Eco-friendly lubricants*

Every moving part has to overcome some friction to do work. Bearings have low friction and low wear, brakes have high friction and low wear, cars have variable frictional needs and low wear, and walking involves medium friction and low wear. Friction and wear cause damage to a component or structure; this damage can be plastic deformation, cracks, wear or corrosion[1].

A lubricant is a substance (fluid, semi-fluid or solid) introduced between two moving surfaces to reduce friction. It may also serve other purposes such as distribution of heat, transportation of contaminants, and protection against wear and corrosion (http://en.wikipedia.org/wiki/Lubricant). Lubricants find applications in a variety of systems, including two-stroke engines, four-stroke engines, clutches, gears, brake systems and chainsaws.

Lubricants comprise of a blend of base oils and additives which enhance performance. Various oil additives such as viscosity modifiers, antiwear agents, oxidation inhibitors, foam inhibitors, friction modifiers, rust and corrosion inhibitors are available. Base oils have conventionally been mineral-based – these are toxic, environmentally unfriendly and unsustainable (as they are made from crude, a non-renewable resource). The additives used are also non-biodegradable.

But we find that lubricants based on vegetable oils and animal fat have been used for centuries for various applications. Grease based on calcium soaps of olive oil was utilized as wheel-axle lubricant in carriages in ancient Egypt[2]. Such lubricants are part of a closed loop, being derived from renewable resources, and do not contribute to health hazards of humans, organisms or the environment as a whole. In order to discuss the recent developments in eco-friendly lubricants, a national workshop was convened.

Bio-lubricants

K. P. Naithani (Indian Oil Corporation Limited (IOCL) R&D Centre, Faridabad) pointed out that for a lubricant to be considered 'eco-friendly', it should be biodegradable[3] and environmentally compatible. Vegetable oils have the highest compatibility with 90–100% biodegradability and significantly lower CO_2 emissions compared to mineral oils; used vegetable oils can be converted into biodiesel and hence recycled. They also have low aquatic toxicity and low volatility, which is beneficial in controlling the quantity and quality in long-term uses.

Though vegetable oils are twice as costly as mineral oils, they have replaced synthetic esters (for the past 20 years) on account of their biodegradability and potential for improvement by additive technology. Vegetable oils, especially native varieties, are preferred in total loss and partial loss applications, where the whole or part of the lubricant is lost to the environment. Total loss takes place in the case of mould-releasing oils and chainsaw oils, whereas partial loss due to evaporation or leakage is observed in the use of hydraulic oils and engine oils. Bio/bio-based lubricants (which are derived from vegetable oils or their chemical derivatives) have been favoured over standard hydraulic oils and greases in cases where environmental contamination is possible.

In India, low cost vegetable oils are available. So far, only ~10–12 out of 100 oil seeds have been tapped for use. The R&D Centre of IOCL has developed textile knitting oils which are more than 70% biodegradable.

The limitations of lubricant bases from vegetable oils are that they have poor thermo-oxidative stability and are hydrolytically unstable. J. K. Mannekote (Indian Institute of Science (IISc), Bangalore) mentioned that limitations can be addressed by chemical modification at any of three reaction points: (i) ester group: hydrolysis and transesterification/interesterification; (ii) carbon–carbon double bond: selective hydrogenation and epoxidation; (iii) hydroxyl group (in case of castor oil): hydrolysis, selective/complete hydrogenation, epoxidation and dehydration.

Mannekote also noted that regulations and eco-labelling play an important role in the propagation of vegetable oils. The Blue Angel label, created in 1978, differentiates four products indicating the product's environmental goal: protection of climate, protection of health, saving resources and protection of water. In India, the Eco Mark label, started in 1991, has 16 product categories. The criteria follow a cradle-to-grave approach, from raw material extraction and manufacturing to disposal. The Bureau of Indian Standards is under process to incorporate Eco Mark requirements.

Lubricant performance

A. Sethuramaiah (Vellore Institute of Technology, Vellore) stated that good performance of a lubricant is based on trouble-free operation over a prescribed period of time. Nowadays, good performance also demands eco-friendliness; these two could be conflicting requirements.

The performance requisites of lubricants, depending on applications, include oxidation stability, detergency, high viscosity index, additive compatibility and demulsibility. Two specific issues are oxidation stability and lubricant wear. Bio-lubricants have poor oxidation stability; genetically modified oils like canola have relatively better oxidation stability.

In many cases, wear in lubricated contacts is controlled by anti-wear chemical additives. But determination of wear in real systems is difficult as measurable changes occur after a long duration. For example, engine linear wear is measurable only after 1000 hours with gauge techniques. Sethuramaiah illustrated a new approach to measure linear wear by bearing area curves.

Conservation and hence lesser pollution is possible through three routes: (i) use lesser quantity of lubricant, e.g. cutting oils; (ii) extend useful life of lubricant, e.g. long-drain engine oils; (iii) refine used oils and use them back, e.g. engine oil refining plants. New chemistry is being developed to overcome the problems due to polluting chemical additives.

