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Effect of Additives in Vegetable Lubricating Oil

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A B S T R A C T

Commercial lubricants used currently are mainly based on mineral oil (MO) due to its availability, performance and cost. However, these factors could not be maintained in the future as the base stock of petroleum is non-renewable and concerns over environmental pollution of mineral oil have increased. The pollution of the environment caused by mineral oil is one of the concerns and could not be taking too lightly. The oil spillage into the land and water may happen mainly due mineral oil. Vegetable oils are a renewable and sustainable resource that can be used to produce lubricants. However, vegetable oils have some limitations as lubricants, such as poor oxidative stability and low cold flow properties. Additives can be used to improve the properties of vegetable oil lubricants. This paper reviews the different types of additives that can be used in vegetable oil lubricants and discusses the benefits of using these additives.

Keywords: Mineral oil, vegetable oil, Tribological, lubrication, biodegradability, additives.

1. Introduction

Commercial lubricants used currently are mainly based on mineral oil (MO) due to its availability, performance and cost. However, these factors could not be maintained in the future as the base stock of petroleum is non-renewable and concerns over environmental pollution of mineral oil have increased. The oil spillage into the land and water may happen mainly due to human negligence which may be caused by the spillage of used engine oil or petroleum crude oil. In the ocean, the oil spill may come from the oil tankers and offshore oil platforms. Vegetable oils are seen as potential primary ingredients for green lubricants due to their superior lubrication properties, biodegradability, viscosity-temperature traits, and minimal volatility. They offer a renewable alternative for environmentally safe lubricants, given their capacity to decompose into non-toxic substances. Lately, there's been a growing interest in promoting the application of biodegradable vegetable oils in lubricants, largely driven by environmental considerations and health and safety concerns, which have arisen from shifts in economic and supply dynamics. The use of additives in vegetable oil as a lubricant has gained significant attention in recent years due to the increasing demand for environmentally friendly and sustainable lubricants. This essay aims to provide a comprehensive and detailed academic response to this topic by exploring the properties of vegetable oil, the role of additives in enhancing its lubricating properties, and the potential applications of vegetable oil-based lubricants in various industries

Vegetable oils are being investigated as a potential source of environmentally favourable lubricants, due to a combination of biodegradability, renewability and excellent lubrication performance. Low oxidation and thermal stability, poor low-temperature properties and narrow range of available viscosities, however, limit their potential application as industrial lubricants. The basic mechanism of vegetable oil autoxidation is presented, along with methods used to monitor and analyse the products of oxidation. Recently, due to environmental issues, there has been a growing concern regarding the use of mineral oils as lubricants. This concern has promoted research into biodegradable lubricants such as vegetable oils, since vegetable oils do not contaminate or pollute. Furthermore, vegetable oils possess many properties such as good lubrication in contact area, high flash point, high biodegradability, and low volatility. The high polarity of vegetable oils allows them to be useful boundary lubricants. Therefore, at higher loads, there is a performance drop in the lubricants. Additives have been used as friction modifiers due to their extremely small size, which allows them to slide into the two metals' contact area. This allows the particles to act as a rolling bearing in the interface. The addition of additives helps with the wear and friction properties. Early this century, environmental concerns have stimulated increased interest in biodegradable lubricants. Since, vegetable oils and most esters are more biodegradable than mineral oils, worldwide attention on the biodegradability of lubricants has prompted many lubricant manufacturers to reconsider vegetable oils as base stocks. Many studies have explored the possibility of replacing mineral oils with vegetable oils. When vegetable oils are used as base stocks for lubricants, they exhibit good lubricity and high viscosity index. However, their oxidative stability and low temperature properties are inferior to those of petroleum-based lubricants. Vegetable oil-based lubricants are currently used in many countries Lubricant oil is very important component in modern technology that can be used as an intervening, friction and wear reducing films between two sliding surfaces. Mineral oils are the main lubricant fluid consumed worldwide. Yet, the depletion of world fossil fuel resources, stronger environment concern and strict environment regulations have boosted the demand on developing eco-friendly and cost-effective lubricants. Hence, replacing mineral oil-based lubricants with sustainable plant-derived resources is highly desired. Vegetable oils are considered as an alternative with great potential to replace toxic, non-renewable petroleum-based lubricants. Unlike mineral oils, vegetable oils provide benefits such as economic feasibility, low toxicity, renewability, biocompatibility and satisfactory lubricating performance.

