Vol. 43, No. 4 (2021) 511-523, DOI: 10.24874/ti.979.10.20.02

Tribology in Industry

www.tribology.rs

REVIEW

Study of Vegetable Oil Based Biolubricants and Its Hydrodynamic Journal Bearing Application: A Review

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Keywords:

Biolubricant
Hydrodynamic journal bearing
Vegetable oil based lubricant
Chemically modified vegetable oil
Nano additives

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Received: 3 October 2020
Revised: 29 November 2020
Accepted: 18 February 2021

A B S T R A C T

Mineral oil based lubricants are generally used in hydrodynamic journal bearing. These lubricants are toxic, non biodegradable and harmful for the environment. Vegetable oil being biodegradable and non-toxic has emerged as an alternative lubricant. This paper reviews recent researches related to biodegradable, environment friendly vegetable oil based lubricant and its application in hydrodynamic journal bearing. Important physicochemical properties of biolubricant for hydrodynamic journal bearing have also been discussed in the paper. Challenges relating to the usage of vegetable oil based biolubricant along with available mitigation strategies are also highlighted. Based on the study it can be concluded that chemically modified vegetable oil along with properly selected additives can effectively replace conventional lubricants.

1. INTRODUCTION

Hydrodynamic Journal bearings are friction reducing machine element that supports load from rotating shafts. These bearings are used in machineries with high speed and heavy load application such IC engines, turbines, compressors and pumps [1-3]. With effective lubrication system and lubricant, these bearings can have longer life and better performance [2].

Hydrodynamic journal bearings are designed to operate in hydrodynamic lubrication regime but it also experiences boundary lubrication regime and mixed lubrication regime. During start or stop when the shaft speed is slow, the journal remains in contact with the bearing's lower face and this condition is known as boundary lubrication. Relatively higher friction coefficient and considerable wear is experienced in this regime. As the shaft speed increases, oil is dragged around the shaft, penetrating the shaft and bearing interface leading to mixed lubrication regime. The journal may occasionally contact the bearing causing moderate wear in this regime. This also happens when shock loading occurs. When the shaft speed becomes high enough, sufficient oil film thickness is formed to completely avoid journal contact with the bearing forming hydrodynamic lubrication regime and no or minimal wear occur in this regime [4-8]. Fig. 1 shows hydrodynamic journal bearing during operation with shaft load W and shaft speed ω. Fig. 2 depicts Stribeck curve with respect to sliding speed representing various lubrication regimes [9]. As thick film of oil barrier is formed between journal and bearing, solid friction (dry friction) is completely replaced by fluid friction which is much lower and ideally doesn't cause wear. But this thick film of oil doesn't exist all the time between the journal and bearing. There are conditions such as shock loading, start and stop conditions where this thick film forming hydrodynamic regime gets diminished leading to mixed or boundary lubrication regime. For minimum wear and optimal lubrication, lubricant has to perform in all three lubrication regimes. For lubricants to perform in mixed and boundary lubrication conditions, specific additives are generally added in lubricant formulations. Thus lubricant plays an important role in journal bearings working in various loading conditions [7, 10].

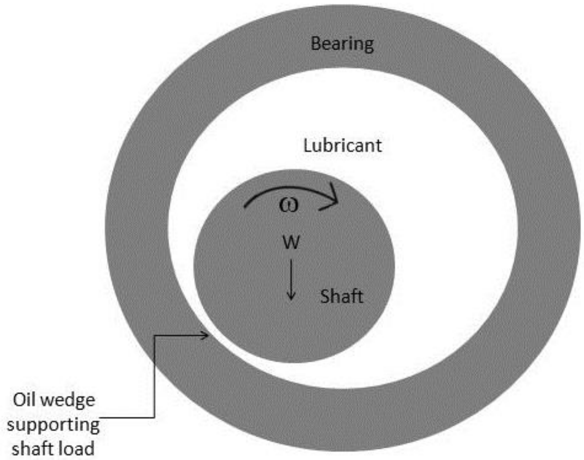

Fig. 1. Hydrodynamic Journal Bearing during operation.

