BIOBASED LUBRICANTS: A VIABILITY STUDY

Adam Ing
151 Booth Ave
Toronto, Ontario, Canada, M4M2M5
adam.ing@utoronto.ca

ABSTRACT

Biobased lubricants are an attractive alternative to conventional petrobased lubricants due to a number of their physical properties including: renewablility, biodegradability, high lubricity and high flash points. Biobased lubricants have not replaced petrobased lubricants due to their higher cost, oxidative and thermal instability and limited temperature applications.

Research has been done to improve the physical properties of biobased lubricants. Dupont has bioengineered soybean seeds to yield soybean oil that is more oxidatively stable. The Prileshajev Epoxidation Process was developed to increase the oxidative stabilty of soybean oil. The Amberlyst 15 Catalyst was used to Reduce Pour Point of Vegetable Oil.

Biobased lubricants are generally more expensive than petrobased lubricants, but their increased lubricity allows for monetary savings through a decreased energy input requirement. As biobased lubricants are derived from vegetable oil, careful work must be done to balance the allocation of crop used to make lubricant. Currently there is not enough arable land to support the widespread use of biobased lubricants, so a collaboration of industry and government policy must be used to promote the use of biobased lubricants.

INTRODUCTION

Annually, 40 million tonnes of lubricants are consumed worldwide, to be used in everything from car engines to office chairs. The most common type of lubricant is petroleum derived (petrolubricant). As the idea that oil soon may no longer be available, industries have been searching for a cheap, renewable source of lubricant. Biobased lubricants have been the most promising as they have useful physical properties, but they are also have undesirable physical properties that make petrobased lubricants the obvious alternative. Much research is being done to vegetable oils to improve the physical properties so that they may compete as a economical alternative with petrobased lubricants. Currently there are steps being taken towards creating an economy that prefers a biobased lubricant through policy, but there are complications in the perception of biobased oil and the allocation of arable land. The world cannot completely switch over to biobased lubricants, it must be a gradual process requiring the collaboration of government support, agriculture, industry and research.

BACKGROUND

Following the rapid economic growth in Asia in the last decade, the demand for lubricants has risen sharply. The world annual consumption is 40 million tonnes, and is projected to continue to rise 1.6% annually for at least the next 3 years (TransWorldNews, 2009). As only a small fraction of lubricants are recycled, we are currently looking for a renewable source of lubricant to meet the growing demands of the economy.

Biobased lubricants are currently used in a limited number of environmentally-sensitive industrial applications such as agricultural machinery or machines in close proximity to water. Biobased lubricants are used in these applications because they are non-toxic, and would create a much smaller disturbance to the ecosystem if there was a spill. Biobased lubricants are also sometimes used in consumer goods such as petro/bio lubricant motor oils blends, but the high concentration of petroleum makes them harmful to the environment.

PETROBASED LUBRICANTS VS BIOBASED LUBRICANTS

Petrobased lubricants share many similar physical properties with biobased lubricants, but have a much different environmental impact. Petrobased lubricants are more commonly used than biobased lubricants because they are cheap, and can satisfy lubricant demands. Biobased lubricants is an attractive alternative because of their useful physical properties, and they are clean and renewable.

Petrobased Lubricants – Background and Physical Properties

Petrobased lubricants currently dominate in commercial markets for three major reasons. Firstly, petrobased lubricants are the cheapest alternative, making them attractive for application or inclusion into a wide variety of consumer goods (Office of the Federal Environmental Executive 2009; AMSOIL Syntheic Oil Canada, n.d). Secondly, petroleum is abundant readily accessible to satisfy the global demand for lubricant. Lastly, petrobased lubricants have the longest drain interval (the operating life of a lubricant) of the lubricant alternatives, which lowers the downtime of the machine as completely changing the lubricant takes a significant amount of time. .