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replacing mineral oil-based lubricants with sustainable plant-derived resources is highly desired. Vegetable oils are considered as an alternative with great potential to replace toxic, non-renewable petroleum-based lubricants. Unlike mineral oils, vegetable oils provide benefits such as economic feasibility, low toxicity, renewability, biocompatibility and satisfactory lubricating performance. Furthermore, their superior anti-wear and friction properties allow them to be better lubricating oil than the mineral ones [27].

1.1 Vegetable oil as a Alternative Lubricant

Vegetable oil, derived from plants such as soybean, sunflower, and rapeseed, has been traditionally used for cooking and food preparation. However, its potential as a lubricant has been recognized due to its inherent lubricating properties, biodegradability, and renewability. When used as a lubricant, vegetable oil offers several advantages over conventional petroleum-based lubricants, including lower environmental impact, reduced toxicity, and improved biodegradability. While the use of additives in vegetable oil as a lubricant shows great promise, several challenges need to be addressed to facilitate its widespread adoption. These challenges include the development of cost-effective additives, improving the oxidative stability and thermal resistance of vegetable oil-based lubricants, and ensuring compatibility with existing lubrication systems and materials. Additionally, further research is needed to optimize the formulations of vegetable oil-based lubricants with additives for specific applications, as well as to assess their long-term performance, biodegradability, and environmental impact. The use of additives in vegetable oil as a lubricant presents an exciting opportunity to develop sustainable and environmentally friendly lubricants for various industrial applications. By leveraging the inherent lubricating properties of vegetable oil and enhancing them with carefully selected additives, it is possible to create high-performance lubricants that offer a compelling alternative to conventional petroleum-based lubricants. However, continued research and development efforts are essential to overcome the technical challenges and to realize the full potential of vegetable oil-based lubricants with additives in the global lubricants market. Vegetable oils have been used as lubricants for centuries, dating back to ancient civilizations such as the Greeks and Romans. However, the use of additives in vegetable oil as a lubricant is a relatively modern development that has revolutionized the industry. This essay will explore the historical context, key figures, and the impact of additives in vegetable oil as a lubricant. It will also identify and analyze influential individuals who have contributed to this field, discuss various perspectives, and provide a well-reasoned analysis of the positive and negative aspects of this technology. Finally, potential future developments related to additives in vegetable oil as a lubricant will be considered.

Table 1. Physicochemical properties of oils [15]

Vegetable oils non-edible	Density (Kg/m^3)	Kinematic viscosity at 40 °C (mm^2/s)	Oxidation stability 110°C, h	Cloud point °C	Flash point °C
Jatropha	878	4.82	2.3	2.75	136
Karanja	918	4.80	6.0	9.0	150
Mahua	850	3.40	-	-	210
Neem	885	5.20	7.2	14.5	44
Castor	898	15.25	1.2	−13.5	260
Tobacco	887	4.25	0.8	-	166

Vegetable oils edible	Density (Kg/m^3)	Kinematic viscosity at 40 °C (mm^2/s)	Oxidation stability 110 °C, h	Cloud point °C	Flash point °C
Palm	875	5.72	4.0	13.0	165
Sunflower	878	4.45	0.9	3.42	185
Coconut	805	2.75	35.4	0	112
Soybean	885	4.05	2.1	1.0	176
Linseed	890	3.74	0.2	−3.8	178
Olive	892	4.52	3.4	-	179
Peanut	882	4.92	2.1	5.0	177
Rape seed	880	4.45	7.5	−3.3	62
Rice bran	886	4.95	0.5	0.3	-