Mostly mineral oils along with additives are used as lubricant in these bearings [11-12]. Mineral oils are non biodegradable and toxic, causing environmental pollution. It has been known that most of these lubricant ends up in environment via various medium as there is no accountability of their disposal causing harm to the wildlife, agriculture, marine life and fresh waters. Because of these harmful effects, many citizen committee, industry partners and government organizations around the world are taking steps to counter such effects [13-14].

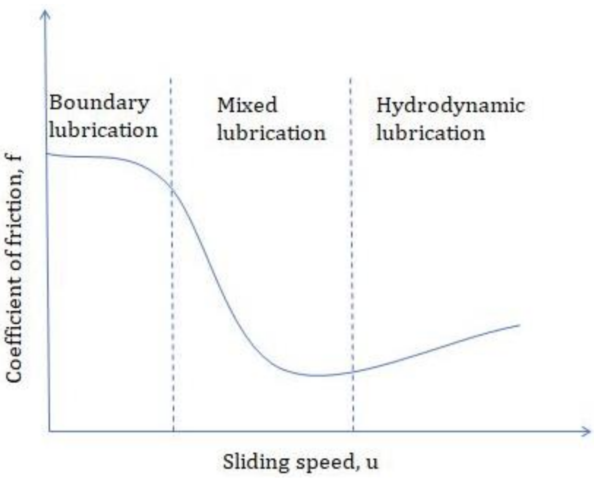

Fig. 2. Stribeck curve with respect to sliding speed.

Also the petroleum sources of mineral oil based lubricants are non renewable, finite and can't be produced domestically [15]. All such reasons have influenced many researchers to look for an alternative to these conventional lubricants.

Vegetable oil based biolubricant has earned attention of many researchers as an alternative lubricant because of its non toxicity, biodegradability, renewability and other inherent properties such as excellent lubricity, low volatility, higher viscosity index and higher flash point [16]. Various studies showing vegetable oil based biolubricants as an alternative in different applications have been done by researchers around the world [17-20]. Based on these studies various review papers have also been published but there isn't any review paper specifically for hydrodynamic journal bearings. Most of the review papers already published about biolubricants discusses about its synthesis process, chemical structures, feedstock considerations, laws and regulations regarding biolubricants. Only few of them discussed from application point of view. Since each application is unique in its lubricant requirements, biolubricants has to be critically reviewed for each application. This motivated us to review works regarding biolubricants for hydrodynamic journal bearing application. Researchers over the years have tested different types of vegetable oil based biolubricants in different lubrication regimes/conditions to establish the case for hydrodynamic journal bearings. This paper reviews all such recent works done regarding vegetable oil based biolubricant for hydrodynamic journal bearing application.

The structure of this paper comprises of following sections. In section 2, the capabilities of vegetable oils as biolubricants have been discussed highlighting merits and demerits of vegetable oil based biolubricants. In section 3, physicochemical properties of biolubricants important for hydrodynamic journal bearing application have been discussed. Section 4 reviews all the recent works done for biolubricant usage in hydrodynamic journal bearings. And section 5 highlights the challenges and mitigation strategies related to the usage of vegetable oil based lubricant in hydrodynamic journal bearing application.

2. VEGETABLE OIL BASED BIOLUBRICANT

Historically vegetable oil has been used as a lubricant since early days of lubrication. But its usage declined after the advent of petroleum products in 19th century as mineral oil based lubricants were cheaper and had a variety of industrial applications [21]. Now because of the environmental concern, certain government regulations and depletion of fuel reserves, vegetable oil has gained interest among researchers around the world [13-14, 22-23].

Table 1. Advantages of Biolubricants.

