The Prospects of Vegetable based Oils as Metal Working Fluids in Manufacturing Application –A Review

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***Abstract*-Lubricants provide smooth operation between movable parts of all machines. It maintains the reliability of machine functions and reduces the risk of failures. In present time with a great development in industry the use of lubricating oil has increased. Increase in the price of mineral oil and with the depletion of crude oil reserves will impact the industrial market in future,. hence bio lubricant can be a good alternate as a lubricant. Bio lubricants are being used as cutting fluids, metal forming fluids, biodiesel etc.**

Vegetable bio lubricants are non toxic, degradable, renewable and have good lubricating properties. In this paper it is reviewed vegetable oils performance in metal working operation, machining operation and industrial heat treatment. In the reviewed papers mainly edible oils are used as fluid while non edible oils such as castor, karanja, mahua also have a great potential as lubricant.

Keywords:- Bio lubricants, Biodegradable, Machining, Metal forming, Non edible oils, Tribological characteristic, Environment friendly.

1. INTRODUCTION

Lubricants are being utilized in all sectors of industry for lubricating their machines and materials. Report says that nearly 38 million metric tons of lubricants were used globally in 2005, with a increment about 1.2% over the next decay. About 85% lubricants being used around the world are petroleum based oils. Use of petroleum based oil created adverse effect on environment [1].The depleting trend of conventional, non-renewable, mineral oil has triggered research and development on alternative renewable bio lubricant. Bio lubricant is one of the most promising renewable energy in the present as well as future. It is significant interest to focus on improving environmental friendliness, reliable, durable, and efficient lubricant in the automotive and machinery industries [2].Reducing wear and friction is a key element to decrease energy losses, particularly in engines and all machine relative moving elements.

By the use of mineral oil there are some unwanted and undesirable elements such as calcium, phosphorous, zinc, magnesium, and iron particles due to combustion in engine [3]. .Vegetable oil has a great potential as a lubricant in automotive sector and metal working fluid (MWF'S). Metal working fluid increases the productivity and manufacturing quality by cooling and lubricating. Due to their advantage the use of metal working fluids is increased in machining industry. Most of the metal working lubricants are mineral oil based fluid, hence they are not degradable. Cutting fluids are normally classified into three main groups; that is; (i) neat cutting oils (ii) water-soluble fluids and (iii) gases. The water-soluble fluids can be classified as emulsifiable oils (soluble oils), chemical (synthetic) fluids or semi-chemical (semi-synthetic) fluids[4]. Fluids within these classes are available for light, medium and heavy duty performance A report informs that European Union consumes approximate 320000 tones metal working fluid's per year and about two-third is disposed to environment [5]. Disposing of this huge amount of MWF's diminishing the environmental friendliness and impacting an adverse effect on the environment. Estimation shows that in the USA alone about 700,000 to one million workers are exposed to MWFs [6]. As cutting fluids are complex in their composition, they may cause irritation or allergy. Even microbial toxins are generated by bacteria and fungi present, particularly, water-soluble cutting fluids [7], which are harmful to the operators, hence there is a need of alternatives which can overcome these problems. Such alternatives are synthetic lubricants, solid lubricants and vegetable based lubricants, out of which vegetable based oils are highly attractive alternate to mineral based oil because they are environment friendly, renewable, highly biodegradable, less toxic [8-9]. Phadke stated "The overall lubricant market in India is projected to grow at 3.7% per year to reach 2,230 KT by 2014.

The increasing oil prices, the depletion of the crude oil reserve in the world and the demand to protect the environment against pollution caused by lubricating oils and their uncontrolled consumption have directed towards interest in developing and using alternative lubricants. Bio lubricant oils are perceived as alternatives to mineral oils because they possess certain natural technical properties and they are biodegradable. Compared with Mineral oils, vegetable oil-based bio lubricants generally exhibiting lubricity, high viscosity index (VI), high flash point, and low evaporative losses [10-16]. Both boundary and hydrodynamic lubrications can be obtained from bio lubricants because of their long fatty acid chains and the presence of polar groups in the structure of vegetable oil [17–19].

2. LUBRICANT

A lubricant is a substance which reduces the wear by reducing friction by providing a protective layer between two contacting surfaces that have relative motion. The main purpose of lubrication is to reduce wear but it also provides insulating property in transformer, cooling in metal working processes. Lubricants are generally composed of a majority of base oil and a minority of additives to impart desirable characteristics. Typically lubricants contain 90% base oil (most often petroleum fractions, called mineral oils) and less than 10% additives. Vegetable oils or synthetic liquids such as hydrogenated polyolefins, esters, silicone fluorocarbons and many others are sometimes used as base oils [20].