Bio-lubricants derived from vegetable oils possess numerous advantageous physicochemical properties, offering several technical benefits. These oils are characterized by high lubricity, a high viscosity index, a high flash point, and low evaporative losses. They are currently under investigation in various research and development endeavors aimed at enhancing their physicochemical attributes. Research indicates that these bio-lubricants can serve as efficient and cost-effective alternatives to petroleum-based oils. Table 8 summarizes the findings of studies conducted on vegetable oil-based bio-lubricants. Additionally, researchers have observed that these bio-lubricants exhibit superior lubricity compared to petroleum-based oils, contributing to their increasing popularity due to these positive attributes. Notably, their major characteristics include a less corrosive nature and the behavior of unsaturated hydrocarbon chains. Sulek et al. found that bio-lubricants derived from rapeseed exhibit lower friction coefficients than petroleum-based oils. The lubricity development of these bio-lubricants was noted even at low blend levels. Furthermore, research suggests that friction and wear tend to slightly improve with increasing temperature. Kalam et al. experimentally investigated the friction and wear characteristics of conventional lubricants, lubricants with additives, and lubricants contaminated with waste vegetable oil. They found that waste vegetable oil-contaminated lubricants, supplemented with amine phosphate as an anti-wear additive, reduced wear and friction coefficients while increasing viscosity. Maleque et al. explored the tribological performance of palm oil methyl ester blended lubricants in a steel cast iron pair, observing that corrosive wear is the predominant wear mode. While mineral oils are commonly utilized in various applications such as engine oil, hydraulic oil, metalworking fluid, insulating oil, and grease, products derived from vegetable oils, including jatropha, neem, karanja, soybean, palm, coconut, castor, olive, mahua, and sunflower oils, demonstrate comparable or superior performance at lower costs. Arumugam et al. investigated the effects of bio-lubricants and biodiesel-contaminated lubrication on the tribological behavior of a cylinder liner piston ring combination using a pin-on-disc setup. They found that bio-lubricants reduced the coefficient of friction, as well as frictional force and wear. Zulkifli et al. evaluated the wear prevention properties of a palm oil-based Trimethylolpropane (TMP) ester as an engine lubricant using a four-ball machine. They tested blended lubricants containing different proportions of palm oil TMP esters and conventional lubricants, concluding that palm oil-based TMP ester lubricants enhance wear-preventive properties in terms of the coefficient of friction and wear-scar diameter.

Table 2. Summary of the work done by various researchers on vegetable oil (1)

Vegetable Oils	Reference lubricant	Test method and condition	Results	References
Coconut Oil	SAE 20 W 50	Four ball tester	Less coefficient of friction Higher anti-wear properties Better lubricity properties	[51]
Palm Oil	SAE 20 W 50	High-frequency reciprocating ring	Less corrosive nature Low coefficient of friction Good oxidation and anti-corrosion properties Reactivity of unsaturated hydrocarbon chain Strong stability of lubricant film	[52][53][54] [55][56][58]
Waste palm oil	SAE 40	Four ball tester	Low coefficient of friction High viscosity	[57]
Jatropha, Neem, Karanja, Soybean, Palm coconut, Castor, Olive, Mahua, Sunflower, etc	Petroleum-based mineral oil	Different tribo-tester with a standard method	High flashpoint High viscosity index Low evaporate loss Less coefficient of friction Better lubricity properties Offer better performance Cheaper and eco-friendly	[2][35][59] [60][61][62]
Castor Oil	SAE 20 W 50	Four-Ball Tester	Greater viscosity index Low coefficient of friction High lubricity	[48]
Rapeseed oil and Palm oil	SAE 20 W 40	Pin on disc tribo-wear tribometer	Reduce the coefficient of friction and wear Excellent lubricity Renewable and biodegradable	[63][64]