Higher lubricity	Energy savings from reduction in friction losses.
Lower volatility	Decreased evaporative losses at higher temperatures.
Higher viscosity index	Wider temperature range of application.
Higher boiling temperatures	Fewer emissions.
Higher detergency	Cleaner metal components with fewer deposits.
Higher flashpoints	Safer to store and transport.
Biodegradable and non-toxic	Less pollution and better environment.
Oil mist and vapour reduction	Less harmful for operating personnel and safer work place.
Better skin compatibility	Less dermatological effects.
Lower cost than synthetic oil	Increased chance of acceptance for wider applications.
Renewablity	Feedstock will always be available.
Higher shear stability	Better service life of lubricant.
Higher dispersancy	High solubility for polar contaminants and additives.

Researchers over the time have studied many vegetable oil to be used as biolubricant which includes both edible oils such as rapeseed oil, sunflower oil, palm oil, soybean oil and non edible oils such as jatropha oil, neem oil and karanja oil [24-29]. The amphiphilic nature of vegetable oils due to the fatty acid composition forms better tribochemical film on the lubricated surface, which makes them perform better in boundary, mixed and hydrodynamic lubrication conditions [30-32]. This makes vegetable oils perfect for lubricant formulations. Vegetable oil based biolubricant have various other advantages too over the mineral oil based lubricant which is listed in Table 1 [16, 23, 33].

Despite having so many benefits, Vegetable oil can't be used directly as a lubricant because of its high pour point, poor thermal and oxidation stability. These can be improved through chemical modification, genetic engineering, blending or use of additives such as pour point depressant and anti oxidants. Valeru et al. (2018) improved pour point, oxidation and thermal stability by addition of Polyalphaolefin 4 (PAO 4), Poly (Ethylene co-vinyl acetate) (PPD) and 2, 6 Di-tetra butyl phenol as additives in coconut oil [34]. Haun et al. (2014) genetically modified soybean oil to improve its oxidative stability by increasing oleic acid content from 20% to 80% and decreasing linoleic acid content from 50% to under 4% [35]. Genetic modification of vegetable oils improves thermal and oxidative stabilities by increasing the oleic acid content whereas increasing proportions of short-chain saturated or long-chain monounsaturated fatty acids improves the cold flow behaviour of oil. Pathmasiri et al. (2019) found improved pour point of palm oil when blended with castor oil [36]. Heikal et al. (2016) found improved pour point, viscosity indices and moderate thermal stabilities in jatropha oil when chemically modified through transesterification reaction [37]. Salimon et al. (2011) got better pour point and higher flash point when castor bean oil is chemically modified to form estolide ester by reacting ricinoleic acid of vegetable oil with saturated fatty acid [38]. Aelst et al. (2016) partially hydrogenated soybean oil using Pt/ZSM-5 catalyst to improve oxidative stability and cold flow behaviour for biolubricants [39]. Borugadda and Goud (2014) improved thermal and oxidation stability of castor oil through epoxidation of castor oil forming fatty acid methyl esters of vegetable oil suitable as a biolubricant base stock [40]. Kulkarni et al. (2013) found improved thermo-oxidative stability and better cold flow properties for mustard oil when oxirane ring opening reaction of epoxidized mustard oil was carried out with 2-ethylhexanol [41]. Transesterification, estolide formation, selective hydrogenation, epoxidation and additional ring opening or acetylation after epoxidation are some common chemical modification techniques which targets the acyl (C=O) functional group, alkoxy (O-R) functional group and double bonds present in the oil to improve thermo-oxidative stability and cold flow properties of oil [42]. Fig. 3 depicts various modification techniques used by the researchers to improve pour point and thermo-oxidative stability of vegetable oil.