Although petroleum based lubricants possess many useful physical properties, they are also non-renewable and toxic to the environment. If improperly disposed, petrobased lubricants may leech into water systems, cause infections and possibly death to organisms. Industrial machines used in offshore drilling or agriculture require machinery to be in close proximity with a water source, and using petrobased lubricants can potentially be dangerous to the environment. Environmental groups have pressured industrial groups to use biobased lubricants instead of petrobased lubricants in these situations (IENICA, 2004).

Vegetable Based Lubricants – Background and Physical Properties

There are many petrolubricant alternatives available, such as synthetic or animal fat lubricants, but lubricants derived from vegetable oil have received the most attention due to a number of their useful physical properties. Firstly, biobased lubricants have a higher lubricity and thus a much lower coefficient of friction when used when compared to petrobased lubricants. Secondly, biobased lubricants have high flash points, which makes then effective in high temperature environments to preclude evaporation or dissipation. Thirdly, they have relatively stable viscosity indexes, so that they are useful over a large range of temperatures. Fourthly, biobased lubricants are generally derived from vegetable oils, and processing can be clean and renewable. Lastly, biobased lubricants are easily disposed of as they are non-toxic and biodegradable. These properties make biobased lubricants an attractive alternative to petrobased lubricants (Honary 2001).

Although biobased lubricants have many useful properties, they also have a number of drawbacks that are associated with most organic materials. Firstly, biobased lubricants are fully biodegradable because they oxidize easily, but the rapid oxidization requires them to be changed more frequently. Secondly, the initial cost per volume of a biobased lubricant is generally two to three times that of a petrobased lubricant. Thirdly, biobased lubricants can only be applied over a moderate range of temperatures as they have high pour points in cold and low thermal stability in heat. Finally, specialized crops (rather than food byproducts) are the raw materials for higher quality lubricants, diminishing sources that would otherwise be applied for food production

CURRENT RESEARCH

The amount of research in biobased lubricants has drastically increased as the public has become more environmentally conscious. Most of this research is to improve the physical properties of biobased lubricants through bioengineering and chemical processes, but there is also much research being done to improve the physical properties of vegetable oils through the use of additives and is outside the scope of this paper. Research has lead us to the discovery of soybeans high in Oliec acid, the invention of the Prileshajev epoxidation, and new uses for the Amberlyst-15 catalyst.

High Oleic Acid Soybeans Yield Oxidatively Stable Vegetable Oil

Vegetable oils high in Oleic acid such as rapeseed, soybean and sunflower have become the preferred raw materials for biobased lubricants. Vegetable oils with high concentrations of Oleic acids yield stable lubricants that oxidize much more slowly (Castro 2006). While conventional soybeans contain approximately 20 percent Oleic acid, whereas Dupont has bioengineering a soybean seed with a concentration of Oleic acid over 83 percent. This derived oil was shown to be 30 times more oxidatively stable than conventional soybean oil in hydraulic pump tests (Honary 2001). Additionally, the modified soybean seed does not differ nutritionally when compared to a conventional soybean, but the seed is generally more expensive to purchase, preventing it's widespread use (Castro 2006).

Prileshajev Epoxidation Process used to Increase Oxidative Stability of Vegetable Oil

Vegetable oils have poor thermal stability and are oxidized rapidly due to the double Carbon-Carbon bonds in their molecular structure. Techniques used to saturate vegetable oils include: transesterfication, selective-hydrogenation, and selective hydrogentation via epoxidation. The epoxidation process has received the most recent interest as the oxirane ring is highly reactive and can be further processed in moderate reaction conditions (Lathi 2007). Currently Prileshajev epoxidation is the most popular epoxidization process, used to annually generate 200.000 tonnes of epoxidized soybean oil (Maurer, 2005). As seen in Illustration 1, this process uses Hydrogen Peroxide in the presence of a mineral acid to break the double bonds in the triglyceride and forming peroxy acids. The resulting saturated molecule is much more oxidatively stable, but increases the pour point of the oil, limiting the epoxidized vegetable oil to higher temperature applications.