1.2 Role of Additives Lubricants

Additives play a crucial role in enhancing the performance of vegetable oil-based lubricants by addressing their inherent limitations. Various types of additives can be incorporated into vegetable oil to improve its lubricating properties, including antioxidants, anti-wear agents, extreme pressure additives, and viscosity modifiers. Antioxidants are used to inhibit the oxidation of vegetable oil, which can lead to the formation of sludge, varnish, and acidic by-products that degrade the lubricant and increase friction. Anti-wear agents form a protective film on metal surfaces to reduce wear and friction, while extreme pressure additives prevent metal-to-metal contact under high loads and temperatures. Viscosity modifiers help maintain the viscosity of vegetable oil at different operating temperatures, ensuring adequate lubrication under varying conditions. Lubricants are used to reduce friction and wear between moving parts. They also help to cool and clean the parts. Petroleum-based lubricants are the most common type of lubricant, but they are not sustainable resources. Vegetable oils are a renewable and sustainable alternative to petroleum-based lubricants. Vegetable oils have some limitations as lubricants. They have poor oxidative stability, which means they can break down and form harmful deposits when exposed to oxygen. They also have low cold flow properties, which means they can become thick and viscous at low temperatures. Additives can be used to improve the properties of vegetable oil lubricants. Additives can improve oxidative stability, cold flow properties, and other properties of vegetable oil lubricants.

- **Types of additives for oil lubricants**

There are many different types of additives that can be used in vegetable oil lubricants. Some of the most common types of additives include:

1. Antioxidants: Antioxidants help to prevent vegetable oil lubricants from breaking down due to oxidation.
2. Pour point depressants: Pour point depressants help to reduce the viscosity of vegetable oil lubricants at low temperatures.
3. Antiwear additives: Antiwear additives help to protect metal surfaces from wear.
4. Extreme pressure additives: Extreme pressure additives help to protect metal surfaces from wear under high pressure conditions.
5. Corrosion inhibitors: Corrosion inhibitors help to protect metal surfaces from corrosion.
6. Defoamers: Defoamers help to prevent the formation of foam in vegetable oil lubricants.

1. **Antioxidants:**

Antioxidants are a series of compounds that can prevent oil from breaking down and thickening. They are important for maintaining the performance and longevity of engines. Natural antioxidants are found in mineral oil, bio-oil, and biological systems. However, the mineral oil refining process strips the base oil of its natural antioxidants. There are three types of antioxidants: radical scavengers, peroxide decomposers, and metal passivates/deactivators. Radical scavengers stop chain propagation by blocking or reacting with free radicals generated in the initiation stage of oxidation. Peroxide decomposers convert hydro peroxides to non-radical derivatives such as alcohols. Metal passivates/deactivators reduce the catalytic effect of metal ions on oxidation. Antioxidants are often used in combination to achieve a synergistic effect. There are different classifications of antioxidants based on their source, solubility, and mechanism of action. Oil-soluble organic antioxidants are an important group for (hydrocarbon) lubricating oils. Antioxidants help to prevent vegetable oil lubricants from breaking down due to oxidation. Oxidation can cause the lubricant to become thick and viscous, and it can also produce harmful deposits that can damage the machinery. Tocopherols (vitamin E). Tocopherols are natural antioxidants that are found in many oils, including vegetable oils, fish oils, and soybean oil. They are effective at preventing the oxidation of oil at both high and low temperatures. Amines.

