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A Study on the Tribological and Environmental Benefits of Iron Oxide Nanoparticle-Enriched Biodiesel Blends for IC Engines

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Abstract

This study investigates the development of bio-lubricants derived from Honge, Neem and Mahua seed oils, enhanced with iron oxide (Fe_2O_3) nanoparticles, for potential use in internal combustion engines. Through transesterification, using methanol and sodium hydroxide, biodiesel was produced and then blended in varying proportions with diesel and Fe_2O_3 nanoparticles. The properties of these blends, including flash and fire points, kinematic viscosity, cloud and pour points, density, ash content and acid number, were thoroughly assessed according to standard methodologies. Results indicated higher flash points for bio-lubricants over diesel, suggesting enhanced safety. Nanoparticle addition notably improved fuel properties, suggesting a pathway to optimising biodiesel blends for both performance and environmental benefits. The study underscores the viability of these nano-enhanced bio-lubricants as sustainable alternatives to conventional lubricants, offering significant environmental advantages, including lower sulfur emissions and cleaner combustion, aligning with global efforts towards greener energy solutions.

Keywords: *Biodiesel, Bio-lubricants, Environmental Sustainability, Iron Oxide Nanoparticles, Transesterification*

1.0 Introduction

The global reliance on oils derived from petroleum for a wide variety of purposes, such as fuels and insulating liquids, is causing a fast depletion of the oil resources that are now available. Acid rain, enormous pollution and global warming are just a few of the environmental consequences that come along with using fossil fuels, making an already serious situation even worse. Concurrently, the burgeoning demand for lubricants, underscored by the continuous rise in automotive vehicle sales worldwide, necessitates an urgent shift towards sustainable alternatives that can provide the required efficiency without compromising environmental integrity. Historically, India's agricultural sector has emerged as a significant energy consumer, where the optimisation of energy resources is crucial for economic development and environmental sustainability. The emphasis on biofuels, particularly bio-lubricants derived from renewable sources, aligns with the country's strategy to achieve energy security and environmental

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sustainability. Ethanol, with its potential to diminish carbon deposition and maintain engine cleanliness due to its inherent properties, exemplifies the shift towards bio-based alternatives. Moreover, the exploration of biodiesel, predominantly produced from edible oils, presents a viable pathway to reduce the reliance on fossil fuels[1-3].

The literature provides a substantial amount of evidence that vegetable oils have the potential to serve as environmentally friendly substitutes for traditional lubricants and the positive effects that biodiesel has on the environment, according to Chuah *et al.*,[4] diesel engines perform magnificently when fed methyl ester, a byproduct of palm olein used in cooking. On the other side, research by Fernandez *et al.*,[5] established that oils derived from vegetables are biodegradable and environmentally beneficial, making them potential power transformer alternatives. In their study of biodiesel production in Brazil, Brondani *et al.*,[6] highlighted other environmental benefits of biofuels made from edible and non-edible oils, animal fat and algae.

Kamath and Lakshmin[7] explored the dielectric properties of vegetable oils, indicating their utility in electrical applications before the 1990s. The patent issued to Shedigian[8] for using soybean oil in capacitors signifies the longstanding recognition of the utility of vegetable oils in technical applications. Bertrand *et al.*,[9] and Hosier *et al.*,[10] investigated the suitability of vegetable oils like castor and rapeseed for medium voltage equipment, highlighting their superior breakdown voltages compared to mineral oils. Kohtoh *et al.*,[11] studied the ageing effects on the electrical characteristics of insulating oil, emphasising the need for sustainable alternatives. Recent studies, such as those by Ganiger and Yuvaraj[12], focused on the incorporation of nanoparticles like Al_2O_3 to enhance the properties of biodiesel, indicating a progressive move towards nano-enhanced bio-lubricants. Based on the above studies, the present investigation focuses on the exploration of the development of bio-lubricants derived from *Honge*, *Neem* and *Mahua* seeds, blended with methyl ester and iron oxide (Fe_2O_3) nanoparticles. Unlike previous studies that predominantly focused on biodiesel fuel properties, this work specifically investigates the lubrication properties of these bio-derived lubricants in the context of Internal Combustion (IC) engines. There has to be a dramatic change in the way high-performance eco-friendly lubricants are formulated if we want to explore the use of nanoparticles such as Fe_2O_3, in bio-lubricants to enhance their tribological qualities. At a time when lubrication solutions that are both ecologically friendly and effective in reducing engine wear are urgently needed, our study contributes to the expanding body of literature on renewable lubricants. This research is unique since it reports on an exhaustive investigation of the tribological characteristics of a bio-lubricant that has been nano-enhanced and made from seed oils that have received little attention. Indeed, this is a giant leap forward in the quest to find environmentally friendly and technologically superior lubricants that do not rely on petroleum.