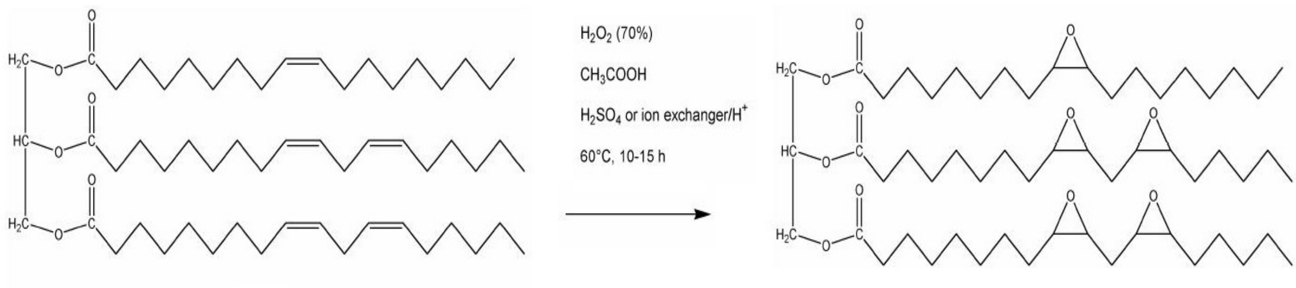


Illustration 1: Prileshajev epoxidation (Maurer 2005)

Amberlyst 15 Catalyst used to Reduce Pour Point of Vegetable Oil

Biobased lubricants generally have high pour points, which prevent them from being used in lower temperature applications. A process has been developed by Piyush et al. to lower the pour point of the epoxidized soybean to as low as -15 degrees Celsius by treating epoxidized soy bean oil with branched alcohols in the presence of the catalyst Amberlyst 15. As seen in illustration 2, the epoxide undergoes a ring opening reaction and forms bonds with the alcohols. It was shown that longer branched alcohols resulted in lubricants with lower pour points. The catalyst Amberlyst 15 has the effect of allowing the ring opening reaction to occur on 100% of the sample. The altered product also maintained the viscosity and biodegradability of the epoxidized vegetable oil. The catalyst was reusable to an estimated 5 reactions, which allows for greater economic viability (Lathi 2007).