Amines are organic compounds that contain nitrogen. They are effective antioxidants at high temperatures. Some common amines used as oxidative stability additives for oil include dibenzylidene sorbitol (DBTS) and 2,6-di-tert-butyl-4-methylphenol (BHT). Phenolic compounds. Phenolic compounds are organic compounds that contain a benzene ring with one or more hydroxyl groups. They are effective antioxidants at both high and low temperatures. Some common phenolic compounds used as oxidative stability additives for oil include catechol, hydroquinone, and resorcinol. Phosphites. Phosphites are inorganic compounds that contain phosphorus. They are effective metal deactivators, which means they can prevent metal ions from catalyzing the oxidation of oil. Some common phosphites used as oxidative stability additives for oil include tributyl phosphate (TBP) and triethyl phosphate (TEP).Borates. Borates are inorganic compounds that contain boron. They are effective metal deactivators, and they can also form protective films on the surface of oil. Some common borates used as oxidative stability additives for oil include sodium borate and tetraethyl borate. Molybdenum compounds. Molybdenum compounds are effective metal deactivators. Some common molybdenum compounds used as oxidative stability additives for oil include molybdenum dithiocarbamate and molybdenum trioxide the type of oxidative stability additive that is best for a particular oil will depend on the specific properties of the oil and the conditions in which it will be used. For example, an oil that will be used at high temperatures will need a different type of antioxidant than an oil that will be used at low temperatures. It is important to note that oxidative stability additives can only slow down the oxidation of oil, they cannot prevent it completely. The amount of time that an oil will last before it starts to oxidize will depend on the type of oil, the additives that are used, and the conditions in which it is used.

2. Pour point depressants:

Pour point depressants can help to reduce the viscosity of vegetable oil lubricants at low temperatures. This makes the lubricant easier to pump and distribute at cold temperatures, which is important for applications where the machinery is exposed to cold weather. Here are many additives that can be used to improve the cold flow properties of oil. Some of the most common ones include:Polymer cold flow improvers (PCFIS). These additives are made up of long chains of molecules that surround the wax particles in the oil, preventing them from clumping together and forming crystals. Pour point depressants (PPDs)-These additives lower the pour point of the oil, which is the temperature at which it becomes too viscous to flow. Wax dispersants-These additives help to keep the wax particles suspended in the oil, preventing them from settling to the bottom of the container. Anti-oxidants - These additives help to prevent the oil from breaking down and forming harmful deposits. The best additive for a particular oil will depend on the type of oil, the climate in which it will be used, and the desired performance improvement. It is always important to follow the manufacturer's instructions when adding any additive to oil.

Here are some specific examples of cold flow improvers:

- Dimethyl azelate is a fatty acid ester that is used as a cold flow improver for biodiesel. It is effective at lowering the cloud point and pour point of biodiesel, and it also helps to improve the oxidation stability of the fuel.
- Triacetin is a colorless, odorless liquid that is used as a cold flow improver for many different types of oils. It is effective at lowering the pour point of oil, and it also helps to improve the lubricity of the oil.
- Polyethylene glycol (PEG) is a synthetic polymer that is used as a cold flow improver for a variety of fluids, including oils, greases, and hydraulic fluids. It is effective at lowering the pour point of fluids, and it also helps to improve the viscosity of the fluids.

3. Antiwear properties:

Antiwear additives can help to protect metal surfaces from wear. This can help to extend the service life of the machinery and can also help to reduce maintenance costs. There are many additives that can be used to improve the anti-wear properties of oil. Some of the most common ones include: Zinc dialkyldithiophosphate (ZDDP) is a phosphorus-based additive that is used in many different types of oils, including engine oils, gear oils, and hydraulic fluids. It forms a protective film on metal surfaces that helps to prevent them from rubbing against each other and wearing away. Molybdenum dithiocarbamate (MoDTC) is another phosphorus-based additive that is used in some oils. It is similar to ZDDP, but it is thought to be more effective at high temperatures. Sulfurized isobutylene is a sulfur-based additive that is used in some oils. It is thought to be effective at preventing wear in high-pressure conditions. Graphite is a non-metallic additive that is used in some oils. It helps to reduce friction and wear by forming a slippery layer on metal surfaces.

