

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 6, June 2015

Tribological and Emission Studies on Two Stroke Petrol Engine Lubricated with Castor Oil Methyl Ester

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ABSTRACT: There are growing commercial and research interests in replacing products based on non-renewable petroleum with those derived from renewable resources. As petroleum supplies decrease, production migrates toward higher transportation fuel fractions, and geopolitical considerations affect supply, the move towards national self-sufficiency for liquid energy supplies will become even more important. This research aims to develop engine lubricants that are both derived from renewable castor oil and are equivalent in every way to their petroleum-based counterpart. In addition to providing somewhat greater security against disruption of foreign-sourced oil supplies, they will supply the domestic industry with an environmentally friendly and biodegradable replacement for hydrocarbon lubricants.

This study aimed at using castor oil methyl ester (CME) and manufacturers recommended oil (MAK2T oil) mixed in definite proportions as two stroke crankcase lubricants. Conducting emission analysis for smoke is to be perform on definite proportion of CME along with MAK 2T oil using exhaust gas analyser, what we expecting is to reduce the emission level

KEYWORDS: oil methyl ester (CME), (MAK2T oil)

I. INTRODUCTION

1.1 Lubrication

Lubrication completely or partially separates the surface of the friction bodies by selectively introducing an interfacial medium (lubricant) that minimise friction and wear. Most lubricants are fluids (mineral oils, synthetic oils, etc..) yet they can also be solid e.g., for using in dry sliding bearing polytetra fluoroethylene [PTFE], graphite, molybdenum disulfide (MoS₂) etc., greases are also applied, e.g., in ball bearing and sliding bearing and occasionally in gears too. Gases (air) are also employed e.g., In gas lubricated bearings, powders, lubricating varnishes and pastes can be classified as solid lubricants. Similar to friction states, different lubrication states can also be defined to be precise fluid film lubrication, mixed lubrication, boundary lubrication and solid lubrication.

1.2 Fluid film lubrication

Fluid film lubrication i.e., the complete separation of the frictional surfaces by a lubricating film can be achieved by hydrodynamic, elasto hydrodynamic or hydrostatic lubrication. A load dependent pressure is developed in the lubricating film, as a result of which the load can be carried.

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1.3 Hydrodynamic lubrication

The following conditions must be met to produce hydrodynamic lubrication. A viscous lubricant that adheres to both the moving and the fixed friction body must be used (adhesive effect of the lubricant). Furthermore the friction body surfaces must be converging and the lubricant must be dragged into the converging gap. The entraining velocity depends on the velocity at which the lubricant is dragged in to the contact and is frequently confused with the relative velocity. The latter is decisive for friction, while the entraining velocity is essential for load carrying capacity. Above all it is the lubricant's viscosity that determines the lubricating effect in hydrodynamic lubrication. Friction is generated by the shear of the viscous lubricant. Apart from the viscosity, the relative velocity between the moving bodies, lubricating gap surfaces and the lubrication height are decisive for friction. If both surface slides with the same sliding velocity, the relative velocity is $v = 0$ i.e., friction does not occur. However, when the sliding conditions are identical, the entraining velocity in the lubrication gap can be high. So that the tribo technical system then has a high load carrying capacity and a friction force of zero.

1.4 Elasto hydrodynamic lubrication

Elasto hydrodynamic lubrication is a form of hydrodynamic lubrication in which the elastic deformations of the lubricated surfaces become significant. The essential prerequisites for hydrodynamic lubrication, lubricant entraining velocity in the converging gap and a viscous lubricant between the surfaces, are also important in EHL. In hydrostatic lubrication of the friction bodies, a pocket or recess is incorporated in one friction bodies loaded surface into which a fluid is forced from outside at constant pressure. Hence the lubricant pump and lubricating pocket in to which the lubricant is fed under pressure are the most important features of hydrostatic lubrication. The lubricating pocket is normally positioned opposite the external load. The load carrying capacity of a contact with hydrostatic lubrication is also assured when surface are not moving. When the volumetric flow of lubricant into the lubricating pocket is constant, the minimum lubrication film is proportional to the cube root of the ratio of the average lubricant viscosity in the lubrication gap and the load, i.e., the minimum lubrication film thickness is less than is the case in hydrodynamic lubrication.