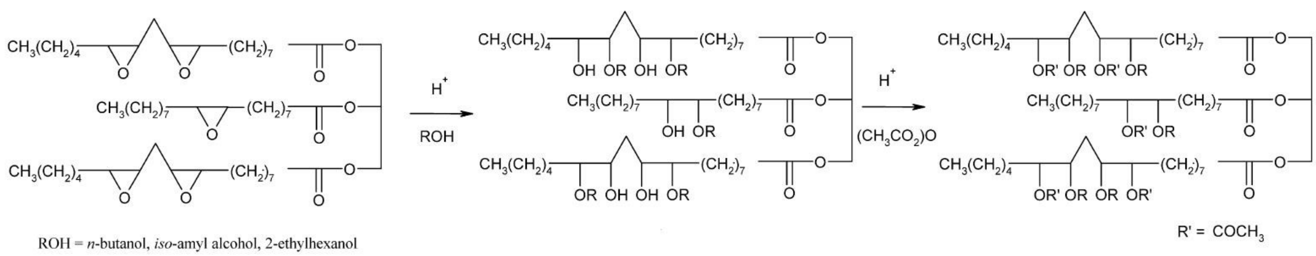


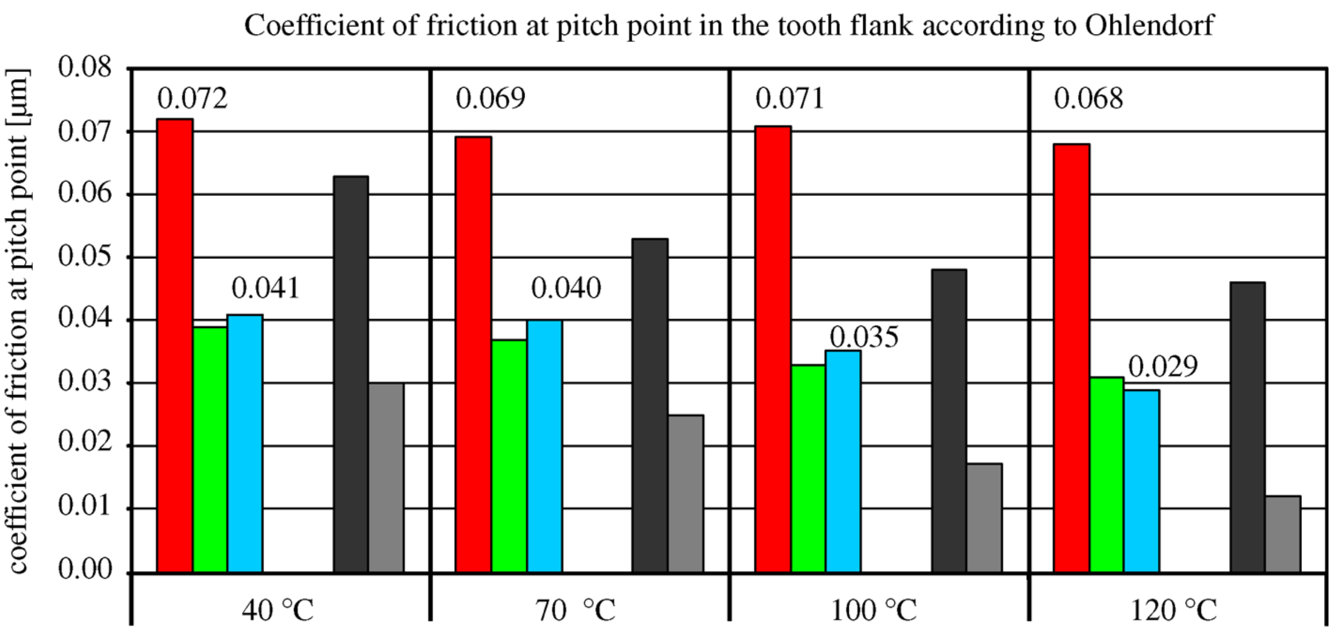
Illustration 2: Ring-opening reaction of epoxidized vegetable oil with n-butanol (Lathi 2007)

ECONOMICS

There are three major aspects of the biobased lubricant economy that must be considered in order for it to be an effective alternative. Firstly, commercial businesses will choose biobased lubricants as substitutes for petrobased only if they are cost effective. Secondly, available arable land to grow raw materials for the lubricant is limited, and the amount of land dedicated to growing lubricant must be carefully allocated to prevent food shortages. Lastly, the world does not have the physical, social and political infrastructures that encourage and/or make feasible a economy that prefers biobased lubricants.

Energy Savings from the High Lubricity of Biobased Lubricants

Biobased lubricants can be superior to petrobased lubricants in many applications, but they are generally about three times as expensive to purchase. This initial acquisition cost may deter potential buyers, but is offset by reduced energy costs resulting from the high lubricity of the biobased lubricants. As seen in table 1, biobased lubricants lower the coefficient of friction at the pitch point much more than petrobased lubricants. At higher temperatures, the coefficient of friction at the pitch point drops dramatically in the presence of biobased lubricants indicating increasing lubricity. Petrobased lubricants also increase in lubricity as temperature increases, but they increase at a much less pronounced rate. This high lubricity makes biobased lubricants an attractive alternative to use in various high temperature applications such as injection moulding equipment or heated presses (Cliff, 2007).