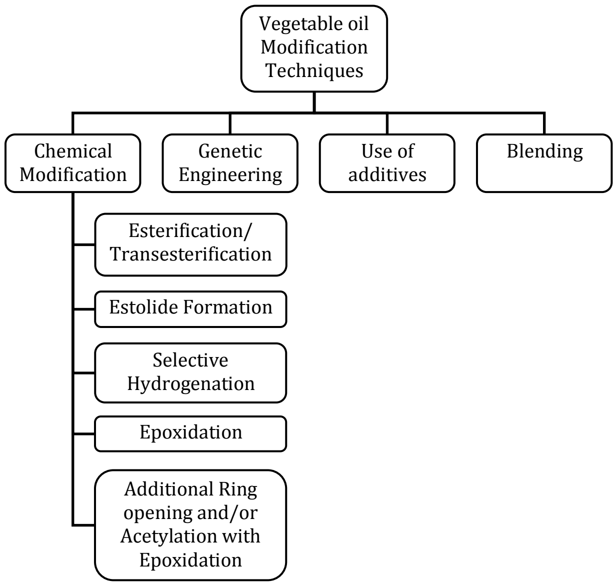

Fig. 3. Vegetable oil modification techniques to improve pour point and thermo-oxidative stability.

3. PHYSICOCHEMICAL PROPERTIES

For hydrodynamic journal bearing application, biolubricant should have certain physicochemical properties to ensure effective lubrication of the system. These properties of biolubricants and its effects on hydrodynamic journal bearings have been discussed in this section. The physicochemical properties of some vegetable oil based biolubricant and standard reference lubricant has been shown in Table 3 [37, 43-44].

3.1 Viscosity

Viscosity is the measure of resistance to the flow of vegetable oil based biolubricant. Viscosity of biolubricants is measured using ASTM D445-19a standard [45]. Viscosity is the most important property of a lubricant in journal bearing. If viscosity is too high, lubricant would be thicker and friction losses and operating temperature will be high. If viscosity is too low, lubricant will be thinner and load carrying capacity will be inadequate. Taking all these factors into consideration, selecting an optimum viscosity for the lubricant is a challenging task [11].

Selection of an optimum viscosity for hydrodynamic journal bearing application depends upon bearing speed, load and oil temperature. Higher the bearing speed, lower will be the viscosity requirement for the lubricant whereas lubricant's viscosity requirement has proportional relation with the operating temperature and load [46]. For moderate speed journal bearings with no shock loading, optimum viscosity for lubricant is generally taken 22-35 cSt at operating temperature [47].

3.2 Viscosity Index

Viscosity index is a measure of change in viscosity of biolubricant with temperature. Viscosity index is measured using ASTM D2270-10 standard in which viscosities at 40^0C and 100^0C are utilized for calculation [48]. Higher the viscosity index, lower the temperature change effect on biolubricant's viscosity and hence biolubricant can be used for wider range of temperature in hydrodynamic journal bearing.

3.3 Pour Point

Pour point is the temperature below which biolubricant ceases to flow and is measured using ASTM D97-17b standard [49]. This low temperature property is essential when machinery using hydrodynamic journal bearing has to perform at lower temperatures.

3.4 Flash Point

Flash point is the lowest temperature at which the biolubricant vaporizes to form ignitable mixture with air when ignition source is brought near to the mixture. ASTM D92-18 and ASTM D93 are the commonly used standards for flash point measurement [50-51]. Flash point is used to describe the volatility of oil. Higher the flash point better is the lubricant for journal bearing application at higher operating temperature. Also higher flash point ensures safe transportation and storage [52].

Table 2. Summary of physicochemical properties of biolubricants for hydrodynamic journal bearings.

Physicochemical Property	Definition	Hydrodynamic journal bearing lubricant requirement
Viscosity	It is the measure of resistance to biolubricant flow.	Depends on end application(bearing speed, load and operating temperature)
Viscosity Index	It is a measure of change in viscosity with temperature.	Higher the better.
Pour Point	It is the temperature below which biolubricant ceases to flow.	Lower the better.
Flash Point	It is the lowest temperature at which biolubricant vapors ignite in presence of source.	Higher the better.
Acid Value and Base Value	Acid value determines the acidic concentration and base value determines alkaline concentration of biolubricant.	Lower acidity is desirable.
Thermo-oxidative stability	It is the ability of biolubricant to resist degradation on exposure to oxygen and high temperature.	Higher the better.
Hydrolytic stability	It is the ability of biolubricant to resist degradation in presence of water.	Higher the better, but required for specific applications involving water contamination.