1.5 Boundary lubrication

In the boundary lubrication, the friction bodies are not separated by a lubricant, the hydrodynamic lubricating film effects are negligible and there are extensive asperities contacts. The physical and chemical properties of the thin surface films of molecular thickness control the lubricating mechanism in the contact. The base lubricant's properties are of little importance. The coefficient of friction is on the whole independent of the lubricant's viscosity. The frictional characteristics is determined by the properties of the solids involved in the frictional process and the boundary layer forming on the material surfaces, which primarily depends on the lubricant's properties, particularly the lubricant additives, as well as the material surface properties. These boundary layers are formed by physisorption, chemisorption and/or tribo chemical reaction. The thickness of the surface boundary layer varies between 1 and 10 nm depending on the molecule size.

1.6 Partial or mixed lubrication

If the load in hydro dynamically or elasto hydro dynamically lubricated machine elements groups too large or the lubricant entraining velocity in the lubrication gap is too small, the lubricating film becomes too thin so that asperity contacts appears at the some points. This is mixed friction, in which the states of boundary friction and fluid friction coexist. The lubricating film is no longer coherent because individual surface asperities of the paired parts penetrate it and cause direct contact of the sliding surface.

1.7 Lubricating oil

Lubricating oil or crankcase oil is a oil used for lubrication of various internal combustion engine parts. Engine lubricating oil is designed to facilitate enough oil film layers between sliding surfaces. While the main function is to lubricate moving

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parts, lubricating oil also cleans, inhibits corrosion, improves sealing and cools the engine by carrying heat away from the moving parts.

Lubricating oils are derived from petroleum and non-petroleum synthesized chemical compounds used to make synthetic oil. Lubricating oil mostly consists of hydrocarbons, organic compounds consisting entirely of carbon and hydrogen. These include motor or road vehicles such as cars and motorcycles, heavier vehicles such as buses and commercial vehicles, non-road vehicles such as go-karts, snowmobiles, boats (fixed engine installations and outboards), lawn mowers, large agricultural and construction equipment, trains and aircraft, and static engines such as electrical generators. In engines there are parts which move very closely against each other causing friction which wastes otherwise useful power by converting the energy to heat. Contact between moving surfaces also wears away those parts, which could lead to lower efficiency and degradation of the motor. This increases fuel consumption and decreases power output and can, in extreme cases, lead to total engine failure.

Lubricating oil creates a separating film between surfaces of adjacent moving parts to minimize direct contact between them, decreasing friction, wear, and production of excessive heat, thus protecting the engine. Lubricating oil being a good conductor of heat, it is brought into contact with a hot surface, thereby absorbing some of the heat from said surface so the oil can then transfer the heat elsewhere, typically to the air or a heat sink of some variety.

Coating metal parts with oil also keeps them from being exposed to oxygen, inhibiting oxidation at elevated operating temperatures preventing rust or corrosion. Corrosion inhibitors may also be added to the Lubricating oil. Many Lubricating oils also have detergent and dispersant additives to help keep the engine clean and minimize oil sludge build-up.

Rubbing of metal engine parts inevitably produces some microscopic metallic particles from the wearing of the surfaces. Such particles could circulate in the oil and grind against the moving parts, causing erosion and wear. Because particles inevitably build up in the oil, it is typically circulated through an oil filter to remove harmful particles. An oil pump, a vane or gear pump powered by the vehicle engine, pumps the oil throughout the engine, including the oil filter. Oil filters can be a full flow or bypass type. In the crankcase of an internal combustion engine, Lubricating oil lubricates rotating or sliding surfaces between the crankshaft journal bearings (main bearings and big-end bearings), and rods connecting the pistons to the crankshaft. The oil collects in an oil pan, or sump at the bottom of the crankcase. In some small engines such as lawn mower engines, dippers on the bottoms of connecting rods dip into the oil at the bottom and splash it around the crankcase as needed to lubricate parts inside. In modern vehicle engines, the oil pump takes oil from the oil pan and sends it through the oil filter into oil galleries, from which the oil lubricates the main bearings holding the crankshaft up at the main journals and camshaft bearings operating the valves.

In typical modern vehicles, oil pressure-fed from the oil galleries to the main bearings enters holes in the main journals of the crankshaft. From these holes in the main journals, the oil moves through passageways inside the crankshaft to exit holes in the rod journals to lubricate the rod bearings and connecting rods. Some simpler designs relied on these rapidly moving parts to splash and lubricate the contacting surfaces between the piston rings and interior surfaces of the cylinders. However, in modern designs, there are also passageways through the rods which carry oil from the rod bearings to the rod-piston connections and lubricate the contacting surfaces between the piston rings and interior surfaces of the cylinders.