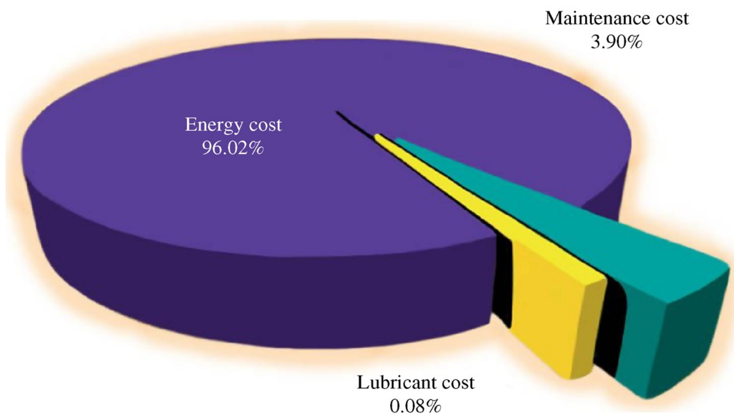
Notes: Mineral oil (red/ black); biolube (green) = PLANTOGEAR 220 S;
PAO (blue) = RENOLIN UNISYN CLP 220; polyglycol, PG (grey) = RENOLIN PG 220
Source: Bartels and Bock (2001)

Table 1: Coefficent of friction at pitch point in the tooth flank (Cliff, 2007)

The high lubricity of biobased lubricants result in mechanisms with lowered energy input needs, varying depending on the application. Indicative energy savings include (Cliff, 2007):

-Hydraulics – 1-3% energy savings
-Plastics Injection Moulding equipment – 2-3% energy savings
-Compressors – 2-7% energy savings
-Worm Gears – 15-30% energy savings
-Spur Gears – 1-5% energy savings

As seen in illustration 3, the cost of operating a machine is 96.02% from the operating energy requirement. Increasing the effectiveness of the lubricant can result in large savings in energy and maintenance costs. As an example, a 100HP compressor using a biobased lubricant instead of a petrobased lubricant, operating on a full load over three shifts would save approximately $750(CAD) annually. Biobased lubricants reduce maintenance costs of the machine as the decreased coefficient of friction will minimize the gradual degradation that a machine is exposed to during operation. The increased cost of the lubricant is negligible when compared to the savings in energy in maintenance costs (Cliff, 2007).



Source: Cuthbertson (2001)

Illustration 3: Relative Lubricant, Energy and Maintenance Costs (Cliff, 2007)

Food vs Fuel Debate

Between 2005 and 2008 food prices rose dramatically, at the same time that biofuel production increased. In Brazil, (although food production stayed the same) corn has tripled in price since biofuel has become a common energy source (Beatty, B. and Aubele , M. 2008). Like biofuels, biobased lubricants are derived from vegetable oils, thus arable land must be carefully allocated to prevent further increases in food prices.

Unlike biofuels, a specialized crop high in Oliec acid is required to make a quality lubricant. Fortunately the soybean developed by DuPont does not differ nutritionally, allowing flexibility in the use of the soybean. This flexibility only applies to soybeans and therefore other crops may need to be more carefully allocated.

The lubricants that are derived from crops are usually chosen from a pool of specialty crops. These specialty crops are sometimes subsidized, and generally have higher premiums than food crops. There is a trend in the US for large scale farmers to dedicate a portion of their land that is normally used for growing food, to instead growing specialty crops. If this trend continues, it may be expected that food prices will rise slowly as there is effectively a lower supply grain in the country (Wright, n.d)

Supporting a Biobased Lubricant Economy – Infrastructure Analysis

Generating a large amount of biolubricant would require a substantial amount of arable land dedicated to growing specialized crop. A single hectare of land used to grow soybean will yield 446 liters of soybean oil annually, which is just enough to lubricate a heavy Caterpillar for half a year (Oil yields and characteristics, 2001). Although the U.S is the largest producer of soybean oil, the US only produces 8.5 million metric tonnes, which is not enough to replace the 10.2 million metric tonnes of petrobased lubricant consumed annually (Soy Stats, 2000; Freedonia Group, 2002; Soy Stats, 2005).

In order to meet US annual demand, the US would need to dedicate 248 million hectares of arable land, which is currently more than the 190 million hectares of arable land in the U.S. (Oil yields and characteristics, 2001; Carrying Capacity, n.d). Therefore, a collaboration of different biobased and petrobased lubricants must be used together to even make a dent in the lubricant economy.