Table 3. Physicochemical properties of biolubricant and reference lubricant.

Oil	Kinematic Viscosity@40C, cSt	Kinematic Viscosity@100C, cSt	Pour Point, C	Flash Point, C	Viscosity Index	Acid Value, mg KOH/g	Reference
Jatropha TMP ester	51.89	8.53	-3	296	140	0.52	[37]
Palm TMP ester	38.25,50.33	7.58,10.87	5	240,253	171,214	-	[37]
ISO VG32	>28.8	>4.1	-6	204	>90	-	[37]
ISO VG46	>41.4	>4.1	-6	220	>90	-	[37]
Soybean NPG ester	10.5, 11	3.2, 3.5	-3, -9	-	198, 218	18.5, 25.5	[43]
Castor NPG ester	116.8, 133.1	11.3, 12.6	-24,-27	-	79, 84	90, 85.5	[43]
Rubber seed PE ester	62.6	12.6	-3	308	206	0.311	[44]
Rubber seed TMP ester	38.4	8.6	-6	299	212	0.229	[44]

3.5 Acid Value and Base Value

Acid value determines the acidic concentration of biolubricant whereas base value determines alkaline concentration present in the biolubricant. ASTM D974-14e2 standard is used to calculate acid number and base number of biolubricant by color indicator titration [53]. The acidity is not desirable in biolubricant as it leads to the corrosion of journal bearing material. With the passage of time biolubricant usually breaks down due to oxidation and contamination leading to the increased acidity. That is why alkaline additives are always preferred in biolubricant [54].

3.6 Thermo-Oxidative Stability

Hydrodynamic journal bearing lubricant should have high thermo-oxidative stability for longer storage as well as high temperature applications. Poor thermo-oxidative stability will lead to oxidation of oil with exposure to air or high temperature application resulting in corrosion, sludge formation, increased viscosity and acidity. Thermogravimetric analysis and Differential scanning calorimetry has been often used by researchers for thermo-oxidative stability analysis of vegetable oil based lubricant [37, 55-58].

3.7 Hydrolytic Stability

Hydrolytic stability of biolubricant is defined as its ability to resist degradation due to the presence of water. ASTM D2619 standard is used to determine hydrolytic stability [59]. Hydrolytic stability is generally not a problem but can become important in applications such as hydrodynamic journal bearing working in marine environment. Hydrolysis of biolubricant can result in decreased viscosity, rust formation and increased acidity [60-61].

4. BIOLUBRICANT ALTERNATIVE FOR HYDRODYNAMIC JOURNAL BEARING

In machine design, energy saving and reduction in environmental pollution are two important concerning aspects [62]. Biolubricants can be seen as an alternative only if they can perform well enough in reducing friction and wear to replace conventional lubricant in hydrodynamic journal bearing application. Various studies have been done on feasibility of vegetable oil based biolubricant as an alternative to journal bearing lubricant which is shown in Table 4.

Din and Kassfeldt (1999) studied rapeseed oil based semi synthetic oil in mixed lubrication regime on a full scale Journal bearing test rig. They wanted to investigate the suitability of environmentally adapted lubricant for full scale journal bearing application under industrial lubricating conditions. That is why they investigated mineral oil as well as rapeseed oil semi synthetic ester under two conditions: uncontaminated condition (without silica contamination) and contaminated condition (with silica contamination) to simulate industrial conditions. They found that semi-synthetic oil has lower wear rates and frictional torque than the mineral oil irrespective of the contamination conditions. Also maximum wear has been found at highest oil temperature and lowest rotational speed chosen for study for both the oil [63].

Durak and Karaosmanoglu (2004) studied cottonseed oil as a friction modifier additive to SAE20W50 mineral oil for journal bearing application. They were motivated for the study by the fact that toxic friction modifier additives are being used in environmental friendly lubricants. That is why they tested vegetable oil as an environmental friendly alternative to available toxic friction modifier additives for journal bearing application. It has been found in their study that CSO additive lowers the coefficient of friction at low journal speeds and small loads and maximum reduction was achieved for 10% by volume mixture which is the highest concentration considered in the study. They concluded that cottonseed oil works well in boundary lubrication regime as a friction modifier [64].