*A report on the national workshop on 'Recent Advances in Eco-Friendly Lubricants' (RAIEFL-2010) held at the Indian Institute of Science (IISc), Bangalore during 8–9 April 2010. The workshop was jointly organized by the Department of Mechanical Engineering, IISc and the Tribology Society of India, Karnataka Chapter.

Table 1. Types of eco-friendly hydraulic fluids

Hydraulic fluid	Base oil	Constituents	Merits	Demerits
Triglycerides (natural esters)	Rapeseed oil, sunflower oil, canola oil, mustard oil (Indian origin)	Variety of fatty acids – about 12 types + additives	Easily biodegradable, high viscosity index (VI), good antiwear, high flash point, compatibility with seals	Poor thermal and oxidation stability, poor cold flow behaviour, poor hydrolytic stability
Synthetic esters	Organic acids + alcohols – chemically synthesized	Variety of fatty acids + additives	Properties better than triglycerides, compatible with mineral oils	Poor hydrolytic stability, more expensive than triglycerides
Polyglycols	Many varieties of glycol – polyalkylene and polyethylene glycols are more common	Mixture of glycols + additives	Water-soluble, good oxidation stability and fire resisting property, high VI and operating temperature	Incompatible to many seals and materials, more expensive

Challenges in research on bio-lubricants

S. V. Kailas (IISc), mentioned that environmentally-damaging zinc dialkyldithiophosphate (ZDDP) has been used to control interfacial friction and highlighted the necessity of producing lubricants without zinc, sulphur or phosphorus. It is necessary to develop biodegradable additives also.

He stressed on the significance of the 'Stribeck curve', which is a plot of the friction coefficient and the bearing characteristics of a system. These parameters play an important role in identifying different kinds of lubrication regimes, enabling the formulation and selection of suitable lubricants for specific applications. He pointed out that an 'optimal lubricant' works best under its 'optimal conditions'. A lubricant designed for a German car will be different from that for a Bangalore car as the conditions under which the car is driven are different.

Kailas questioned the purpose in creating a 'global' eco-friendly lubricant, when locally grown oils can be used for local solutions, leading to less transportation and hence lesser pollution. For example, coconut oil does not solidify in Kerala but does so in Bangalore. He also said that making sustainable lubricants using unsustainable methods is not acceptable; there is a need to revert to farming based on renewable resources, which is a closed-loop system.

Biodegradability of lubricants

Petroleum products, though ultimately biodegradable, are environmentally incompatible due to the negative effects arising from their presence in nature for a long duration. This is not the case with vegetable oils which degrade within a limited time. Naithani showed that biodegradability does not imply environment friendliness.

Biodegradable lubricants are recommended for use in agricultural and construction machinery, paper and textile industry, and forestry. Some common ecologically accepted fluids are rapeseed oil, synthetic esters, polyglycols and water-based fluids. In the design of biodegradable lubricants, factors to be kept in mind include base-oil composition, hydrocarbon structure, concentration, viscosity, additives, toxicity and system factors to design for ecological disposal. The specification criteria for environment-friendly lubricants include: (i) no lead, barium, halogenated compounds; nitrites and tin to be $<0.25\%$; (ii) no carcinogenic material; (iii) no toxic effect on aquatic organisms.

Bio-based hydraulic oils, engine oils and greases are possible. For biodegradable grease, the common base fluids are vegetable fluids and glycols, green additives are sulphurized esters and amino phosphates, and green thickeners comprise of polyurea and organoclay. This grease has a biodegradability of 93%.

Naithani mentioned that the future embraces the use of suitable amounts of antioxidants, development and selection of correct test methods to determine oxidation stability, development and use of suitable pour point depressants and flow improvers, development of new packaging and sealing techniques for storage, use of vegetable oils in combination with mineral oils in grease manufacturing, and exploring the potential for bio-based lubricants and methodologies for genetic modification of non-edible vegetable oils in India.

But Kailas advised caution in genetically modifying vegetable oils to get more saturated oils.

Hydraulic fluids

The consumption of hydraulic fluids (HFs) is the largest among industrial lubricants. HFs function primarily as a power transmitter and secondarily as a lubricant. To fulfil performance requirements, additives such as antifoam, antioxidant and pour point depressants are employed. M. Radhakrishnan (ex-Central Manufacturing Technology Institute, Bangalore) described the types of 'eco-friendly' hydraulic fluids available at present (Table 1).

The lack of growth in eco-friendly HFs is due to high cost, deficiencies in certain areas of performance and insufficient legal regulations. These fluids are found suitable as transmission fluids which need stable friction, anti-shudder, oxidation stability and antifoaming properties, and fuel economy.

