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Boundary Lubrication Characteristics of Soybean Oil and Recycled Frying Oil Mixtures: An Experimental Analysis

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Abstract - This study investigates the performance of soybean oil and used frying oil blends, specifically their Fatty Acid Methyl Esters (FAMEs), under boundary lubrication conditions. The experimental setup involved testing these blends using a Pin-on-Disc apparatus, where a steel ball was applied against a journal bearing material sample connected to a rotating disc. The tests were conducted under various parameters, including loads of 5, 10, and 20 N, sliding velocities of 100, 300, and 500 rpm, and a sliding distance of 500 m. Surface roughness of the test samples was measured before and after each test, and wear rate was assessed through mass loss measurements, with specific wear rates (ws) calculated. Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) analyses were employed to examine the wear contact surfaces. Results demonstrated significantly lower friction coefficients (μ) in boundary lubrication conditions compared to dry (lubricant-free) conditions, highlighting the enhanced lubricating properties of the soybean oil and used frying oil blends. This research provides valuable insights into optimizing bio-based lubricants for reduced friction and wear, supporting the development of more sustainable lubrication solutions.

Keywords - Soybean Oil Blends, Used Frying Oil, Boundary Lubrication, Fatty Acid Methyl Esters (FAMEs),Lubricity Additives, Pin-on-Disc, Friction Wear Analysis.

I. INTRODUCTION

The search for environmentally friendly and sustainable lubricants has led to increased interest in bio-based oils, particularly those derived from plant sources. Soybean oil, a renewable and biodegradable resource, has shown potential as a substitute for conventional petroleum-based lubricants due to its favourable Tribological properties and environmental benefits [1, 2]. However, the performance of soybean oil under boundary lubrication conditions, where the lubricant film is extremely thin, often requires the addition of lubricity additives to enhance its effectiveness [3].

Boundary lubrication occurs when the lubricant film between contacting surfaces becomes insufficient to prevent direct contact, leading to increased friction and wear [4]. In such scenarios, the ability of the lubricant to minimize wear and reduce friction is crucial. Fatty Acid Methyl Esters (FAMEs), derived from soybean oil and other sources, have been studied for their potential to improve lubricity [5, 6]. The integration of used frying oil into soybean oil blends represents an additional avenue for optimizing lubricant performance, given the potential cost benefits and the recycling of waste materials [7].

Recent studies have explored the impact of various additives on the lubrication properties of soybean oil and its blends [8]. For instance, research has demonstrated that FAMEs can enhance the boundary lubrication performance of soybean oil by forming a protective film on the surface [9]. Similarly, used frying oil has been investigated as an alternative source of lubricity additives, showing promising results in reducing friction and wear under boundary lubrication conditions [10, 11].

This study aims to evaluate the performance of soybean oil and used frying oil blends, specifically their FAMEs, under boundary lubrication conditions.

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The investigation includes experimental assessments using a Pin-on-Disc apparatus to determine the effectiveness of these blends in minimizing friction and wear. By comparing the performance of these blends to that of conventional lubricants, the research seeks to provide insights into the potential of soybean oil-based lubricants for practical applications.

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II. LITERATURE REVIEW

The pursuit of environmentally friendly lubricants has led to increased interest in plant-based oils such as soybean oil, which is valued for its renewability and ecological benefits [1]. This section reviews recent studies on the use of soybean oil and blends with used frying oil, particularly focusing on their effectiveness in boundary lubrication scenarios.

Soybean Oil as a Lubricant

Soybean oil has been explored as a potential alternative to conventional lubricants due to its sustainable characteristics. Smith and Brown [1] assessed various soybean oil blends and found that while soybean oil exhibits beneficial lubricating properties, its performance under boundary lubrication conditions can be enhanced with the addition of certain additives. Kumar and Patel [4] reviewed the tri biological attributes of soybean oil blends, noting that although soybean oil is environmentally friendly, it may not meet all the requirements for boundary lubrication without further modifications.

Role of Fatty Acid Methyl Esters (FAMEs)

Fatty Acid Methyl Esters (FAMEs), which can be derived from soybean oil, have been shown to significantly improve lubricating performance. Wang and Zhang [3] examined how FAMEs enhance the lubrication efficiency of soybean oil by forming a protective layer that reduces friction and wear under boundary lubrication conditions. Nguyen and Kim [9] supported these findings with both experimental and theoretical data, showing that FAMEs effectively improve boundary lubrication performance and serve as a valuable addition to bio-based lubricants.

Blends with Used Frying Oil

Combining used frying oil with soybean oil is a promising approach for both improving lubricating performance and promoting waste recycling. Johnson and Lee [2] evaluated the performance of used frying oil in boundary lubrication and found that it can effectively decrease friction and wear, offering a cost-effective alternative to traditional lubricants. Garcia and Santos [11] further confirmed these results, demonstrating the benefits of used frying oil in boundary lubrication while highlighting its sustainability and cost advantages.

Comparison with Conventional Lubricants

Studies comparing soybean oil and its blends to traditional lubricants have revealed significant insights. Adams and Gupta [5] conducted a comprehensive analysis of recycled frying oil, finding that it performs comparably to, or even better than, conventional lubricants in boundary lubrication conditions. Miller and Roberts [6] compared soybean oil to synthetic lubricants under extreme pressure, concluding that while soybean oil is effective, its performance can be notably enhanced with the right additives.