A possible compromise would be to mix petrobased and biobased lubricants together to form a lubricant blend. This is common practice in many companies, as mixing lubricants can improve the desirable physical properties of the parent lubricants. Lubricant blends are, however, still toxic and not as efficient as lubricants derived from pure vegetable oil. Mixing only lessens our dependency on petrobased lubricants, and is therefore only a short term solution that will require further research.

CONCLUSION

In conclusion, biobased lubricants are clean renewable lubricants but currently lack the physical properties that petrobased lubricants posses, and therefore more research must be done to improve their physical properties. Promoting an economy that prefers biobased lubricants will require the support of government government policy in order for it to be a viable alternative.

References:

AMSOIL Syntheic Oil Canada n.d, *Side-by-side comparison of synthetic vs conventional Mineral / Petrolium oil*, AMSOIL Syntheic Oil Canada, viewed April 12, 2009, <http://www.worldsbestoil.ca/long-engine-life.php>

Beatty, B. and Aubele , M. 2008, 'Ethanol production cited in corn price increase', Pittsburgen Tribune-Review, viewed April 13, 2009, <http://www.pittsburghlive.com/x/pittsburghtrib/news/cityregion/s_564584.html>

Carrying Capacity Network n.d, *Food, Land, Population, and the U.S. Economy*, Carrying Capacity Network, viewed April 12, 2009, <http://www.carryingcapacity.org/resources.html>

Castro, W., Perez, J.,Erhan, S., and Caputo, F. 2006. 'A Study of the Oxidation and Wear Properties of Vegetable Oils: Soybean Oil Without Additives'. *JAOCS, Journal of the American Oil Chemists' Society*, 83(1), 47-52.

Cliff, L. 2007. 'Energy savings through use of advanced biodegradable lubricants', *Industrial Lubrication and Tribology*. Vol. 59, no. 3, pp. 132-136.

Freedonia Group 2002, *US lubricants demand to reach nearly 3 billion gallons in the year 2006*, Research Studies - Freedonia Group, viewed April 07, 2009 < http://www.allbusiness.com/specialty-businesses/348350-1.html>

Honary, L. 2001, 'Biodegradable/Biobased Lubricants and Greases', *Machinery Lubrication Magazine,*, Issue Number: 200109, Machinery Lubrication, Lubricant Selection

IENICA 2004, *Biolubricants: Market Data Sheet*, IENICA, viewed April 12, 2009, <http://www.ienica.net/marketdatasheets/biolubricantsmds.pdf>

Journey to Forever 2001, *Oil yields and characteristics*, Journey to Forever, viewed April 12, 2009, <http://journeytoforever.org/biodiesel_yield.html>

Lathi, P. and Mattiasson, B. 2007, 'Green approach for the preparation of biodegradable lubricant base stock from expoxidized vegtable oil', *Applied Catalysis B: Environmental* 69 (2007) 207-212

Maurer, S. and Schmid, R. 2005, 'Biocatalysts for the Epoxidatino and Hydroxylation of Fatty Acids and Fatty Alcohols', *University of Stuttgart Publications*, viewed April 5, 2009, <http://linkinghub.elsevier.com/retrieve/pii/S0960852405003275>

Office of the Federal Environmental Executive 2009, *Green Purchasing*, , Office of the Federal Environmental Executive, viewed April 12, 2009 <http://www.ofee.gov/gp/policydev.asp>

Soy Stats 2005, *U.S. Soybean Oil Production 1979-2004*, Soy Stats, viewed March 17, 2009, <http://www.soystats.com/2005/page_21.htm>

[14]Soy Stats 2000, *Consumption and Exports*, Soy Stats, viewed March 17, 2009 <http://www.soystats.com/2000/page_27.htm>

TransWorldNews , *World Lubricant Demand to Reach 40.5 Million Metric Tons in 2012*, TransWorldNews, viewed April 6, 2009, <http://www.transworldnews.com/NewsStory.aspx?id=81121&cat=18>

Wright, J., *Chains for Drives and Conveyors - Lube 'Em to Last*, Noria Learning Center, viewed April 6, 2009, <http://www.noria.com/learning_center/category_article.asp?articleid=316&relatedbookgroup=Lubrication>