2.1 Biodegradable lubricants

Biodegradability of any component is the ability to decay by microorganism [21].A lubricant is classified as biodegradable if its percentage of degradation in a standard test exceeds a certain marked level. Vegetable oils exhibit better biodegradability than mineral oils and others, as shown in Table1. The ecotoxic property of lubricating materials depends on the base oils and additives used in their production [22]. Biodegradability is primarily influenced by the base oil of lubricants [23]. It depends on the chemical structures of organic compounds.

Biodegradables oils are :-

- Vegetable oil
- low viscosity polyalphaolefins
- polyalkylene glycols
- dibasic acid esters
- polyol esters

Types of fluid	Biodegradability (%)
Mineral Oil	20-30
Vegetable oil	95-98
Esters	75-100
Polyols	75-100

Table1. Biodegradability of some base fluids

2.2 Vegetable oils

Vegetable oils are the oils made from plants such as palm, soybean, sunflower, rapeseed, pongamia pinnata and coconut etc [24].. Bio lubricants are generally considered as lubricants with high biodegradability as well as low human and environmental toxicity.

2.3 Source of bio lubricants

It is observed that bio lubricant feed stock depends on climate and geographical locations. There are more than 350 oil bearing crops that may be used as an alternative lubricant among those some edible oil are palm, soybean, sunflower, coconut, safflower, rapeseed, cottonseed, and peanut oil and some non edible are pongamia pinnata, mahua, castor, etc. Their production and properties depends upon region and geographical area. Linseed, Mahua, Karanja are the main producing oil seeds of India in the category of Non edible oil seeds. Some edible and non edible oil seeds with their oil contents are shown

Edible Species	Oil content (% by volume)	Non Edible species	Oil content (% by volume)
Rapeseed	38-46	Castor	45-60
Palm	30-60	Jatropha	40-60
Peanut	45-55	Neem	30-50
Olive	45-70	Karanja	30-50
Corn	45-50	Mahua	35-50
Coconut	63-65	Linseed	35-45

Table 2 Oil contents of some Edible and Non Edible seeds [25-32]

2.3.1 Non edible vegetable oils

(a) Castor oil **–** It's scientific name is Ricinus Communis L. It is non edible oil which is obtained from castor bean but technically is not a member of bean. Castor oil is a color less to very pale yellow liquid with mild or no odor or taste. Its boiling point is 313 °C and its density is 961 kg/m3. It is a triglyceride in which approximately 90 percent of fatty acid chains are ricinoleic acid [33]

(b) Karanja oil **-** A thick yellow orange to brown oil is extracted from seed and scientific name is Millettia Pinnata. Its boiling point is 316 ^{o}C and density is 924 Kg/m3.Oleic acid is main fatty acid composition of karanja oil and it is

about 52%. Linoleic Acid and palmitic acid present in karanja oil is 17% and 11% respectively [34].

(c) Jatropha Curcas L **-** Non edible Jatropha curcas is a succulent shrub from the Euphorbiaceae family. Jatropha is a perennial tree, which has a life span of 40-50 years and can bear fruits for 25 years [35]

(d) Moringa oil **-** The characteristics of moringa seed oil can be highly desirable especially with the current trend of replacing polyunsaturated vegetable oils with those containing high amounts of monounsaturated acids. Moringa oil has 74% oleic acid content and thus possesses improved oxidation stability over many other natural oils [36].

(e) Mahua oil **-** Mahua seed contain 30-40 percent fatty oil called mahua oil. It is a slightly greenish yellow and derived from a tropical tree belonging to the family Sapotoceae. It has density of 945 kg/m3 and fire point is 250^{o}C.[37].

2.3.2 Edible vegetable oil

(a) Rapseed oil **–** It belongs to Brassica family including mustard, rutabagas, kale. These seeds have oil content over 40%. In which oleic acid, linoleic acid are dominant fatty acid [38].

(b) Soybean oil **-** "Soybean" or "Soya" is referred to Glycine max which is found only under cultivation and is a member of the Papilionaceae. The oil content in soybean seed ranges from 15% to 22% depending on environmental conditions during seeds maturity. The major fatty acids are oleic and linoleic [39].

(c) Palm oil **-**Palm first received its botanical name from Jacquinin1763 as Elaeis guineensis . Palm oil is more saturated than soybean oil and rapeseed oil as its major fatty acids include palmitic, stearic, oleic, and linoleic acid [40].

