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Soy-Based Lubricants: Performance and Sustainability

TRACK OR CATEGORY
Environmentally Friendly Fluids

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INTRODUCTION

Lubrication needs are diverse and a wide range of materials are needed. The biobased and vegetable oil category is already well established. Soybean oil provides a cost-effective base material for a wide range of lubrication fluids while having an environmentally favorable footprint. There are good performance reasons for using soybean oil in lubricant formulations. It has well-established uses and supply chain infrastructure. New developments in chemical modifications and soybean agriculture are leading to more effective soy-based lubricants.

Vegetable oil-based lubricants

The triglyceride structure of vegetable oils explains several properties important for lubrication applications. Long, polar fatty acid chains provide high strength lubricant films. Strong intermolecular interactions are resilient to changes in temperature - more stable viscosity. Unsaturated double bonds in the fatty acids are active sites for many reactions (including oxidation). The triglyceride ester is susceptible to hydrolysis. Strong intermolecular interactions provide a durable lubricant film but poor low-temperature properties. The triglyceride is environmentally friendly, non-toxic, and readily biodegradable. [1] [2]

Compared to mineral oils vegetable oil base stocks exhibit higher viscosity index, lower evaporation loss, enhanced lubricity, excellent friction and wear characteristics, lower thermal, oxidative, and hydrolytic stability (which may be improved with additives). Worker safety and environmental impact are improved with their relatively low toxicity, high flash point, and low volatile organic compound emissions. Soybean oil lubricant base stocks have low volatility and small viscosity change with temperature. They decrease exhaust emission and reduce engine sludge. Soybean oil more readily solubilizes polar contaminants compared to mineral base fluids, reducing the need for detergent additives. They show good solubility with oil additives for lubricity, antiwear protection, load-carrying capability, rust prevention, and foaming. [3] [4] [5] [6]

Soybean oil supply

Year round global supply of soybean oil is possible with plentiful supplies grown in both northern and southern hemispheres. [7] Researchers in the U.S. soybean industry have recently developed oilseeds with an increased proportion of oleic acid. High content of oleic acid and low content of polyunsaturated linolenic and linoleic fatty acids result in an oil that has high oxidative stability. [8] High oleic soybeans were planted on nearly 200,000 acres in 2014, yielding 90 million pounds of oil for 2015. Supply is increasing and is projected to reach 18 million acres by 2023, resulting in 9.3 billion pounds of available oil by 2024. [9]

Estolides

Estolides are oligomeric esters made from the addition of a fatty acid to a hydroxyl containing fat or by the condensation of a fatty acid across the olefin functionality of a fat. Reducing unsaturation improves oxidative stability. Molecular branching improves cold temperature properties. The viscosity of the estolide can be tailored across a wide range depending on the carboxylic ester functionality and the degree of oligermization. [10]

Vegetable oils estolides maintain low coefficient of friction and good lubricity characteristics and demonstrate wear scars that compare well to those for a fully formulated commercial crankcase lubricant. Estolides are miscible with Group I-V base oils and are readily soluble with a broad range of lubricant additives. With their high molecular weight and good lubricity, estolides yield lower evaporative loss values compared to similar viscosity grade oils. Estolides exhibit low volatility, resulting in increased flash and fire points and lower evaporative loss as compared to other high performance base stocks, which is important in applications where operating temperatures are high and flammability is a concern. The higher viscosity indices of estolides provide increased film thickness at elevated temperatures, resulting in better protection, and potentially lower wear. At lower temperatures, viscous drag on moving parts is reduced, leading to higher horsepower and increased energy efficiency. While maintaining excellent stability in rigorous lubricating environments, estolide products biodegrade quickly once released into the environment. [11]

Epoxidation

Epoxidation of olefinic materials and oleochemicals makes them more oxidatively stable and increases their adsorption to metal surfaces while negatively effecting pour point and viscosity index. [12] Linoleic and linolenic polyunsaturated fatty acids in soybean oil make the oil susceptible to oxidative and thermal degradation. Epoxidized soybean oil (ESO) has a reduced deposit-forming tendency due to removal of multiple unsaturation in the fatty acid chains. ESO shows good response to antioxidant additives at low concentration and maintains low thermal and oxidative behavior. In addition, ESO has low coefficient of friction reducing properties due to the formation of a stable polymeric film on the metal surface during boundary lubrication. Such film formation in ESO is achieved through the –O– cross linking on the metal surface, thus reducing friction between the moving parts. [13]

Soybean oil used in the lubricants industry

Soybean oil is used in a wide range of lubricant and functional fluids applications [14] [15]:

- Gear oils and lubes
- Chainsaw bar oil
- Compressor oil
- Two-cycle engine oil
- Metalworking oils and
- Wire rope, chain, and cable lubricants
- General purpose and penetrating lubricants
- Transformer and transmission line cooling fluids
- Greases - automotive, machinery, rail curve, track
- Food-grade, industrial, and elevator hydraulic fluids

Biobased metalworking fluids show good viscosity stability as machining temperature increases and as ambient temperatures fall. The slight polar charge attracts the oil to metallic surfaces and leads to better corrosion protection. Its higher flash, fire, and smoke points make a safer choice for workspaces, especially those tightly enclosed or near open flames. Oxidative and hydrolytic stability deficiencies and potential for microbial growth can be mitigated with additives or chemical modification. [16]

Soybean oil sustainability

Soybean life cycle assessment studies show environmental benefits: lower energy production cost, lower VOC content of products, reduced exposure to toxic chemicals, lower carbon dioxide emissions during production, and supply chain sustainability, [17] Looking forward, lubricants impact the environment throughout production, usage, and disposal. The awareness and concern over their impact on the environment has many state, federal, and international regulatory bodies reviewing current policy, with some agencies beginning to enact new regulations. Impending global regulations have led many lubricant manufacturers to seek environmentally acceptable alternatives that also meet the rigorous performance demands of industry. [11]

The case for soybean oil as a biobased lubricant is based on its good lubrication performance - enhanced lubricity, high viscosity index, low evaporation loss, and low flammability. It provides a sustainable and renewable option for a broad range of lubrication fluid applications requiring low toxicity and readily biodegradable. Established uses include lubrication fluids in hydraulic cylinders, metalworking machines, and moving surfaces where the lubricant is lost directly into the environment. Improved thermal stability is now possible with the recent development of high oleic soybeans. [18]

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KEYWORDS
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