for each oil blend, resulting in a combined total of 27 oil samples collected throughout the entire experiment. First experiment was carried out using the 100% commercial EP90 gear oil. In the second experiment 25% castor oil was added in the base commercial EP90 oil and in the third experiment 50% castor oil was added in the base commercial EP90 oil. Table 2 shows the details of all the 3 oil blends selected for this experiment.

Table 2. Experimentation details for castor oil additive.

<table>
<tr><th>Reading</th><th>Time (Hours)</th><th>Load applied (Kg)</th><th>Oil Blend Name & % of Oil Content</th><th>Additives %</th><th>Oil Sample Collection</th></tr>
<tr><td rowspan="5">Experiment With Minimum External Load</td><td>Initial</td><td rowspan="5">5</td><td rowspan="3">EP-90-01
[100 % Commercial Gear Oil EP90]</td><td rowspan="3">No Additives added</td><td rowspan="10">After every 2-hour operation.
9 samples collected for each oil blend

Total 27 oil samples are collected for 3 oil blends</td></tr>
<tr><td>After 2 hours</td></tr>
<tr><td>After 4 hours</td></tr>
<tr><td>After 6 hours</td><td rowspan="4">EP-CAS-01
75% Commercial Gear Oil EP90
+
Additive</td><td rowspan="4">25% Castor Oil</td></tr>
<tr><td>After 8 hours</td></tr>
<tr><td rowspan="5">Experiment With Constant External Loading</td><td>Initial</td><td rowspan="5">40</td></tr>
<tr><td>After 2 hours</td></tr>
<tr><td>After 4 hours</td><td rowspan="3">EP-CAS-02
50% Commercial Gear Oil EP90
+
Additive</td><td rowspan="3">50% Castor Oil</td></tr>
<tr><td>After 6 hours</td></tr>
<tr><td>After 8 hours</td></tr>
</table>

As shown in Fig. 2, The examination of gathered oil samples is facilitated by the employment of the Fluid Scan Q1000 device. Fluid Scan represents a user-friendly handheld apparatus, designed for straightforward operation. The individual simply needs to apply a small amount of oil onto the glass surface for further examination. Once the user has identified the appropriate reference oil via the device's User Interface, comprehensive tribological characteristics of the chosen oil sample are promptly presented on the device's screen. The functioning of this device relies on an infrared light mechanism to assess various properties of the provided oil sample. ASTM EP gear oil has been chosen as the foundational lubricant category for this study.

The examination of physicochemical characteristics, including parameters like TAN and TBN, forms an integral part of this study. Subsequently, the attributes of the chosen oil blends are compared with the established properties of EP 90 commercial gear oil. Visual representations in the form of histograms are exercised to analyze the performance of the selected oil blends based on the collected data. The fluid scan device, which is used for lubricant oil properties investigation, don't have natural oil properties details in its database, hence the natural oil blends & standard EP90 oil properties are equated with the EP 90 gear oil properties present in the fluid scan device database. So, instead of absolute numerical value comparison, it will be better to refer how the property result variations are happening between used oil samples of commercial EP 90 oil and the castor oil blends.

Fig. 2. Oil scanning using Fluid Scan Q1000 device.

5. RESULTS

In this experimentation, oil samples are collected for a fixed interval to check the changes occurring in the physicochemical properties of the oil during gearbox operation. Total 3 different oil blends are selected for the experiment. Nine samples were gathered for each oil blend, resulting in a total of 27 oil samples collected throughout the entire experiment.

Histogram is drawn for these readings to understand the property variation in better format. Fig. 3 shows the TAN, TBN fluid scan results for the selected three oil blends in histogram format.

The physicochemical properties (TAN, and TBN) results obtained through the utilization of the Fluid Scan device for all the gathered oil samples are elaborated upon in the following section.

TAN: TAN (The Total Acid Number) is a lubricant's acid concentration measurement. The TAN measurements indicate a noticeable rise in values for the EP-CAS-01 and EP-CAS-02 blends when compared to the reference standard blend, EP-90-01.

TBN: TBN (Total Base Number) is a lubricant's alkaline concentration measurement. Alkaline additives are incorporated into the formulation of oils to prevent the formation of acids as lubricants degrade. The TBN values have exhibited a noticeable decline in the case of blends EP-CAS-01 and EP-CAS-02 when compared to the reference blend EP-90-01.