2.4 Properties of bio lubricants

Bio lubricants have many valuable and useful physicochemical properties. They offer technical advantages unlike those of typical petroleum-based lubricants. Bio lubricants have high lubricity, high VI, high flash point and low evaporative losses [41-43]. Overall, vegetable oil-based bio lubricants exhibit several excellent proper- ties compared with mineral oils. Table 3 shows the comparative analysis result of properties of vegetable oils

2.4.1 Viscosity Index

The Viscosity index indicates changes in viscosity with changes in temperature. A high VI indicates small changes in temperature; where as a low VI indicates high changes in temperature. Vegetable oil-based bio lubricants have higher VI than mineral oils, which ensures that bio lubricants remain effective even at high temperatures by maintaining the thickness of the oil film. Hence, bio lubricants are suitable for a wide temperature range.

2.4.2 Viscosity

Viscosity is the most important property of oil. It indicates resistance to flow, and is directly related to temperature, pressure, and film formation. High viscosity indicates high resistance to flow and low viscosity implies low resistance to flow.

2.4.3 Flash Point & Fire Point

Flash point is the lowest temperature at which a lubricant must be heated before it vaporizes. When mixed with air, a lubricant will ignite but will not burn. By contrast, fire point is the temperature at which the combustion of a lubricant continues. Flash and fire points identify lubricant volatility and fire-resistance properties. Both factors are important for transportation and storage requirements. Vegetable oil-based bio lubricants have higher flashpoint than mineral oils, thus considerably reducing the risks of fire in case of a lubricant leak.

2.4.4 Oxidation Stability

Oxidation stability is the ability to exhibit resistance toward oxide-forming tendency, which increases when temperature rises. The most significant contribution to oxidation includes metal surfaces, temperature, contaminants, pressure, agitation, and water. A low oxidative stability indicates that oil oxidizes rapidly during use if it is untreated, becoming thick and polymerizing to a plastic-like consistency. Bio lubricants have poor oxidation stability as base oil and hence oxidation inhibitors are required.

2.4.5 Pour Point

Pour point is the lowest temperature at which oil flows or pours. Pour point is an important factor. Vegetable oil-based bio lubricants have lower pour points than mineral oils, thus providing excellent lubrication for cold starts.

2.4.6 Antiwear Properties

Boundary lubrication occurs when oil viscosity is insufficient to prevent surface contact .Anti-wear additives provide a defensive film at contact surface to reduce wear. Anti-wear property is identified by standard laboratory tests. Vegetable oil-based bio lubricants have better anti-wear properties than mineral oils.

2.5 Structure and Rheological properties of vegetable oils

Vegetable oils are mainly triglycerides, which are glycerol molecules with three long chain fatty acids attached at hydroxyl group ester linkage [44]. The fatty acids in vegetable oil triglycerides are all of similar length, between 14 and 22 carbons long, with varying level of un saturation. Excess of saturated long chain fatty acids leads to poor low temperature behavior, while excess of certain poly unsaturated fatty acids leads to unfavorable oxidation behavior and resination at high temperatures. Even very long mono unsaturated fatty acids worsen the low temperature behavior.

The triglyceride structure of vegetable oils provides qualities desirable in a lubricant. Long, polar fatty acid chains provide high strength lubricant films that interact strongly with metallic surfaces, reducing both friction and wear. The triglyceride structure gives a high natural viscosity and viscosity index and is also responsible for structural stability over reasonably operating temperature ranges. The flash point is high, which correlates to a very low vapor pressure and volatility, thereby reducing or eliminating potential hazards during use. Even so, they have poor oxidative stability as compared to mineral oils and in general they cannot withstand reservoir temperatures over 80◦C. However, the use of appropriate antioxidants can combat this. These oils are also less hydrolytically stable, foam more and have lower filterability than comparable mineral oils. Without additives vegetable oils outperformed mineral base oils in anti wear and friction, scuffing load capacity and fatigue resistance [45-48]. In figure R1, R2, R3 are the long carbon hydrogen chains.

