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A methodological review on bio-lubricants from vegetable oil based resources

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ABSTRACT

Finiteness of global crude oil reserve, rising crude oil prices, and issues related to environment seems to be a reality check for the problems of emerging generations. Present article focuses on lubricating oils as well as lubricating greases developed from vegetable oil. Vegetable oil based lubricants are an attractive alternative to conventional petro based lubricants due to number of their physical properties including renewability, biodegradability, high lubricity and high flash points. Still they have not yet replaced petro based lubricants due to their inappropriate chemical structure, which lags them behind at various odd conditions during applications. The challenges in this field are to improve certain characteristics of vegetable oils without impairing their excellent tribological and environmentally relevant properties. Chemical modification of vegetable oils overcomes the structural problems related to vegetable oils which in turn makes them fit for the application of lubricant. In this review article, we have reviewed the available literature and recently published data related to development of bio-lubricants by chemical modifications of vegetable oils.

1. Role of lubricant

Lubricating the moving parts has been known to humans since the invention of the wheel. At that time the primary aim of using a lubricant was to reduce the friction, it can be easily visualized that the use of wooden axles and wheels, or even a combination of metallic wheels and axles would create great amount of friction and wear. Lubrication then becomes the basic need for mechanical machines [54,37]. In any mechanical equipment, the moving parts or the metal surfaces come in contact but they do not usually touch over the whole of their apparent area of contact. In general, they are supported by the surface irregularities which are present even on the most carefully prepared surfaces [73,50,83]. Every working surfaces are rough and this roughness on the surface creates macroscopic ridges and valleys which in turn supports friction. The tribological interactions between exposed sides with the interfacing material and surrounding system may result in loss of material from the surface. The process leading to loss of material due to abrasion is termed as wear. Wear is a process which occur when the surfaces of engineering components are loaded together and are subjected to rolling or sliding motion. The type of friction generated during rolling or sliding motion depends upon the load and the geometry of the substrates. Wear can be minimized by modifying the surface properties of solids by one or more of "surface engineering" processes or by use of lubricants [47,48,85,93]. Lubrication is the process, or technique employed to reduce wear of one or both surfaces in close proximity, and moving relative to each another, by interposing a substance called lubricant between the surfaces to carry or to help carry the load (pressure generated) between the opposing surfaces. The main purposes of lubrication are (i) to reduce wear and prevent heat loss that results due to contact of surfaces in motion, (ii) to protect it from corrosion and reduce oxidation; (iii) to act as an insulator in transformer applications; and (iv) to act as a sealing agent against dirt, dust, and water. While wear and heat cannot be completely eliminated, they can be reduced to negligible or acceptable levels by the use of lubricants. As heat and wear are associated with friction, both effects can be minimized by reducing the coefficient of friction between the contacting surfaces. Any material used to reduce friction in this way is a lubricant [3,40]. Lubricants are available in liquid, solid, and gaseous forms, amongst which liquid and solid or semisolid are used widely in day to day life.

2. Why bio-lubricants?

Trend of using bio-mass for the synthesis of various value added products have been in the priority zone of researchers. Researchers have explored various renewable feed stocks like protein [68,66,67,65], tree leaves [69,31,13], various seaweeds [89,90,49], vegetable oils [41,88,18], coffee pulp [30], paper mill sludge [29], lignocellulose

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and other agro-residues [46,28,8,1] for the synthesis of bio-plastic, bio-diesel, bio-lubricant, bio-adsorbent, bio-stimulants and bio-ethanol. These bio based products are now being used successfully at commercial level in many developed countries.

If one thinks of lubricants today, the first thing that flashes in mind is the petroleum oil. Petroleum oil components continue to form the major proportion of lubricants. The major source of almost all lubricants is the lube fraction which is obtained from crude petroleum [55,51]. Wide use of petro based lubricants is because they have the longest drain interval i.e. the operating life of a lubricant, which decreases the frequency of breakdown time of the machine as completely changing the lubricant takes a significant amount of time [87]. Lubricants and functional fluids are omnipresent due to their widespread use and they thus pollute the environment in small, widely-spread amounts and rarely in large, localized quantities. Although petroleum based lubricants possess many useful physical properties, they are also non- renewable and toxic to the environment [53]. Industrial equipment's used in offshore drilling or agriculture require machinery to be in close proximity with a water source, and using petro based lubricants can be dangerous to the surroundings. Improper disposal of used petro based lubricants contaminates water bodies, cause infections and affects vitally on the survival of aquatic ecosystem. Numerous environmental groups and nature clubs have pressured industrial groups to use bio based lubricants instead of petro based lubricants in these situations [4,39,82].