Here are some specific examples of anti-wear additives:

- ZDDP is the most common anti-wear additive used in engine oils. It is effective at preventing wear in a variety of conditions, including high temperatures and high pressures.
- MoDTC is a more expensive additive than ZDDP, but it is thought to be more effective at high temperatures. It is often used in oils for high-performance engines.
- Sulfurized isobutylene is a less expensive additive than ZDDP or MoDTC, but it is still effective at preventing wear. It is often used in oils for lower-cost engines.
- Graphite is a non-metallic additive that is often used in gear oils. It helps to reduce friction and wear by forming a slippery layer on metal surfaces.

4. Extreme pressure properties:

Extreme pressure additives can help to protect metal surfaces from wear under high pressure conditions. This is important for applications such as gear drives and hydraulic systems. Extreme pressure (EP) additives are used to protect metal surfaces from welding and seizure under high loads and temperatures. They do this by forming a sacrificial film on the metal surfaces that prevents direct metal-to-metal contact.Some of the most common EP additives include: Zinc dialkyldithiophosphate (ZDDP) is a phosphorus-based additive that is widely used in engine oils, gear oils, and hydraulic fluids. It is effective at preventing wear in a variety of conditions, including high temperatures and high pressures. Molybdenum dithiocarbamate (MoDTC) is another phosphorus-based additive that is used in some oils. It is similar to ZDDP, but it is thought to be more effective at high temperatures. Sulfurized isobutylene is a sulfur-based additive that is used in some oils. It is thought to be effective at preventing wear in high-pressure conditions. Chlorinated paraffins are organic compounds that contain chlorine. They are used in some oils to prevent wear and corrosion. Boron compounds are also used in some oils to prevent wear and corrosion. The best EP additive for a particular oil will depend on the type of oil, the application, and the desired performance improvement..

Here are some specific examples of EP additives:

- ZDDP is the most common EP additive used in engine oils. It is effective at preventing wear in a variety of conditions, including high temperatures and high pressures. However, it is also known to be harmful to the environment.
- MoDTC is a more expensive additive than ZDDP, but it is thought to be more effective at high temperatures. It is often used in oils for high-performance engines.
- Sulfurized isobutylene is a less expensive additive than ZDDP or MoDTC, but it is still effective at preventing wear. It is often used in oils for lower-cost engines.
- Chlorinated paraffins are used in some oils to prevent wear and corrosion. However, they are also known to be harmful to the environment.
- Boron compounds are also used in some oils to prevent wear and corrosion. They are considered to be more environmentally friendly than chlorinated paraffins.

5. Corrosion resistance:

Corrosion inhibitors can help to protect metal surfaces from corrosion. This can help to extend the service life of the machinery and can also help to reduce maintenance costs. There are many additives that can be used to improve the corrosion resistance of oil. Some of the most common ones include:

- Zinc dialkyldithiophosphate (ZDDP) is a phosphorus-based additive that is widely used in engine oils, gear oils, and hydraulic fluids. It forms a protective film on metal surfaces that prevents them from corroding.
- Molybdenum dithiocarbamate (MoDTC) is another phosphorus-based additive that is used in some oils. It is similar to ZDDP, but it is thought to be more effective at high temperatures.
- Sulfurized isobutylene is a sulfur-based additive that is used in some oils. It is thought to be effective at preventing corrosion in high-pressure conditions.
- Chlorinated paraffins are organic compounds that contain chlorine. They are used in some oils to prevent corrosion.
- Boron compounds are also used in some oils to prevent corrosion.

6. Foam control:

Defoamers can help to prevent the formation of foam in vegetable oil lubricants. This can improve the lubrication process and can also help to protect the machinery from damage. Defoamer additives are used to control foam in lubricating oil. Foam in lubricating oil can cause a number of problems, including: Reduced lubrication, Increased wear, Clogging of filters, Reduced heat transfer, Increased noise Defoaming additives work by breaking down the surface tension of the foam bubbles, causing them to collapse. They can also help to absorb water and other contaminants that can contribute to foaming. The most common defoamer additive for lubricating oil is silicone oil. Silicone oil is a liquid that has a very low surface tension. This means that it can easily spread out and break up foam bubbles. Silicone oil is also non-toxic and biodegradable, making it a safe choice for most applications.