Most Lubricating oils are made from a heavier, thicker petroleum hydrocarbon base stock derived from crude oil, with additives to improve certain properties. One of the most important properties of motor oil in maintaining a lubricating film between moving parts is its viscosity. The viscosity of a liquid can be thought of as its "thickness" or a quantity of resistance to flow. The viscosity must be high enough to maintain a satisfactory lubricating film, but low enough that the oil can flow around the engine parts satisfactorily to keep them well coated under all conditions.

Oil is largely composed of hydrocarbons, which can burn if ignited. Still another important property of lubricating oil is its flash point, the lowest temperature at which the oil gives off vapors, which can ignite. It is dangerous for the oil in a motor to ignite and burn, so a high flash point is desirable. At a petroleum refinery, fractional distillation separates a motor oil fraction from other crude oil fractions, removing the more volatile components, and therefore increasing the oil's flash point.

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1.8 Mineral oil

Mineral oils are obtained from naturally deposited crude oil with the aid of distillation and refining. Crude oils chiefly consist of hydrocarbons and organic oxygen, sulphur, and nitrogen compounds. The exact composition of crude oil depends on its origin (provenance). When mineral oils are manufactured, systematic selection of the base oil and control of the manufacturing process can produce particularly compositions and thus influence desired properties. Mineral oils are mixture of hydrocarbons, which can subdivided as a function of their structure into open-chain hydrocarbons (paraffin) and cyclic hydrocarbons (naphthenes), which can each be saturated or unsaturated.

Mineral oils performance characteristics change as their working life increases. A primary reason for diminished performance is gradual oxidation of hydrocarbons chain, with aromatic reacting more than naphthenes more than paraffin. As a result, sludge-like deposits can form, which impede the oil supply by clogging oil feed lines and filters. Moreover, the formation of organic acids can be boosted, which can cause corrosion of machine parts. This can be prevented in part by admixing additives (e.g., antioxidants, detergent, and dispersant agent). More information on their effect and the use of additives can be found in the section of additives.

1.9 Synthetic oil

Synthetic base lubricating oils are produced by chemical synthesis from chemically defined structural element (e.g., ethylene). Their development has made it possible to systematically satisfy even extreme requirements (e.g., lubricant temperature > 150). According to their chemical composition, synthetic lubricant are subdivided in to synthetic hydrocarbons, which only contain carbon and hydrogen[e.g., polyalphaolefines(PAO), dialkylbenzenes (DAB), polyisobutenes (PIB), and synthetic fluids(e.g., polyglycols, carboxylic acid esters, phosphoric acid ester, silicon oils, poluphenyl esters, fluorine-chlorine-carbon oils). Typical characteristics of synthetic oils are provided in the table. And a comparison of the properties of the synthetic oils with those of mineral oils is presented.

Synthetic oils have a number of advantages over mineral oils. They have better resistance to aging (thermal and oxidative stability) and thus their useful life is three to five times longer. They exhibit more favourable viscosity-temperature behaviour (with a significantly lower dependence of viscosity on temperature). Display better flow properties at low temperature and low volatility at high temperatures, can cover applications operating at a substantially expanded range of temperature, and are radiation and flame resistant. Moreover, synthetic lubricants can be used to obtain specific frictional properties e.g., lower friction coefficients to minimize power loss in ball bearings gears, or higher friction coefficients to increase the transmittable torque in friction gears.

On other hand synthetic lubricants often cannot be used as universally as mineral oils since they have been developed for specific properties. In addition, they are more strongly hydroscopic (water attracting), display only slight air release characteristics (risk of foaming), mix poorly or not at all with minerals oils, are toxic to a large extent. It is characterized by poor compatibility with other materials (risk of chemical reaction with seals, paints, and nonferrous metals) and by poor solubility for additives. They are not always available, most notably in certain viscosity classes, and they frequently cost substantially more.

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II. BIO LUBRICANTS

2.1 General

Environmentally compatible lubricating oils are increasingly being used for example, in motor vehicles and equipment in water protection areas and in hydraulic engineering, in vehicles for agriculture and forestry, and in openly running are readily and rapidly degradable, have a low water base substances have to be degraded in a degradability test (e.g., CEC L-33-T-82) by a defined amount within a specified time and the additives used (up to maximum of 5%) should be potentially degradable. Native oils (e.g., rape oil and natural esters) are unsuitable for high temperature (>70) and additionally have

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low thermal stability and resistance to aging. The synthetic oils suitable for continuous high temperatures are often used as hydraulic oils in agriculture and forestry machines. Polyglycols are used, for example as readily biodegradable oils in water engineering. Bio lubricants' are often, but not necessarily, based on vegetable oils. In all different current discussions bio lubricants are at the least products for which formulation for (a certain extend of) rapid. Biodegradability and low environmental toxicity is a deliberate and primary intention. However, no universal agreement exists on the origin and chemical composition of the bio lubricants. They can also be synthetic esters which may be partly derived from renewable resources i.e. the hydrolysis of fats and oils to produce the constituent fatty acids.