2.0 Experimentation

2.1 Materials and Methods

Seeds from *Honge*, *Neem* and *Mahua* trees were gathered, dried and mechanically pressed to obtain crude oil. An average oil yield of 25% was observed for all three seed types, which is equivalent to 250 ml/kg of seeds. The addition of methanol and the use of sodium hydroxide as a catalyst allowed for the transesterification of crude oils. For each type of oil, 250 millilitres of methanol and 5.5 grams of sodium hydroxide were combined with one litre of filtered oil. Two hours of swinging at 600rpm followed by 60°C heating of the mixture was the final step.

Here are the items that made up the samples: The following samples were prepared: four samples of pure biodiesel (labelled as B), three blends of 20% biodiesel and diesel (labelled as B20), three blends of 30% biodiesel and diesel (labelled as B30) and nine samples of 20% biodiesel and diesel (labelled as B20A50, B20A75, and B20A100, respectively) with 50, 75 and 100 ppm of Fe_2O_3 nanoparticles. To separate the biodiesel from the glycerol and soap residues, the mixture was given time to settle down after the transesterification process. This was done since the three components had different densities. After a series of water washes, the biodiesel was cooked to eliminate any residual methanol. To achieve homogeneity, the last nine samples were mixed with Fe_2O_3 nanoparticles and agitated at 400°C for 1 hour. This process aimed to study the influence of nanoparticle additives on the properties of the fuel.



Figure 1. Transesterification apparatus.

2.2 Property Analysis

A Pensky Marten flash point apparatus was used to ascertain the fuels' flash and fire points in accordance with the regulations outlined in IS: 1448: 1992. The purpose of this was to ensure their safety by testing their flammability. Cloud and pour points were measured using instruments that adhere to the requirements of IS: 1448. The purpose of this test is to determine how well the gasoline holds up in cold weather.

The flow properties of the lubricants at various temperatures were assessed using Redwood Viscometer No.1, in accordance with IS: 1448 guidelines. A higher viscosity index signifies improved temperature stability of the lubricating film. The energy content of the samples was analysed using a bomb calorimeter following the IS: 1448 1962 standard, which revealed information about the efficiency of the fuels. The samples' density was determined with a hydrometer using the principle of buoyancy to evaluate the biofuels' suitability for engine design specifications. The ash content analysis is conducted using an electric muffle furnace in accordance with IS: 1448 1984 standards to assess the cleanliness and combustion quality of fuels. The concentration of free fatty acids, which reflects the quality and stability of the fuel, was determined through titration following IS:1448 guidelines.

3.0 Results and Discussions

This study set out to examine the characteristics of biodiesel blends made from the oils plants *Honge*, *Neem* and *Mahua*. In particular, the research considered the use of these mixes as bio-lubricants for gasoline-powered vehicles. The investigation covered pure biofuel samples, biodiesel-diesel blends with different concentrations and blends enhanced with iron oxide (Fe_2O_3) nanoparticles. The physical and chemical properties of these samples were thoroughly evaluated using a series of tests detailed in the methodologies section. Here is a comprehensive analysis of the findings, linking them to the corresponding tables that summarise the experimental results.