The analysis of Total Acid Number indicates an increase in values, while the Total Base Number (TBN) demonstrates a decrease, as illustrated in Figure 3. This suggests a shift towards higher acidity and reduced alkalinity in the oil. TBN is crucial as it reflects the oil's capacity to neutralize acidic contaminants. Based on the TAN and TBN values, it can be inferred that the interior of the gearbox is susceptible to corrosion. Notably, as the percentage of castor oil additive in the base EP90 oil rises, the TBN decreases, and the TAN increases. With the TBN results it is observed that that the acidicity of the blend oil increases with the addition of castor oil in it and hence addition of castor oil as an additive should be limited to small percentage only.

Typically, the formation of weak organic acids is a common outcome of lubricant oil oxidation. However, the primary origin of acidic contamination within lubricants can be attributed to the introduction of fuel combustion byproducts, particularly sulfur and nitrogen oxides. The presence of acids in the oil accelerates the corrosion process. Notably, non-ferrous metals, such as copper, are susceptible to chemical erosion and can dissolve in the oil. Additionally, iron corrodes more rapidly in acidic oil, leading to the formation of rust, which, in turn, exacerbates mechanical abrasive wear. The removal of these corrosion particles can instigate a chain reaction, causing further wear. Elevated acid levels in the oil promote oxidation and contribute to oil aging. Oxidized oil typically thickens, and this increased viscosity may eventually impede the effective lubrication of vital components.

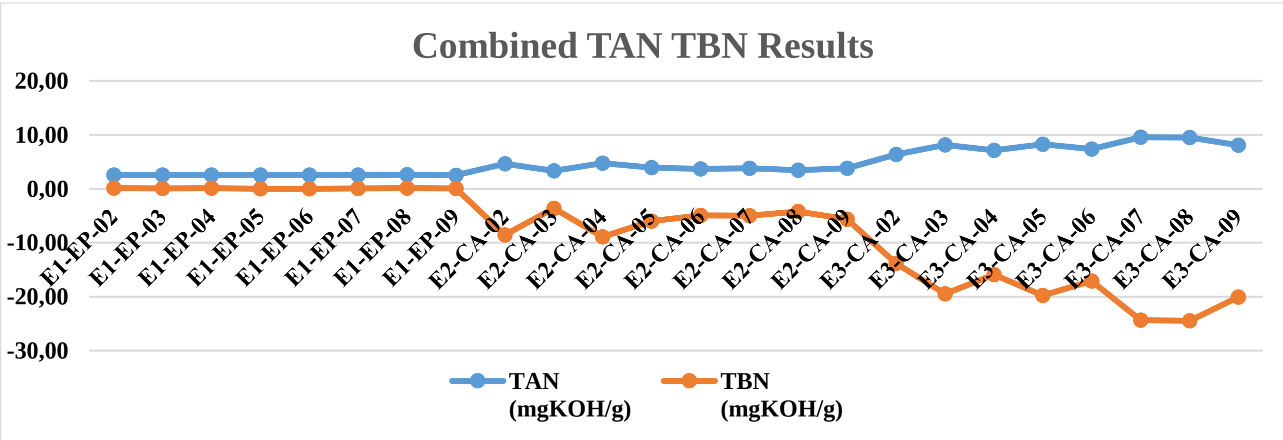

Fig. 3. TAN TBN results comparison.

6. CONCLUSIONS

The acidity level of the base lubricant that is EP 90 commercial gear oil, tends to rise with the greater inclusion of castor oil as an additive. For instance, a sample containing 25% castor oil as an additive exhibited a lower Total Acid Number (TAN) compared to a sample with 50% castor oil as an additive.

Introducing castor oil into the base lubricant oil has expedited the sulfation mechanism. The reaction between the commercial oil and the natural castor oil at optimum temperate is causing this state. Hence to limit the acidic properties of the base lubricant oil, the castor oil additive should be added in limited percentage in the base lubricant oil.

With this results a clear relationship can be observed between changes in acidic properties and changes in alkaline properties. As the acidic nature increases, the alkaline nature decreases, demonstrating an inverse proportionality. When oxidized oils with weak acids interact with strong oil bases, they mutually neutralize each other, and this equilibrium persists.

Only TAN and TBN parameters cannot provide the exact details of the oil's health and hence more precise analysis of the oil is needed to predict its accurate health. A combined condition monitoring approach is helpful in predictive maintenance.

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