They can be made from a wider variety of natural sources including solid fats and low grade or waste materials such as tallow's. Genetically-modified vegetable oils, such as high-oleic sunflower and rapeseed, are also beginning to find use in applications where higher oxidative stability is needed. Vegetable oils offer biodegradability and low toxicity. Obviously during the formulation of a biodegradable and low toxicity fluid the additives must be biodegradable and have low toxicity.

In the beginning of the development of bio lubricants (some 20 years ago) the focus was on the formulation of products based on pure vegetable oils. Over the last ten years, however, the trend has been the use of synthetic ester types which may be partly derived from renewable resources. To avoid controversies associated with the term bio lubricants, as well as to create a starting point for more environmental preferable products to enter the market, a European harmonization of the term is highly desirable. The market for natural esters is increasing, but nevertheless strong efforts are still needed from ester base oil, additive and lubricant industry to develop improved products which will be generally more accepted by toxicologists and legislation as well as by end users.

There is a necessity to develop more analytical tailor-made methods to better understand the nature of lubricants and to better study which are the modifications occurring during their use. Simply transferring the well-known methodologies from mineral oils to vegetable oils would result in an unrealistic picture of these products. A preliminary chemical evaluation of base esters should detect defects that may cause problems during in-use operation.

III.LITERATURE SURVEY

The search for environmentally friendly materials that has potential to substitute mineral oil in various industrial applications is being considered a high priority research in the fuel and energy sector. This emphasis is largely due to the rapid depletion of world fossil fuel reserves and increasing concern for environmental pollution from excessive mineral oil use and their disposal especially in loss lubrication. It has been reported that more than half of the lubricants that are sold worldwide pollute the environment due to total loss lubrication spillage and through evaporation (Horner 2002).

Bio based products are industrial products made from the renewable agriculture and one of the main application are a read of these efforts in the area of lubricants. Vegetable oil as lubricants are preferred because they are not bio degradable and non-toxic unlike conventional mineral based oils (randles et al., 1992) popular ester groups are able to adhere to metal surfaces, and therefore possess good lubrication properties.

On the other hand, vegetable oils have poor oxidative stability to presence of bis-allylic. Protons and are highly susceptible to radial attack and subsequently undergo oxidative degradation to form polar oxy components (beckor et al, 1996) low temperature study also shown that vegetable oil undergo cloudiness, precipitation poor flow and solidification upon long term exposure to cold temperature (Sctclosberg et al. 2001: Hwang 2001)

The poor oxidative tability of vegetable oil is typically attributed to the rapid reactions that occurring that c=c (double bond) functional groups in molecule (Frankel, 1999: Porter et al 1981). Many research groups have focused on adding commercially available anti-oxidants to the oil to improve oxidation stability (Beeker 1996) similarly efforts have been made to improve the lo w temperature properties by mending the vegetable oils with diluents such as poly and olefin (Asadauskas 1999)

The other possible way to control these obstacles is structural modification of the oils by chemical reaction (Erhan 2001)

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Epoxidation is the promising technique for this purpose, since the epoxy group radially functionalized. Although many valuable polymeric materials derived from epoxidised soyabean oil have been reported (Thames 1999)(Hwang et al 2001). Prepared products with improved pour points by the ring opening reaction of epoxidised oil followed by esterification resulting hydroxy groups. The developments of the bio lubricants and their proper use are of great importance for the national economy and environment.

The piston ring & cylinder liner is most complex tribological component in IC engine. The study of mechanism of piston ring lubrication and related friction phenomena found that piston rings contribute significantly to the total engine friction losses (Hosni 1984). A reciprocating test rig has been developed for tribological studies of engine moving components (Ting 1993). It was confirmed that test rig was capable and acceptable for performing simulated piston/piston ring combination. The tribological behaviour of rig /liner has been studied using a reciprocating tribotester. (Masjuki et al 1999)

(Asadauskas et al) have investigated lubrication properties such as viscosity, oxidative stability, deposit formation and lubricity of biodegradable lubricants. However, research work on the synthetic and tribological behaviour of rapeseed oil based bio lubricants as automotive lubricants have not been reported in the literature.