The flash point of a lubricant was used to determine the ignitability of each sample during the testing process. Biofuel samples had higher flash points than diesel, with

Table 1. Fuel properties of the set 1 sample

Sl. No.	FUEL PROPERTIES	S.I. UNIT	HONGE (H)	MAHUA (M)	NEEM (N)	DIESEL (D)
1	Flash Point	°C	150	179	159	50
2	Fire Point	°C	154	184	165	54
3	Kinematic Viscosity @ 40°C	cSt	5.65	5.17	6.69	2.69
4	Kinematic Viscosity @ 100°C	cSt	2.01	2.01	2.22	1.14
5	Cloud Point	°C	-8	-6	-3	-3
6	Ash Content	%	0.089	Nil	Nil	Nil
7	Total Acid Number	mg KOH/g	1.58	1.55	5.2	0.68

Table 2. Fuel properties of set 2

Sl. No.	FUEL PROPERTIES	S.I. UNIT	(H)+(D) 20:80	(M)+(D) 20:80	(N)+(D) 20:80
1	Flash Point	°C	52	48	48
2	Fire Point	°C	56	52	54
3	Kinematic Viscosity @ 40°C	cSt	2.71	2.55	3.04
4	Kinematic Viscosity @ 100°C	cSt	1.14	1.1	1.27
5	Cloud Point	°C	-3	-1	-5
6	Ash Content	%	Nil	Nil	Nil
7	Total Acid Number	mg KOH/g	1.6	0.64	0.64

Table 3. Fuel properties of set 3 samples

Sl. No.	FUEL PROPERTIES	S.I. UNIT	(H)+(D) 30:70	(N)+(D) 30:70	(M)+(D) 30:70
1	Flash Point	°C	52	48	39
2	Fire Point	°C	58	54	41
3	Kinematic Viscosity @ 40°C	cSt	2.9	2.71	2.43
4	Kinematic Viscosity @ 100°C	cSt	1.21	1.17	1.17
5	Cloud Point	°C	-2	-3	-7
6	Ash Content	%	Nil	Nil	0.0007
7	Total Acid Number	mg KOH/g	0.72	0.72	Nil

Mahua oil having the highest at 179°C, followed by *Neem* and *Honge* oils. This trend highlights the superior safety characteristics of bio-lubricants compared to traditional diesel, which can be attributed to their higher flash points as shown in Table 1. Blending biodiesel with diesel decreased the flash point values, but this decrease was partially offset in blends containing Fe_2O_3 nanoparticles, showing their ability to improve fuel safety characteristics (Tables 2-6).

The kinematic viscosity of our samples, a critical factor affecting lubricant performance, was measured at 40°C and 100°C. Pure biofuels had higher viscosities compared to diesel, which implies improved lubrication properties but also suggests possible difficulties in cold weather performance (Table 1). Blending with diesel decreased the viscosities, aligning them more closely with diesel's values and possibly enhancing cold flow characteristics. The addition of Fe_2O_3 nanoparticles had a significant impact on the viscosities, showing distinct changes depending on the nanoparticle concentrations and blend ratios. The kinematic viscosity decreased with nanoparticle addition, indicating a complex interaction between the biodiesel matrix and nanoparticles that requires more investigation (Tables 4-6).

Cloud and pour points were analysed to evaluate cold weather performance. The biofuel samples and

Table 4. Fuel Properties of Set 4 samples

Sl. No.	FUEL PROPERTIES	S.I. UNIT	(H)+(D) 20:80	(N)+(D) 20:80	(M)+(D) 20:80
1	Flash Point	°C	98	102	105
2	Fire Point	°C	110	119	131
3	Kinematic Viscosity @ 40°C	cSt	2.7	2.8	2.4
4	Kinematic Viscosity @ 100°C	cSt	1.6	1.5	1.2
5	Cloud Point	°C	-13	-15	-16
6	Ash Content	%	<0.01	<0.01	<0.01
7	Total Acid Number	mg KOH/g	<0.1	<0.1	<0.1
8	Pour point	°C	11	9	9
9	Density	Kg/m^3	847.0	814.0	838.0
10	Sulphur	Mg/kg	7.0	5.0	5.0
11	Calorific value	kg/kcal	10157.0	10171.0	10204.0