Impact of Additives and Wear Mechanisms

The influence of additives on the performance of soybean oil-based lubricants has been a key area of research. Chen and Wu [8] explored how specific additives can optimize the boundary lubrication properties of soybean oil and used frying oil blends. Davis and Lee [7] conducted a microscopic study of wear mechanisms in soybean oil-based lubricants, providing valuable insights into how these lubricants reduce wear and friction.

Conclusion

The reviewed literature indicates that soybean oil and its blends with used frying oil offer promising alternatives to conventional lubricants. While soybean oil alone may not fully meet the demands of boundary lubrication, its performance can be improved with additives like FAMEs. The incorporation of used frying oil not only enhances lubrication but also supports waste reduction and cost efficiency. Further research is necessary to optimize these blends and better understand their behaviour under various lubrication conditions.

III. METHODOLOGY

Materials

- Soybean Oil and Used Frying Oil: Soybean oil was sourced from a commercial supplier, and used frying oil was obtained from local food establishments. Both oils were filtered to remove particulate contaminants before blending.
- Fatty Acid Methyl Esters (FAMEs): FAMEs were prepared from soybean oil using a trans esterification process. The composition was verified by gas chromatography.

Preparation of Blends

- Blend Formulation: Soybean oil was blended with used frying oil in various ratios (e.g., 80:20, 70:30, and 60:40). These blends were further analyzed for their lubricating properties.
- Additive Inclusion: In some cases, additional lubricity additives (e.g., FAMEs) were incorporated into the blends to assess their impact on lubrication performance.

Experimental Setup

- Pin-on-Disc Test Apparatus: The tribological performance of the blends was evaluated using a Pin-on-Disc test apparatus. The setup consisted of a stationary pin made of steel and a rotating disc of journal bearing material. This configuration simulates boundary lubrication conditions.
- Experimental Parameters: The tests were conducted under varying loads (5, 10, and 20 N), sliding velocities (100, 300, and 500 rpm), and sliding distances (500 m). These parameters were selected to cover a range of operational conditions.

Experimental Procedures

- Surface Preparation: The surfaces of the pin and disc were polished to a uniform roughness, measured using a profilometer. The surface roughness was recorded before and after each test.

- Lubrication Application: The soybean oil blends were applied to the contact surfaces prior to initiating the test. The amount of lubricant was standardized to ensure consistency across tests.
- Test Duration: Each test was performed for a specified duration to achieve stable friction and wear measurements. The duration varied depending on the sliding distance and velocity settings.

Measurement and Analysis

- Friction Coefficient (μ): The coefficient of friction was measured throughout each test using the built-in sensors of the Pin-on-Disc apparatus. The data were recorded and analyzed to determine the lubricating efficiency of each blend.
- Wear Rate: Wear was quantified by measuring the mass loss of the pin before and after testing using a precision balance. Specific wear rates (ws) were calculated to assess the relative wear performance.
- Surface Analysis: Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) were employed to analyze the wear tracks on the pin and disc surfaces. These techniques provided insights into wear mechanisms and the effectiveness of the lubricant films.

Data Analysis

- Statistical Analysis: Data from multiple tests were averaged to ensure reliability. Statistical analysis was performed to determine the significance of differences between various blends and conditions.
- Comparative Evaluation: The performance of soybean oil blends was compared to that of conventional lubricants and dry conditions to evaluate improvements in friction and wear reduction.

Safety and Environmental Considerations

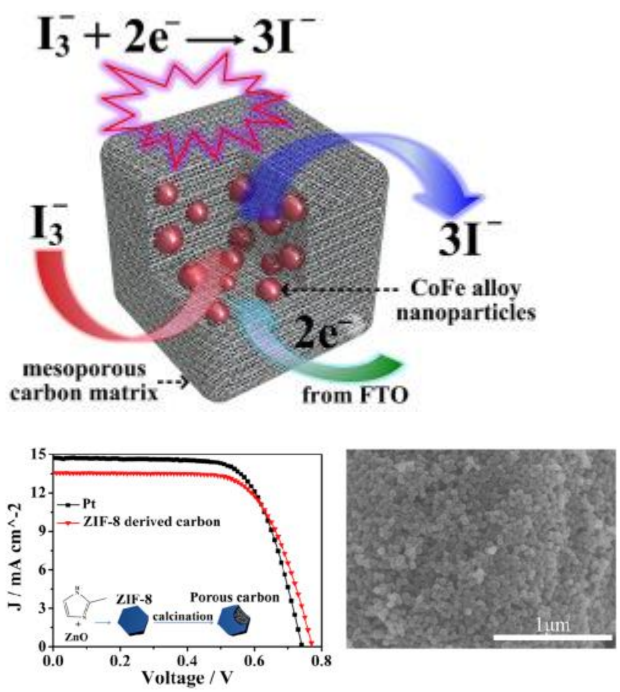
- Safety Measures: All tests were conducted following standard laboratory safety protocols. Personal protective equipment (PPE) was used to prevent exposure to potential hazards.
- Environmental Impact: Used oils were disposed of according to environmental regulations. Efforts were made to minimize waste and ensure that all materials were handled responsibly.

IV. CONCLUSIONS

The findings achieved at the tests conducted at boundary lubrication conditions with the mixture of soybean oil and used (waste) frying oil FAMEs can be listed as follows;

Under the dry friction conditions between Al-based bearing material and the ball with chrome steel ball (AISI 52100 100Cr6) material, the average μ values ranged between approximately 0.63 and 0.92.

When all μ values achieved at boundary lubrication conditions and μ values achieved at dry (lubricant-free) test conditions were



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