SAL SEED OIL AS A BIODEGRADABLE LUBRICANT: PROPERTIES, CHALLENGES, AND COMMERCIAL PROSPECTS

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Annotatsiya: Neftga asoslangan moylash materiallarining atrof-muhitga ta'siri ortib borayotganligi sababli, barqaror alternativalarni ishlab chiqish zarur. *Shorea robusta* daraxtidan olinadigan tabiiy moy bo‘lgan Sal yog‘i (SSO) ajoyib yechim bo‘lib, u yuqori tribologik xususiyatlarga, tabiiy biologik parchalanuvchanlikka va qayta tiklanadigan resurs bazasiga ega. Ushbu keng qamrovli sharh SSO ning biologik parchalanadigan moylash materiali sifatidagi maqsadga muvofiqligini tanqidiy baholaydi, uning fizik-kimyoviy xususiyatlarini, tribologik xatti-harakatini, ekologik afzalliklarini, joriy etishdagi to‘siqlarni va kelajakdagi tadqiqot yo‘nalishlarini amaldagi adabiyotlarni chuqur tahlil qilish asosida sinchkovlik bilan o‘rganadi.

Kalit so’zlar: Sal urug'i moyi, *Shorea robusta*, o'simlik moylari, barqaror moylash materiallari, tribologiya, moylash ko'rsatkichlari, yopishqoqlik indeksi, porlash nuqtasi, biologik parchalanish, aşınmaya qarshi qo'shimchalar, o'simlik moylari, oksidlanish barqarorligi.

Аннотация: Растущее воздействие смазочных материалов на основе нефти на окружающую среду требует разработки устойчивых альтернатив. Саловое масло (SSO), натуральное масло, получаемое из дерева *Shorea robusta*, представляет собой убедительное решение, демонстрируя превосходные трибологические характеристики, присущую биоразлагаемость и возобновляемую сырьевую базу. Настоящий всесторонний обзор критически оценивает пригодность SSO в качестве биоразлагаемого смазочного материала, тщательно изучая его физико-химические характеристики, трибологическое поведение, экологические преимущества, препятствия на пути внедрения и будущие направления исследований, опираясь на тщательный анализ текущей литературы.

Ключевые слова: масло семян сала, *Shorea Robusta*, растительные масла, экологически чистые смазочные материалы, трибология, характеристики смазки, индекс вязкости, температура вспышки, биоразложение, противоизносные присадки, растительные масла, устойчивость к окислению.

Abstract: The escalating environmental impact of petroleum-based lubricants necessitates the development of sustainable alternatives. Sal seed oil (SSO), a natural oil derived from the *Shorea robusta* tree, presents a compelling solution, exhibiting superior tribological performance, inherent biodegradability, and a

renewable resource base. This comprehensive review critically assesses SSO's viability as a biodegradable lubricant by meticulously examining its physicochemical characteristics, tribological behavior, ecological benefits, hurdles to implementation, and future research directions, drawing upon a thorough analysis of current literature.

Keywords: Sal seed oil, *Shorea robusta,* vegetable oils, sustainable lubricants, tribology, lubrication performance, viscosity index, flash point, biodegradation, antiwear additives, vegetable oils, oxidation stability.

INTRODUCTION

The escalating demand for energy and the environmental concerns associated with petroleum-based lubricants have driven the search for sustainable alternatives [1]. Biodegradable lubricants derived from vegetable oils have emerged as promising candidates due to their renewability, low toxicity, and superior biodegradability compared to their synthetic counterparts [5]. Among these, Sal seed oil (SSO), extracted from the seeds of *Shorea robusta* (Sal) trees, has attracted significant attention for its potential as a lubricant base stock due to its unique properties [3].

This review delves into the prospects of SSO as a biodegradable lubricant, exploring its physicochemical properties, tribological performance, modification strategies, and challenges and opportunities in its commercialization. SSO exhibits several desirable characteristics for lubricant applications. SSO is naturally biodegradable with a reported biodegradation rate exceeding 90% within 28 days, significantly higher than mineral oils [2]. SSO boasts a light yellow hue and a pleasant odor, indicating its non-toxic nature. Its fatty acid composition, dominated by oleic acid (55-65%), palmitic acid (25-35%), and stearic acid (5-10%), plays a crucial role in shaping its advantageous properties [6]. These fatty acids contribute to:

- High viscosity index (VI): SSO's VI (150-200) is significantly higher than that of mineral oils (90-100), indicating minimal viscosity change with temperature fluctuations, ensuring consistent lubrication performance across a wider range of operating conditions [4].
- Good oxidation stability: SSO exhibits superior resistance to oxidation compared to mineral oils, minimizing lubricant degradation and extending its lifespan under high-temperature environments [6].
- Low pour point: With a pour point ranging from -15 to -20°C, SSO maintains fluidity at low temperatures, making it suitable for

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applications in cold weather conditions where mineral oils might solidify [4].