Other defoamer additives that can be used in lubricating oil include:

- Amines are organic compounds that can also be used to control foam. Amines work by breaking down the surface tension of the foam bubbles.
- Polymers are long chains of molecules that can also be used to control foam. Polymers work by absorbing the water in the foam bubbles, which causes them to collapse.
- Surfactants are molecules that have both hydrophilic (water-loving) and hydrophobic (water-fearing) ends. Surfactants work by forming a film on the surface of the foam bubbles, which prevents them from growing larger.

Some specific examples of defoamer additives for lubricating oil:

- Polydimethylsiloxane (PDMS) is a type of silicone oil that is commonly used in lubricating oils. PDMS is effective at controlling foam and is also non-toxic and biodegradable.
- Ammonium laurate is an amine that is used in some lubricating oils. Ammonium laurate is effective at controlling foam and is also relatively inexpensive.
- Polyethylene glycol (PEG) is a polymer that is used in some lubricating oils. PEG is effective at controlling foam and is also compatible with a wide range of oils.
- Surfactants are a type of molecule that has both hydrophilic and hydrophobic ends. It is used in some lubricating oils to control foam.

1.3 Effect additives in Vegetable oil

Various agricultural feedstocks are used to produce vegetable oils, which are being increasingly viewed as viable replacements for mineral oil-based lubricants owing to their superior lubricating properties. These oils are biodegradable, environmentally friendly, and simple to dispose of. Thottackkad et al. conducted a study where they incorporated CuO nanoparticles into coconut oil. Their findings revealed that the most favorable outcomes in terms of friction coefficient and wear rate were achieved with an optimal concentration of 0.34% weight of CuO nanoparticles. Additionally, the addition of these nanoparticles led to an increase in viscosity and fire point, while simultaneously reducing surface roughness (39). Alves et al. noted that both Zinc oxide and Copper oxide nanoparticles proved ineffective as anti-wear additives for soybean and sunflower oil. This was attributed to the rise in friction coefficient and abrasive wear observed on the worn surface (12). Xu et al. stated that the tribological characteristics of rapeseed oil improved when hollow spherical precipitates of MoS2 were incorporated alongside nano TiO2 compared to the sample containing MoS2 alone (41). Arumugam and Sriram introduced both TiO2 nanoparticles and microparticles into chemically modified rapeseed oil. They found that the inclusion of TiO2 nanoparticles led to improved lubrication properties compared to microsized TiO2. Specifically, the friction coefficient of chemically modified rapeseed oil decreased by 15.2% with nanoscale TiO2 and 6.9% with micro TiO2 (40). Gulzar et al. studied the impact of CuO and MoS2 nanoparticles on enhancing the anti-wear and extreme pressure characteristics of chemically modified palm oil. Their findings revealed that these nano-additives significantly improved the assessed properties by 1.5 times. Additionally, it was observed that MoS2 nanoparticles displayed superior properties and dispersion stability compared to CuO (43). Rani et al. introduced nanoparticles of TiO2, CeO2, and ZrO2 into rice bran oil. Their findings indicated that the most significant decrease in friction coefficient and wear was achieved with 0.5 wt% CeO2 and 0.3 wt% TiO2, respectively [44]. Kumar et al. incorporated CuO nanoparticles into canola oil, achieving the lowest friction coefficient and specific wear rate at 0.1% wt [48]. Rajaganapathy et al. developed nanolubricants by combining palm oil and brassica oil with CuO and TiO2 nanoparticles. Among the prepared nanolubricants, palm oil with 0.5% CuO nanoparticle exhibited the lowest coefficient of friction and specific wear rate [50]. Singh et al. reported that the minimum friction coefficient and wear rate for castor oil blended with TiO2 nanoparticle occurred at a concentration of 0.2% [51]. Zaid et al. utilized TiO2 nanoparticles to enhance the lubricating properties of jojoba oil, achieving the lowest coefficient of friction and wear when 0.3 wt% TiO2 nanoparticles were added to jojoba oil [52]. Rastogi et al. introduced SiO2 nanoparticles into jatropha oil, resulting in the lowest coefficient of friction and wear loss observed after the addition of 0.6% nanoparticles [53]. Singh et al. explored the tribological characteristics of modified desert date oil with copper nanoparticles. The tribological performance of the formulated biolubricant exhibited enhancement with the addition of copper nanoparticles up to a concentration limit of 0.9% [54]. Singh et al. chemically modified moringa Oleifera oil through a two-step transesterification process and subsequently added SiC nanoparticles in varying concentrations. The coefficient of friction and wear were found to be minimized at a concentration of 0.5 wt% SiC nanoparticle [55]. Cortes et al. assessed the impact of silicon dioxide (SiO2) and titanium dioxide (TiO2) nanoparticles as lubricant additives on the tribological and rheological properties of sunflower oil. Their findings revealed that the rheological characteristics were contingent upon the type and concentration of nanoparticles used. TiO2 and SiO2 nanoparticles reduced the friction coefficient and wear volume loss by 93.7% and 70.1%, and 77.7% and 74.1%, respectively [56]. Sneha et al. examined the influence of halloysite nanoclay as an anti-wear additive for rice bran oil blended with turmeric oil. The tribological assessment of rice bran oil with 0.1 wt% halloysite nanoclay exhibited the lowest friction coefficient and wear scar diameter (0.072, 0.531 mm) compared to other nanoclay concentrations. Furthermore, the incorporation of 1.5 wt% turmeric oil as an antioxidant additive in rice bran oil with halloysite nanoclay reduced the wear scar diameter to 0.491 mm [57].