McCarthy et al. (2009) studied three environmentally accepted lubricants: Propylene glycol dioleate, VG32 saturated ester and rapeseed oil against ISOVG32, ISOVG46 and ISOVG68 mineral oil in a journal bearing test rig. They wanted to extend the knowledge regarding environment friendly lubricant in hydrodynamic lubrication for hydropower applications and also wanted to explore the effect of viscosity index on bearing performance. The parameters investigated in the study include temperature, power loss and minimum film thickness. Synthetic ester performance found to be close to VG46 mineral oil. Rapeseed oil performed similar to VG68 mineral oil at high speed and high loading conditions in terms of power loss and minimum film thickness. Same is the case with PGD oil but it was having performance characteristics comparable to VG32 oil. Also they concluded that it is possible to replace conventional lubricants with thinner and higher VI vegetable oils in certain applications [65].

Baskar and Sriram (2012) studied the pressure distribution profile for rapeseed oil and soybean oil and compared the same with SAE20W40 on Journal bearing test rig. Pressure distribution profile of journal bearing affects load carrying capacity for the lubricant. They wanted to compare these vegetable oils with SAE20W40 for journal bearing application. They found rapeseed oil had comparable pressure profile with SAE20W40 but soybean oil had larger variations of 50-75%. Also oil film thickness was found to be very low for soybean oil. Low oil film thickness indicates more chances of metal-metal interaction which leads to friction and wear. They concluded soybean oil as raw vegetable oil is not suitable for lubrication purpose in journal bearing and suggested to investigate the esterified vegetable oil [66].

Table 4. Summary of works done on biolubricant alternative for hydrodynamic journal bearing lubrication.

Sr. No.	Biolubricant	Reference Lubricant	Tribosystem	Lubrication Condition	Findings	Ref.
1	Rapeseed semi synthetic ester	Mineral oil	Journal Bearing Test Rig; Bearing material: Babbit	Load: 35 kN; Speed: 100 rpm and 10 rpm; Operating temperature: 70 °C and 25 °C	- Reduction in wear rate - Reduction in frictional torque	[63]
2	Cottonseed oil	SAE20W50	Journal Bearing Test Rig; Babbit alloy bearing with diameter 50.750 mm, width 25.00 mm and clearance 0.050 mm	Load: 260N, 360N, and 460N; Speed: 50 rpm, 100 rpm, 300 rpm, 600 rpm and 1200 rpm	- Reduction in coefficient of friction	[64]
3	Rapeseed oil	ISOVG32, ISOVG46 and ISOVG68	Journal Bearing Test Rig; Babbit bearing with shaft diameter 179.72 mm and bearing radial clearance 154±14 μm; bearing width 129 mm	Load: 1 MPa, 1.5 MPa and 2 MPa; Speed: 1000 rpm, 1500 rpm and 2000 rpm	- Comparable performance with ISOVG68 in terms of power loss and minimum film thickness	[65]
4	Rapeseed oil and Soybean oil	SAE20W40	Journal Bearing Test Rig; Bronze bearing with diameter 45 mm, width 40 mm and clearance 5 mm	Load: 300N and 450N; Speed: 1500 rpm and 1750 rpm	- Comparable pressure profile for rapeseed oil - Soybean oil performance found to be unsuitable	[66]
5	Chemically modified rapeseed oil; chemically modified rapeseed oil with nano CuO	SAE20W40	Pin on disc wear tester; Disk material: EN31 steel; Pin material: Brass	Maximum load: 200 N; Sliding speeds: 2 – 10 m/s.	- Reduction in coefficient of friction and wear	[67]
6	Chemically Modified Rapeseed Oil (CMRO); CMRO+ nano TiO2, CMRO+ nanoWS2 and CMRO+nano CuO	SAE20W40	Journal Bearing Test Rig; Bronze (Cu 90 wt% and Sn10 wt%) bearings of 50 mm nominal diameter, 25 mm length and radial clearance 40-50 μm	Load: 10 kN; Speed: 3000 rpm; Oil temperature: 75 °C	- Reduction in coefficient of friction and wear	[68]
7	Jatropha oil, Jatropha oil blends with ISOVG46 in the ratio 90:60/80:20/70:30 + nano CuO	ISOVG46	Journal Bearing Test Rig; Leaded bronze bearing with diameter 50mm, length 50mm and clearance 0.03mm	Load: 400 N, 600 N and 800N; Speed: 400–1600 rpm	- Reduction in coefficient of friction and frictional torque for Jatropha oil - Comparable performance of 90:10 biolubricant blend with ISOVG46	[69]
8	Palm Mid Olein oil	SAE40 mineral oil	Journal Bearing Test Rig; Phosphorus bronze bearing with diameter 100.104mm, length 50mm and radial clearance 0.042mm	Load: 10 kN, 20 kN and 30 kN; Speed: 200 rpm, 400 rpm, 600 rpm and 800 rpm	- Higher maximum pressure at lower load - Better thermal resistance - Lower coefficient of friction	[70]