The study presents the systematic approach to improve the oxidation and cold flow behaviour of rapeseed oil through chemical modification via epoxidation, hydroxylation and esterification process. Further the tribological characteristics of cylinder liner and piston ring combination under bio lubricant were evaluated using high frequency reciprocating tribometer. The study is also compared with synthetic lubricant.

IV. PROPOSED EXPERIMENTAL SETUP

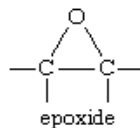
The rapeseed oil based bio-lubricant was synthesized via epoxidation, hydroxylation and followed by esterification process in order to improve their thermo oxidative stability and cold flow property of rapeseed oil.

4.1 Synthesis of rapeseed oil bio-lubricant Materials & Methods

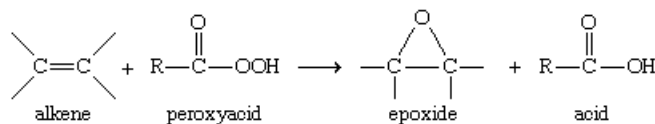
High grade rapeseed oil which was purchased from M/S Ganapathy traders, Chennai, India and the chemicals used for epoxidation reaction AR grade 30 wt% hydrogen peroxide, 90 wt% formic acid, 98 wt% conc. sulphuric acid & methanol, Para-Toluene Sulphonic acid used for ring opening reaction furthermore 0.15N thio solution was procured from M/S Chandanmal Chemicals, Chennai, India.

4.1.1 Epoxidation Reaction

The utilization of epoxidized oil has become more common over the past few years as such epoxidized oil derived from vegetable oils is environmentally friendly. Epoxidized oil contains epoxide group or oxirane ring. The chemical structure of epoxide can be illustrated as follows:



The general process for synthesis of epoxide group is known as an epoxidation reaction where in an alkene is reacted with an organic peroxy acid. The simplified epoxidation reaction is summarized as follows. The epoxidation reaction is an important step in the formulation of crankcase oil.



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The epoxidation of rapeseed oil is carried out in batch type glass reactor consisting of a four necked round bottom flask of 500ml capacity. A motor driven speed regulator stirrer inserted in the reactor through the central neck while the other neck was used for inserting thermometer. A reflux condenser was fitted to the reactor through the third neck and the fourth neck is used for dropping the raw materials into the reactor via dropping funnel. The reactor was heated by an electric heating mantle having an arrangement for accurate control of the temperature within $\pm 1^{\circ}\text{C}$ of the desired temperature. A photographic view of the experimental setup for the epoxidation reaction is illustrated in Fig. 2.



Fig.2. Epoxidation process



Fig3. Epoxidation process

Prior to the epoxidation reaction, rapeseed oil was analysed to determine its iodine value. Rapeseed oil of 326 ml, 0.3253 mol. was placed in the 500ml four necked round bottom flask. Formic acid of 31.4 ml, 0.813 mol at a molar ratio of 0.75:1 to the oil and 0.358ml, 1 wt% of sulphuric acid catalyst was added to the contents were mixed by means of a stirrer and it was maintained at $0-10^{\circ}\text{C}$ with the help of an ice bath. Then 30 wt. % hydrogen peroxide of 265.72 ml, 2.603mol was added drop wise to the reaction mixture at a rate such that the hydrogen peroxide addition was completed over 15 minutes. This feeding strategy was required to avoid the overheating the system as the epoxidation reaction is highly exothermic. Further the contents were well mixed and were performed at a stirring speed of 300 rpm. The temperature is then raised slowly to $55-60^{\circ}\text{C}$ by keeping four necked flask in hot water bath as shown in Fig. 3 and maintained at same temperature

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by using magnetic stirrer. The product of the reaction was cooled and decanted to effect a separation of the epoxidized oil from water phase. The epoxidized oil was then washed with warm water in small aliquots to remove residual contaminants.