Open-gear lubrication

Open-gear drives operate under extreme conditions such as high temperature, contaminated environment, large power transmission, low rotational speeds and large torque levels. They are used in rotary kilns and grinding mills in the cement and mineral industries, and in material-handling equipment in the mining industry. B. Chakrabarti (Larsen and Toubro Limited, Mumbai) pointed out that one of the reasons for failure of open gears is improper lubrication.

Grease, which is used for lubrication, is made up of base oil (mineral or synthetic), thickener (soap or non-soap), solid lubricants and additives. Friction and energy loss are governed by friction modifiers in the form of solid lubricants. The current generation of friction modifiers are micro-ground solids which provide the advantage of a transparent film over the gear teeth.

Work has been done on developing 'green grease' which can be effectively broken down by microorganisms present in the soil, atmosphere or water bodies into non-toxic and harmless by-products within a reasonable time. But cost is a factor – all bioproducts are ~1.5 times costlier than conventional products.

Emerging trends comprise of: (i) the use of non-soap thickeners (inorganic gels, clay or polyurea) in place of metallic soaps or complexes (Ca, Al, Li) for high-performance greases; (ii) looking at life-cycle cost instead of purchase price and trying to quantify intangible benefits; (iii) new business opportunities in waste management, green lubricants and specialized technical services.

Testing of lubricants

V. Martin (IOCL R&D Centre) described various test methods for performance evaluation of lubricants on rigs, encompassing short-duration tests for antiwear and extreme pressure, long-duration tests for antiwear, grease durability/life and leakage tendencies, and special purpose test rigs. He pointed out that though some tests are not satisfactory, they are still run because of industry requirements.

R. T. Naik (IISc) explained different standard tests for eco-friendly lubricants. He emphasized that the test procedures should be internationally recognized and standardized, and that the test results should give an unequivocal measure of ultimate biodegradation. He also stressed that the test conditions should not be so stringent as to fail useful, readily biodegradable products. Careful monitoring, sample purity and suitable test conditions to suit specific applications are necessary.

1. From Kailas' lecture at RAIEFL-2010.
2. Mannekote, J. K. and Kailas, S. V. (review article submitted to *Tribology Online*).
3. The ASTM standard D 6384 definition for ultimate biodegradation states that degradation is achieved when the test material is totally utilized by microorganisms, resulting in the production of carbon dioxide, water, inorganic compounds, and new microbial cellular constituents (biomass or secretions, or both).

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MEETING REPORT

Transport networks for India*

Demand for transport in India is growing at around 10% p.a. for more than a decade, whereas supply of transport infrastructure and services has not been able to keep pace with demand and is proving to be a drag on the economy. Although road transport is the most favoured mode of transport, road infrastructure capacity will not be able to keep pace with transport demand. A major issue has been that most of the Indian transport infrastructure is developed on mode-specific and regional policy premises. We need an integrated transportation system planning for sustainability of the transport system in India.

In this backdrop, a one-day workshop was held recently at CiSTUP, IISc, Bangalore. The main objectives were to (i) review infrastructure and service markets of all modes of transport in India employing a systems approach; (ii) identify key issues and challenges within and between transport modes in India; and (iii) recommend directions for further research for realizing a comprehensive multimodal transport infrastructure and service network at the national level.

B. N. Raghunandan (Department of Aerospace Engineering, Indian Institute of Science (IISc), Bangalore) emphasized the importance of the transport sector in modern economies and its role in stimulating economic growth in peripheral regions in India. T. G. Sitharam (Centre for infrastructure Sustainable Transport and Urban Planning (CiSTUP), IISc) highlighted the inadequacy of transport infrastructure, lack of skilled manpower and shortage of data for monitoring systems as the major challenges confronting the Indian transportation system. He informed that in the XI Five-Year Plan, infrastructure investments have doubled from the previous Five-Year Plans constituting up to 9% of GDP. The present Plan offers a bigger role for private participation in infrastructure development by allowing 30% FDI in infrastructure investment. He also described the major projects planned under the XI Five-Year Plan in each transport mode.

Speaking on the Indian air transport networks, Kota Harinarayana (National Aerospace Laboratories (NAL), Bangalore) identified three typical passenger travel trends, viz. average daily passenger travel times in most cities are around 1.2 h, mobility of passengers/goods increases proportionally with GDP per capita, and modal shift from slow to fast transport modes takes place when the national economy evolves from agriculture to industry to service-based economies. In terms of air connectivity, India has 86 operational airfields out of a total of 449. If all airports are made operational, then two-thirds of the Indian population will be within 50 miles of an airport. Presently, 70% of the total Indian air traffic is between Delhi, Kolkata, Mumbai, Bangalore, Hyderabad and Chennai. The Airports Authority of India has undertaken development of 50 non-metro

*A report on the one-day workshop on 'Transport Network for India: Vision 2020', held on 22 April 2010 at the Centre for infrastructure Sustainable Transport and Urban Planning, Indian Institute of Science, Bangalore.