Baskar and Sriram (2014) further conducted the tribological study of chemically modified rapeseed oil with and without nano CuO additive for journal bearing material (brass) on pin on disk tribometer. Based on their previous study recommendation they studied chemically modified vegetable oil along with nano CuO as anti-wear additive. They found lowest friction coefficient and wear for chemically modified rapeseed oil with 0.5 % (by weight) nano CuO additive. The study was conducted for SAE20W40 synthetic lubricant, chemically modified rapeseed oil and chemically modified rapeseed oil with 0.5% nano CuO. Also Scanning electron microscopy supported the use of chemically modified rapeseed oil +0.5% nano CuO which shows fewer pits and cavities among the three lubricants [67]. As improved performance of chemically modified rapeseed oil with nano CuO additive was found in their previous study based on pin on disk tribometer, Baskar et al. (2016) further studied the chemically modified rapeseed oil in journal bearing test rig with CuO nano additive along with other nano additives of WS_2 and TiO_2. Journal bearing test rig was used to study wear, coefficient of friction and oil film thickness for all the lubricants under hydrodynamic lubrication regime. CMRO with nano additives found to have lower coefficient of friction, lower wear and higher oil film thickness under same operating conditions against synthetic lubricant SAE20W40 as well as CMRO. Among all three nano additives nano CuO gave better results for all measurables. Surface roughness found by using Atomic force microscopy (AFM) was also least for CMRO (chemically modified rapeseed oil) with nano CuO and Scanning Electron Microscopy (SEM) also showed less pits for CMRO with nano CuO [68].

Katpatal et al. (2019) studied three blends of Jatropha oil with ISO VG46 oil in the ratios 10:90, 20:80 and 30:70 respectively. They studied blends as previous studies have shown unsuitability of raw vegetable oil for journal bearing application. Blending of oil reduced the viscosity for the mixture so to compensate nano CuO additive was added to each mixture in different proportions in their study. CuO nano additive has been selected based on previous studies suggesting enhanced journal bearing performance. Journal bearing test rig was used to study the pressure distribution as well as frictional behaviour for all the three blends, Jatropha oil and ISO VG46 oil. It has been found that the nature of pressure distribution was same for all the oil and maximum pressure occurred for all with maximum viscosity. Frictional torque and coefficient of friction was lowest for Jatropha oil but blends with nano CuO found to have higher values. 10:90 blend of Jatropha oil with ISO VG46 found to have similar performance to ISO VG46 oil [69].

Zulhanafi et al. (2020) examined the performance of Palm mid olein in journal bearing application studying the temperature and pressure profiles of biolubricant in journal bearing test rig. They were motivated by the use of palm based biolubricant in different applications, so they tested Palm mid olein for journal bearing application. They found higher maximum pressure and lower temperature rise for palm mid olein showing better performance in comparison to mineral SAE40 lubricant. Also friction coefficient was lower for palm mid olein at studied testing conditions [70].