- High flash point: SSO's high flash point (220-240°C) indicates excellent thermal resistance, making it suitable for high-temperature applications where mineral oils might pose fire hazards [6].

METHODS

This work is a literature-based review synthesizing findings from peer-reviewed articles on SSO. Sources were selected based on their relevance to:

- Physicochemical properties of SSO,
- Tribological testing (e.g., pin-on-disc tribometer studies),
- Modification strategies (e.g., esterification, additive enhancement),
- Commercialization challenges and opportunities.

Comparative data between SSO and mineral oils were compiled from established studies and summarized in tabular format to aid interpretation.

RESULTS AND DISCUSSION

Table 1 highlights how SSO exhibits key characteristics desirable for lubrication.

Property	Sal Seed Oil (SSO)	Mineral Oil
Biodegradability	>90% in 28 days	Low
Viscosity Index (VI)	150–200	90–100
Pour Point	–15°C to –20°C	–10°C to –15°C
Flash Point	220–240°C	170–210°C
Oxidation Stability	High	Moderate
Color and Odor	Light yellow, pleasant	Variable, often odorless

Table 1. Key characteristics of lubrications

These properties suggest SSO is suitable for both high- and low-temperature environments, with excellent thermal resistance, flowability at cold temperatures, and reduced viscosity loss.

Tribological performance refers to the friction, wear, and lubrication characteristics of a material under contact. Studies have demonstrated the promising tribological behavior of SSO as a lubricant. In pin-on-disc tribometer tests, SSO displayed lower friction coefficients and wear rates compared to mineral oil, indicating its superior lubricating ability [2]. Additionally, SSO exhibited good film-forming properties, contributing to reduced wear and protection against metal-to-metal contact [7].

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However, SSO possesses limitations that hinder its widespread application as a lubricant. Its inherent low viscosity, especially at elevated temperatures, can compromise its load-carrying capacity and film thickness, leading to increased wear and friction under high-pressure conditions [5]. Additionally, the presence of free fatty acids in SSO makes it susceptible to oxidation and thermal degradation, limiting its service life and performance [3].

To address the limitations of SSO and enhance its suitability as a lubricant, various modification strategies have been explored. Chemical modification techniques, such as esterification and epoxidation, can improve the viscosity and oxidation stability of SSO [2]. Blending SSO with synthetic or natural high-viscosity oils can also create lubricants with synergistic properties, catering to specific tribological requirements [5]. Furthermore, the addition of antioxidant and antiwear additives can significantly improve the thermal stability and wear resistance of SSO-based lubricants [7].

Despite its promising properties, the commercialization of SSO as a lubricant faces several challenges. The limited availability and high cost of SSO compared to mineral oil pose a significant obstacle to widespread adoption. Additionally, the lack of standardized testing protocols and performance benchmarks for bio-lubricants hinders their acceptance in critical industrial applications [7].

However, several opportunities exist to overcome these challenges and pave the way for the successful commercialization of SSO-based lubricants. Government policies and incentives promoting the use of bio-based products can stimulate demand and encourage investments in SSO production and processing. Additionally, research efforts focused on optimizing SSO extraction, modification techniques, and cost-effective production methods can significantly improve the economic viability of SSO-based lubricants. Furthermore , collaboration between academic researchers, industry stakeholders, and government agencies can accelerate the development and standardization of performance tests for bio-lubricants, including those based on SSO. This would provide crucial data and benchmarks to convince industries and consumers of the reliability and efficacy of SSO-based lubricants in diverse applications. Additionally, exploring the potential of SSO-based lubricants in niche markets, such as eco-friendly lubricants for agricultural machinery or environmentally sensitive areas, can offer promising avenues for early adoption and market penetration. As awareness and demand for sustainable products grow, SSO-based lubricants can gradually establish a foothold and gain wider acceptance.

CONCLUSION

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From this all, it can be concluded that Sal seed oil exhibits tremendous potential as a biodegradable and high-performance lubricant base stock. Its favorable physicochemical and tribological properties, coupled with its eco-friendly nature, make it a compelling alternative to traditional petroleum-based lubricants. However, overcoming challenges related to cost, availability, and standardized testing protocols is crucial for its successful commercialization. By focusing on optimized production, effective modification strategies, and collaborative efforts, SSO-based lubricants can carve a significant niche in the lubricant market, paving the way for a more sustainable and environmentally conscious future.

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