Major portion of the lubricants consumed worldwide ends up in polluting the environment, many efforts are made to minimize spillages and evaporation. These high lubricant losses into the environment were behind the development of environmentally friendly bio based lubricants [55]. Also the idea that oil soon may no longer be available, industries have been searching for a cheap, renewable source of lubricant. As we know that non edible uses of vegetable oils have grown little during the last few decades. Although some markets have been explored based on vegetable oil oriented products, still there are many bright scopes of expansion in the field of vegetable oils [21]. Many countries like India, Sri Lanka, Bangladesh, Nepal etc. have great potential of producing edible and non-edible tree borne oils, which remain untapped and can be used as potential source for vegetable oil based lubricants. Increased markets for such uncommon seeds and oil could increase farmer incomes and maximize the application of agriculture products [84]. Vegetable oils have superb environmental credentials, such as being inherently biodegradable, having low eco-toxicity and low toxicity towards humans, being derived from renewable resources, and contributing no volatile organic chemicals [75], due to which they are used in various industrial applications such as emulsifiers, lubricants, plasticizers, surfactants, plastics, solvents and resins. Although vegetable oils possess many desirable characteristics, currently they are not widely used as lubricant base oils. Largely this is due to undesirable physical properties of most vegetable oils viz. poor oxidation stability, poor low temperature properties, poor viscosity index, etc. [62,59].

Just like two sides of a coin, vegetable oil based lubricants also have their own merits and demerits, they have outstanding physical properties which justifies them as lubricants, but have poor thermo-oxidative property which restricts them to be used as lubricating agent at elevated temperatures [55]. Much research is being carried out to improve the thermo-oxidative property, so that they may compete as an economical alternative with petro based lubricants. Currently there are steps being taken towards creating an economy that prefers a bio based lubricant through policy, but there are complications in the perception of bio based oil and the allocation of arable land. The world cannot completely switch over to bio based lubricants, it must be a gradual process requiring the collaboration of government support, agriculture, industry and research. Globally, crude oil based products have dominated the lubricants market. But this progress is limited to the last century. The application of natural oils and fat as lubricating agents are being used absolutely in many different ways.

3. Vegetable oils as lubricating oil

Can vegetable oils make good lubricant base stocks? Research conducted till date indicates that chemically and genetically modified vegetable oils have excellent potential to perform adequately as lubricants. Vegetable oils have been used as lubricants for machinery and transportation vehicles for a prolonged period of time before the discovery of petroleum resources. Petroleum, primarily being cheaper and having improved performance, quickly replaced vegetable oils as the lubricant. Now, with increased petroleum costs, decreased petroleum reserves, and environmental concerns as major factors, vegetable oils as lubricating agents are making a slow but steady comeback. In the past decade, the initial applications have been niche markets such as chain saws, track lubricants, and other total loss lubricants. Some technical and logistic concerns have been marked regarding the ability to maintain consistent profile of vegetable oils that would meet the final application and performance specifications.

A lot of development and research is being carried out to meliorate the physicochemical properties of vegetable oils so that they may compete with petroleum based lubricants. Number of plant based lubricants have been developed for various sectors of industry (Tables 1-3).

Compared to petroleum based lubricants, vegetable oils in general possess high flash point, high viscosity index, higher lubricity, low evaporative losses, and good metal adherence. The presence of a polar group with a long hydrocarbon chain makes vegetable oil amphiphilic surfactant by nature, allowing it to be used as a boundary lubricant [44]. The molecules have strong affinity for and interact strongly with metal surfaces. The long hydrocarbon chain is oriented away from the metal surface to form a monomolecular layer with excellent boundary lubrication properties [43,42,2].

Various routes of chemical modification of vegetable oils have been developed with an aim to prepare a perfect bio degradable lubricant. Chemical modification of vegetable oil enhances its thermal as well as oxidation stability, which help them to withstand within wide operating conditions. The methods for development of vegetable oil based lubricants are as follows.

4. Transesterification of vegetable oils

Transesterification is a reaction in which an ester is transformed into another ester through interchange of the alkyl group. Transesterification of vegetable oils yields to synthesis of various fatty

Table 1
Specific applications of various vegetable oil [81,38]

Vegetable oil	Application
Canola oil	Hydraulic oils, tractor transmission fluids, metal working fluids, food grade lubes, penetrating oils, chain bar lubes
Castor oil	Gear lubricants, greases
Coconut oil	Gas engine oils
Olive oil	Automotive lubricants
Palm oil	Rolling lubricant,-steel industry, grease
Rapeseed oil	Chain saw bar lubricants, air compressor-farm equipment, Biodegradable greases.
Safflower oil	Light-colored paints, diesel fuel, resins, enamels
Linseed oil	Coating, paints, lacquers, varnishes, stains,
Soybean oil	Lubricants, biodiesel fuel, metal casting/working, printing inks, paints, coatings, soaps, shampoos, detergents, pesticides, disinfectants, plasticizers, hydraulic oil
Jojoba oil	Grease, cosmetic industry, lubricant applications
Crambe oil	Grease, intermediate chemicals, surfactants
Sunflower oil	Grease, diesel fuel substitutes
Cuphea oil	Cosmetics and motor oil
Tallow oil	Steam cylinder oils, soaps, cosmetics, lubricants, plastics