5. CHALLENGES, MITIGATION AND FUTURE SCOPE

Vegetable oil based biolubricant has shown great potential as an alternative but it has limited application because of its poor thermo-oxidative stability, hydrolytic stability and low temperature properties. As discussed earlier these can be improved using chemical modifications and additives. But these mitigation strategies use to increase the overall cost of biolubricants. Though it comes out cheaper than synthetic lubricant but it is still costlier than mineral oil. For the acceptance of vegetable oil based biolubricant in wider application areas, cost reduction is a major challenge. More research is needed in biolubricant production processes to lower down the cost of production. In order to reduce the production cost, many researchers are working towards methods to increase the reaction yield and also looking for reusable biocatalysts for improved production efficiency [71-74].

Another challenge for vegetable oil based lubricant is to not create a scarcity of edible oil for food consumption which may raise the overall cost of edible oil. Researchers have suggested usage of non edible oils as a mitigation strategy to this problem [75-77]. But non edible oils lack market stability which limits their continuous availability to lubricant industry. Various promotional measures would be needed to encourage farming of non edible oils to regularize the market by the government as well as industrial groups [78-79]. Also advances in biotechnology to improve the overall yield of vegetable oils from the crops could be an answer to this challenge which must be looked upon by researchers.

These days' hydrodynamic journal bearings in modern machineries such as automotive bearings undergo severe operating conditions. Higher loadings, increased number of start-stop cycle and usage of low viscosity lubricant is pushing the bearing systems to work more in boundary and mixed lubrication regime [6, 80]. To tackle with such situations anti-wear additives such as zincdialkyldithiophosphate (ZDDP) are more often used in lubricants which are not environmental friendly [81]. Using antiwear additives such as ZDDP in biolubricants to deal with severe operating conditions serves against the purpose of biolubricants. This has lead to a new research area of biodegradable nanolubricants which promotes usage of eco-friendly nanoparticles as anti-wear additives [82-85]. A lot more research is needed in this area in order to get a stable biolubricant with nano additives.

6. CONCLUSION

Mineral oil based lubricants dominate the lubricant market. These lubricants are very harmful for the living beings and there is a great need to replace this with more biodegradable and sustainable alternative. Vegetable oil has shown great potential to replace conventional lubricant to serve as an environment friendly biodegradable lubricant. Hydrodynamic journal bearings, which have wider range of application in areas such as IC engines, steel mills, turbines, compressors and pumps, utilizes a great amount of lubricant. Development of biolubricant alternative for hydrodynamic journal bearing applications will have a major impact on lubricant industry. Continuous research for biolubricants in hydrodynamic journal bearing application is the need of hour.

It can be concluded from various research works done across the globe that chemical modification of vegetable oil and usage of additives improves the physicochemical properties of biolubricant to tailor fit the requirements of hydrodynamic journal bearing application. These modifications however tends to increase the overall cost of biolubricant. But many researchers have also shown that usage of vegetable oil based biolubricant in hydrodynamic journal bearing enhances the tribological performance of the bearing with reduction in friction as well as wear. These improved lubricant performances can lead to energy savings which can justify the increased cost of biolubricant. In order to realize more energy savings, to be competitive with conventional lubricant researchers are encouraged to undertake more study in the field of nanoparticles as an alternative eco-friendly anti wear additive in biolubricants.

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Abbreviations

AFM	Atomic Force Microscopy
CMRO	Chemically Modified Rapeseed oil
CSO	Cottonseed oil
CuO	Cupric oxide
IC engine	Internal Combustion engine
PAO4	Polyalphaolefin 4
PGD	Propylene glycol dioleate
PPD	Pour point depressants
Pt/ZSM-5	Platinum/ Zeolite Socony Mobil–5
SEM	Scanning electron microscopy
TiO_2	Titanium dioxide
WS_2	Tungsten disulfide
ZDDP	Zinc dialkyldithiophosphate