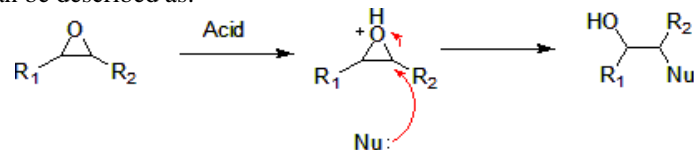
Fig.4. Separation process



Fig. 5. Rotary evaporation process

4.1.2 Ring Opening or Hydroxylation Reaction

The term ring opening reaction is used to refer to the process of introducing hydroxyl groups into unsaturated bonds to the oil. There are various sources of hydroxyl groups that can be used in the hydroxylation process such as alcohols and water. Before the hydroxylation reaction occurs, the oxirane ring must be opened. There are two ways to open an oxirane ring to permit the hydroxylation reaction to occur. In the present work ring opening using acid catalyst is performed. The mechanism of this process can be described as:



Epoxidized oil (300 ml) was treated with methanol and water in the molar ratio of 1:4:2 and Para-Toluene Sulphonic acid was used as catalyst. The course of reaction was followed by withdrawing samples at regular intervals to measure its oxirane % and Iodine value. The collected samples were washed with warm water to make them acid free and extracted with ethyl acetate in a separating funnel as shown in Fig. 4 and dried using a rotary evaporator as shown in Fig. 5. To

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replication of each experiment was performed alongside to determine the percentage deviation between two experimental results and deviation was found to be less than 5%.

4.1.3 Esterification of the Ring Opened Product

The procedure for esterification reaction of the ring opened product adapted from Campanella et al., 2005. Finally the yield was obtained by comparison of the amount of isolated product with theoretical amount of oxirane %.

4.1.4 Epoxidation test

The section summarizes the analysis methods used to evaluate yield from the epoxidation reaction evaluation in terms of the two key variables, namely iodine value and oxirane oxygen content.

4.1.5 Iodine value analysis

Iodine value was determined by applying the Wijs method. The sequence of the procedure is as follows: 0.1 to 0.5 grams of sample were placed in to the flask. 10 ml of chloroform was then added to the sample. Following this, 15ml Wijs iodine solution was added. Using the same procedure, blank solution was also prepared. The mixture was then stored in a dark place for 30mins at temperature of 25±5 °C and after that 10ml of 15wt% potassium iodide (KI) solution and 50ml of water were added in to the mixture. The iodine content in the mixture was then titrated using 0.1N Hydrogen bromide solution until the yellow colour of a solution almost disappeared. A few drops of starch indicator solution were then added and titration was continued until the blue colour was disappeared. The iodine value was calculated using the following equation:

$$\text{Iodine value (IV)} = [(B-A) \cdot N \cdot (12.69)] / C$$

Where

A = volume of HBr solution required for titration of the sample, ml

B = volume of HBr solution required for blank titration solution, ml

C = weight of sample, g

N = normality of HBr solution.

4.1.6 Oxirane content analysis

The oxirane content of the Epoxidized oil must be quantified to determine the conversion of unsaturated bonds in RO to oxirane groups. The procedure is as follows: A calculated amount of Epoxidized oil was added in to a flask. 5 ml of ethyl ether was used to wash the flask side and then 10 ml of the hydro chlorination reagent (0.2N HCl in ethyl ether) was added in to the flask. Simultaneously, a blank solution was prepared using an identical procedure the mixture was then allowed to stand for 3hr at room temperature. The mixture was then titrated with standard 0.1N hydroxide solution prior to this a few drops of phenolphthalein indicator solution and 50ml of ethanol solution were added. The percentage of oxirane content was calculated using %oxirane

$$\text{theoretical content} = [I.V / 2A_i \cdot A_o \cdot 100] / [(100 + I.V / 2A_i) A_o]$$

$$\% \text{oxirane practical content} = [(V_b - V_s) \cdot N \cdot 16 \cdot 100] / [w \cdot 1000]$$

V. CONCLUSION

This study offers a detailed insight about the synthesis of bio-lubricant via chemical modifications. The formation of epoxide and hydroxyl group was confirmed by FTIR spectroscopy analysis. Further assessment of tribological performance of synthetic lubricant and bio-lubricants were carried out using HFRR. Formulated bio-lubricant has excellent coefficient friction reducing properties due to formation of stable polymeric film on the metal surface during boundary lubrication.

Such film formation in bio-lubricant is achieved through the -O- cross linking on metal surface, and then reducing the friction between moving parts. Thermo-oxidative stability and cold flow. Property of vegetable oil can be best improved by chemical modifications via. epoxidation, hydroxylation and esterification process. The lubricants formulated using above

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approach exhibit superior oxidative stability, and improved cold flow property such as pour points compared to the commercially available synthetic lubricant.

Further research efforts are being required to improve the anti-wear behaviour of formulated bio-lubricant.

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