1.4 Conclusion

The use of vegetable oil-based lubricants with additives has the potential to extend beyond traditional industrial applications to various sectors, including automotive, aerospace, and marine industries. In the automotive sector, vegetable oil-based lubricants can be used in engine oils, transmission fluids, and greases, offering improved fuel economy, reduced emissions, and lower environmental impact. In the aerospace industry, the biodegradability and non-toxic nature of vegetable oil-based lubricants make them suitable for use in aircraft hydraulic systems, landing gear, and engine components. Similarly, in the marine industry, vegetable oil-based lubricants can be used in stern tubes, thrusters, and wire ropes, providing a sustainable alternative to conventional lubricants that may pose a risk to aquatic ecosystems. While the use of additives in vegetable oil as a lubricant shows great promise, several challenges need to be addressed to facilitate its widespread adoption. These challenges include the development of cost-effective additives, improving the oxidative stability and thermal resistance of vegetable oil-based lubricants, and ensuring compatibility with existing lubrication systems and materials. Additionally, further research is needed to optimize the formulations of vegetable oil-based lubricants with additives for specific applications, as well as to assess their long-term performance, biodegradability, and environmental impact. Additives are used in lubricating oils to improve their performance and extend their lifespan. There are many different types of additives available, each with its own specific purpose. Additives can improve the performance of lubricating oil in a number of ways, including reducing wear, preventing corrosion, and controlling foam. The type of additive that is used will depend on the specific application and the desired performance improvement. Adding too much additive can actually have the opposite effect and make the oil less effective. Additives can be used to improve the properties of vegetable oil lubricants. This makes vegetable oil lubricants a more viable option for a variety of applications. Future research in this area could lead to the development of even more advanced vegetable oil lubricants with improved properties.

In conclusion, the use of additives in vegetable oil as a lubricant presents an exciting opportunity to develop sustainable and environmentally friendly lubricants for various industrial applications. By leveraging the inherent lubricating properties of vegetable oil and enhancing them with carefully selected additives, it is possible to create high-performance lubricants that offer a compelling alternative to conventional petroleum-based lubricants. However, continued research and development efforts are essential to overcome the technical challenges and to realize the full potential of vegetable oil-based lubricants with additives in the global lubricants market.

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