Table 5. Fuel properties of set 5 samples

Sl. No.	FUEL PROPERTIES	S.I. UNIT	(H)+(D) 20:80	(N)+(D) 20:80	(M)+(D) 20:80
1	Flash Point	°C	110	102	105
2	Fire Point	°C	125	118	120
3	Kinematic Viscosity @ 40°C	cSt	2.8	2.7	2.6
4	Kinematic Viscosity @ 100°C	cSt	1.9	1.5	1.5
5	Cloud Point	°C	-14	-15	-13
6	Ash Content	%	<0.01	<0.01	<0.01
7	Total Acid Number	mg KOH/g	<0.1	<0.1	<0.1
8	Pour point	°C	8	10	7
9	Density	Kg/m^3	820.0	802.0	807.0
10	Sulphur	Mg/kg	8.0	7.0	8.0
11	Calorific value	kg/kcal	10240.0	10121.0	10152.0

Table 6. Fuel properties of set 6 samples

Sl. No.	FUEL PROPERTIES	S.I. UNIT	(H)+(D) 20:80	(N)+(D) 20:80	(M)+(D) 20:80
1	Flash Point	°C	110	105	99
2	Fire Point	°C	132	138	112
3	Kinematic Viscosity @ 40°C	cSt	2.5	2.9	2.6
4	Kinematic Viscosity @ 100°C	cSt	1.8	1.2	1.5
5	Cloud Point	°C	-14	-14.2	-14
6	Ash Content	%	<0.01	<0.01	<0.01
7	Total Acid Number	mg KOH/g	<0.1	<0.1	<0.1
8	Pour point	°C	9	9	11
9	Density	Kg/m^3	821.0	821.0	804.0
10	Sulphur	Mg/kg	9.0	8.0	7.0
11	Calorific value	kg/kcal	10095.0	10150.0	10132.0

their blends had cloud and pour points suitable for bio-lubricant use. Nanoparticles slightly enhanced cold flow properties by reducing these metrics, making them more usable in cold weather (Tables 2-6).

Ash content was minimal in the majority of samples, meeting the desired cleanliness standards for a lubricant. The acid number, which indicates oil acidity and potential corrosiveness, was found to be within acceptable levels, especially in nanoparticle-enhanced blends. This suggests that the biodiesel formulations strike a balance between lubrication performance and compatibility with engine components as shown in Tables 1-6.

Density measurements verified that biodiesel blends are lighter than pure diesel, potentially impacting fuel consumption rates. Lower sulphur content in biofuels indicates environmental advantages, including decreased emissions. The calorific values of all samples were similar, suggesting that the energy content of biodiesel blends is sufficient for engine performance as shown in Tables 4-6.

4.0 Conclusions

- The present investigation led to the following conclusions. The study found that biofuels, particularly those derived from *Honge*, *Neem* and *Mahua* seeds, have inherently higher flash points than conventional diesel. This feature significantly improves the safety of bio-lubricants by lowering their flammability risk. Furthermore, the lower sulphur content found in biofuel samples highlights their environmental benefits, potentially contributing to lower sulfur dioxide emissions during combustion, which is critical for reducing acid rain and air pollution.
- Pure biofuels had higher kinematic viscosities than diesel at both 40°C and 100°C, indicating better lubrication properties. However, blending biodiesel with diesel and adding Fe_2O_3 nanoparticles brought the viscosity closer to that of conventional diesel, optimising the balance between lubrication performance and cold weather operability.
- The addition of iron oxide (Fe_2O_3) nanoparticles to biodiesel blends was found to affect several key properties, including flash point and kinematic viscosity. The usage of nanoparticles proved particularly useful in reducing the flash point decrease caused by diesel blends. This

provides strong evidence that nanoparticles may significantly improve bio-lubricants' heat stability and safety.

- The analysis of cloud and pour points revealed that biofuel blends, particularly those enhanced with nanoparticles, perform well in cold conditions. The nanoparticles' ability to lower cloud and pour points suggests that they can improve the usability of bio-lubricants at lower temperatures, addressing a common limitation of biodiesel.
- The total acid number measurements in all samples were within acceptable limits, indicating the biodiesel blends' stability and low corrosiveness. Furthermore, the low ash content in the majority of the samples indicates that these bio-lubricants have clean combustion characteristics, highlighting their potential to contribute to lower engine deposits and maintenance requirements.

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