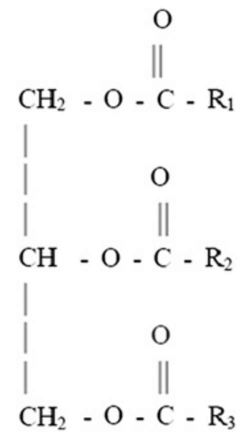

Fig:-Chemical structure of triglyceride of a typical vegetable oil [49]

Some vegetable oils and there phsio-chemical properties are shown in Table-4

Properties	Rapeseed [50,]	Sunflower [51]	Soybean [52]	Jojoba [53]	Karanja [54]	Neem [55]	Castor [50,56]
Kinematic viscosity @ 40⁰C (cSt)	45.6	40.05	32.93	24.9	43	68	220
Viscosity index	216	206	219	233	172	135	220
Specification value(mgKOH/g)	180	-	189	94.69	179	166	180
Total acid value (mgKOH/g)	1.40	-	.61	1.10	22	23	1.40
Iodine value (mg l/g)	104	-	144	98	78	66	87
Pour point(⁰C)	-12.00	-12	-09	9	-9	9	-27
Flash point(⁰C)	240	252	240	-	-	-	250
Oxidation stability (110⁰C, h)	7.5	.9	2.1	-	6.2	7.2	1.2

Table 4 physico-chemical properties of vegetable oils

3.PERFORMANCE OF DIFFERENT VEGETABLE OILS IN MANUFACTURING APPLICATION

De Chiffre L. investigated the performance of cutting fluids for turning drilling, reaming and tapping operation for austenitic stainless steel. Their evaluation parameters were mainly cutting force, tool life and product quality. They used straight oils including mineral oil, synthetic oil and vegetable oil for test. They concluded that cutting forces for vegetable oil was low as compare to reference mineral oil and also revealed that tool life was higher for vegetable oil among all [57].

Andres F. made a comparative analysis of five base oils in straight and emulsified form in a tapping torque experiment. The five oils were petroleum based naphthenic oil, its blend with petroleum based paraffinic oil in equal ratio, high oleic bio based canola oil, soybean oil, and synthetic ester. Commercially available metal working fluid is used for compare those oils. The fluids were tested on 1018 cold rolled steel using uncoated hardened steel tool. Experiment reveals that straight vegetable oils have higher tapping torque efficiency than both mineral base oils. The experiment also reveals that vegetable oil has higher lubricity potential than other oil [58].

Peter Raynor depicted an experiment with emulsions of soybean oil and commercially available metal working mineral based fluid. The experiment was developed to simulate the mist generation by impaction, centrifugal force and evaporation or condensation mechanism, the rate of mist production is measured under the formulated emulsions and results were compared with mineral based fluid and concluded that under impaction mechanism mist production is same for both soybean based emulsion and mineral based, while in centrifugal mechanism mist production is higher for soybean emulsions compare to mineral based fluids [59].

Salete martin used castor oil based fluid for the experiment. Castor oil based was used as cutting fluid for grinding process. To evaluate the performance of formulated cutting fluid radial wheel wear and work piece roughness were choose. It is seen that wheel wear and roughness were reduced by utilizing castor oil compared to reference mineral based fluid [60].

Abdalla and Baines formulated various oils such as commercially and naturally vegetable oils, chemically modified vegetable oil derive fatty acid esters and polyols. Vegetable base oils are coconut, sunflower, rapeseed, olive were selected for study and two materials stainless steel and aerospace-grade titanium alloy were selected to test oils. Various test such as microtap torque, SRV lubricity, kinematic viscosity were performed under standard manner and Tribological studies reveal that very low friction value were found under naturally derived vegetable oil compared to commercial oil. The microtap test shows that vegetable oil with natural additive has low cutting force and torque while machining stainless steel [61].

Lovel M. used blend of canola oil and boric acid as lubricant for deep drawing operation of steel sheet. Friction value is measured by using strip tensile friction simulator. It is concluded that blending of canola oil and boric acid has steady friction value and which is 44% less than commercial fluid. Surface roughness value was also lower than the commercially fluid and formability of steel also increases for blending [62].

Ojole experimentally investigated the effect of straight vegetable oils such as groundnut oil, coconut oil, palm kernel oil on cutting force during cylindrical turning of three materials(mild steel, copper, aluminium) using tungsten carbide tool. Experiment is performed with different cutting variables such as cutting speed, feed rate, depth cut, spindle speeds, Experiment shows that cutting force for different vegetable oil depends on material, as highest reduction in cutting force is obtained when aluminium is turned and groundnut oil as cutting fluid [63].

Bulluco and De Chiffre investigated the performance of vegetable based oil in drilling austentic stainless steel (AISI 316L) using high speed steel cobutt tool. Commercial mineral based oil is used for comparative analysis. Five vegetable oil based (Rapeseed oil) cutting fluid with some additives. Thrust force and tool life were the evaluation parameters. Experiment shows that there is increase in tool life about 177% and more than 7% decrease in thrust when vegetable based oil is used as cutting fluid compare to mineral based oil [64].

S.A.Lawal,I .A.Choudhury ,Y.Nukman used vegetable oil as cutting fluid or metal working fluid with different ferrous metals and concluded in their experiment that vegetable oil has greater lubricity than mineral oil in some specimen. They revealed that coconut oil showed better performance than mineral oil on turning and better surface finish.When vegetable oil was applied to turning of AISI 9310 alloy steel using MQL mode of application, there was remarkable improvement of metal removal rate (MRR), that is, productivity. High productivity means that higher feed rate was achieved when vegetable-oil-based metalworking fluid was used [65].

Peter Fernandes, K. Narayan Prabhu conducted experiment to study the suitability of vegetable oils as bio quench ants for industrial heat treatment. The study involved the assessment of the severity of quenching and wetting behaviour of conventional and vegetable oil quench media. Quench severities of sunflower, coconut and palm oils were found to be greater than mineral oil. Among vegetable oils, highest heat transfer coefficients were obtained for sunflower oil and lowest heat transfer coefficients were obtained for castor oil. The results show that the thermal stability of palm oil is better than mineral oil. Palm oil is thus safer compared to mineral oil and its thermal stability is superior to mineral oil. Thus palm oil could be exploited as an effective bio quench ant for industrial heat treatment [66].

Carcel choose sunflower, corn, soybean, olive oil and mineral oil as reference oil for the stamping test under the boundary lubrication condition. Surface texture was the comparable parameter for the effectiveness of the oil. It is observed that vegetable has low coefficient of friction during the operation compared to reference mineral oil. Another observation is that lubrication performance for steel sheet is superior than reference mineral oil however vegetable oil shows less effectiveness than mineral oil in case of zinc electrocoated sheet and olive oil perform best among vegetable oils.[67].

3. EFFECT OF DIFFERENT FLUIDS ON ENVIRONMENT

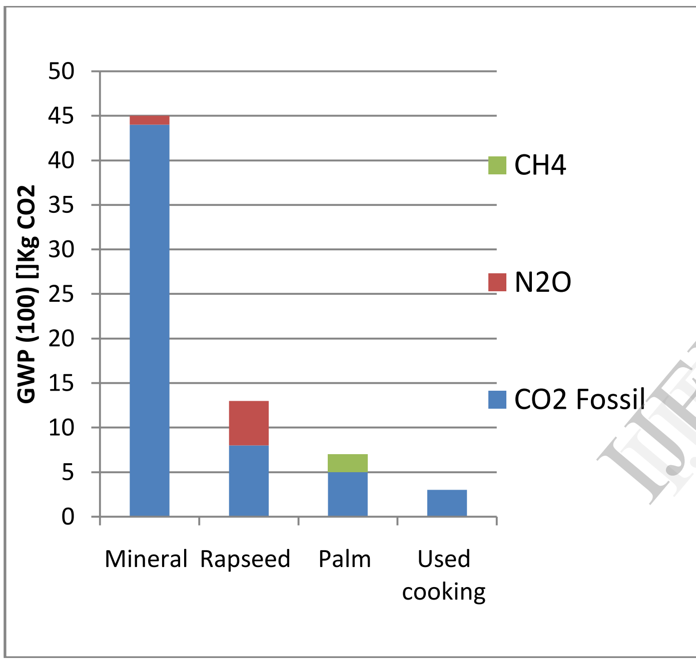

Fig. Global Warming Potential [68]

4. RESEACH GAP

The application of vegetable oils as metal working fluids in machining is increasing and becoming a great attention due to its biodegradability, renewability, ecofriendly and good physical properties. It is observed from above literatures that edible vegetable oil has been tested as MWF's. Non edible oil also has a great potential as MWF's. There is a need to test of non edible oil for materials. One of the observations is that vegetable oils are tested mainly for ferrous material and there is a gap for nonferrous and super alloys.

5. CONCLUSION

It is observed from reviewed literatures that vegetable oils perform well in manufacturing application such as machining, metal forming tan mineral oil and can become an alternate of mineral base oils.

Vegetable oils are highly degradable, non toxic, good physical properties. Vegetable oil-based metalworking fluid is being recognized as having superior lubricating properties compared to other based-oil. The use of these coolants has improved significantly the machining performances with reported increase of 117% in tool life and 7% reduction in thrust force. The combined effect of solid lubricant and vegetable-oil when used in turning of AISI 1040 steel with cemented carbide tool led to the reduction in flank wear. Here mainly edible oils are being used in application while non edible oil such as castor, karanja, mahua, has also potential as cutting fliuids.

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