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Hydro Safe® ISO VG-32 FR, ISO VG-46(FR) & ISO VG-68(FR) Fire Resistive Hydraulic Oils without Sacrificing Performance

The increasingly important issues of environmental acceptance and biodegradability are the drivers behind the quest for alternatives to mineral oil as a base stock for hydraulic fluids. This search for replacements has led in several directions. Currently there are three commercially available biodegradable base stocks. They are polyglycols, polyol esters and naturally occurring triglycerides or vegetable oils.

Polyglycols were one of the first base stocks to be formulated into biodegradable fluids. They offer excellent oxidation stability, but along with synthetic esters, they are the highest priced biodegradable fluids. Polyglycols along with other water base fluids (HFA, HFB, and HFC) are dependent on higher percentages of water for their improved fire resistance. Fluid volatility, bacteria, fungus, corrosion, poor air release, cavitation, and valve erosion are some of the disadvantages of water base formulas. Compatibility with other fluids, elastomers, and other system components should also be considered before changing the system over from mineral based fluids.

Synthetic polyol esters are the reaction product of a fatty ~i4, and can derived from either animal, or plant sources (biobased) and a synthetic polyol. The polyol ester resulting from this condensation reaction can be blended with various additives to produce a biobased/biodegradable hydraulic fluid with improved oxidation stability exceeding conventional petroleum formulations. Synthetic esters can be fully saturated, partially saturated, and unsaturated. Fully saturated synthetic polyol esters represent the current industry top tier standard, especially in high pressure, high performance applications. Depending on the reaction and saturation process, compatibility with other fluids, elastomers, and other system components should also be considered before changing the system over from mineral based fluids.

Naturally occurring triglycerides (natural biobased esters) or conventional vegetable oils are in the same chemical family as polyol esters. Vegetable and animal type oils are some of the oldest lubricant base stocks, as they have been used for centuries. While vegetable oils are favored for their ultimate biodegradability and low environmental impact, they have traditionally exhibited low oxidative stability, which is a crucial shortcoming that has limited their widespread acceptance and use as a cost effective replacement for synthetic polyol ester fire resistant hydraulic fluids. Renewable Lubricants™ Inc (RLI™), through the use of improved base stocks and patented additive technology, has overcome this deficiency.

Where fire resistance is a primary concern, synthetic polyol esters have performed well in extreme operations for over 25 years. Polyol esters have emerged as the fluid of choice, despite costs ranging up to six times more than mineral-based oils. An industry goal has been to develop a vegetable oil based (naturally occurring ester) fire resistant fluid equaling the performance properties found in synthetic esters while reducing fluid costs in the process. This goal has been achieved by RLI™. By optimizing RLI's patented additive technology and using selected base stocks, naturally occurring ester fluids have oxidation stability, lubricity, and cold temperature performance on par with synthetic polyol ester fluids.

Over the past four decades, two general types of products have competed in the fire-resistant fluids marketplace: water based and anhydrous fluids (see ISO 6743-4 for Fire Resistant Fluid Designation). It is important to note that the term "Fire-Resistant" as defined by Factory Mutual Research Corporation means 1) sprayed fluid that contacts an ignition

source will not propagate flame and 2) that if the source of ignition is removed from a fluid spray, any flames will self-extinguish. "Specification Tested" as defined by Factory Mutual Research Corporation means 1) the fluid is less flammable and harder to ignite in a spray area and 2) has a reduced heat release rate. ISO 6743-4 for Fire Resistant Fluid Designation describe the different type tests and temperatures for classification of these fire resistant hydraulic fluids. Wherever fire is a possibility from a spark or heat source, a fire-resistant hydraulic fluid in these different classifications should be determined and considered for use.

Anhydrous or non-water containing technology, on the other hand, provides lubrication much like mineral oil. Synthetic polyol esters (formed by the reaction of a fatty acid with an alcohol, diol or other polyol) have been regarded as one of the best performing of the biodegradable and fire-resistant hydraulic fluids. Their properties have been well-documented.

For synthetic polyol esters, biodegradability ranges up to 90% in OECD 301 A-F Type Tests; lubrication is excellent, as is liquidity and aging stability at low and high temperatures. Polyol esters feature a high viscosity index (over 150); flash point at 530-550 degrees F; and fire point at 600-615 degrees F. As an anhydrous fire-resistant fluid, synthetic polyol esters have proven ideal for applications such as high-pressure mill equipment operating at pressures above 3000 psi and as high as 5000 psi.

In general, vegetable oils (vegetable oils or naturally occurring triglycerides are in the same chemical family as polyol esters) can also meet and exceed the 90% biodegradability ranges of synthetic esters in OECD 301 A-F Type Tests, and can offer good chemical and thermal stability. Their low total acid numbers contribute to their overall good stability. While these fluids are good lubricants for lower temperatures, performance concerns have typically arisen over their tendency toward rapid oxidation at elevated temperatures as they have not shown the oxidation stability of conventional mineral oil formulas.

The oxidation instabilities normally associated with vegetable derived fluids are due to a high content of linoleic and linolenic fatty acids. Research has shown that the oleic acid ester distribution in a naturally occurring ester base stock is critical to fluid performance. These acids are characterized by two and three double bonds, respectively. A greater number of double bonds results in a material more sensitive to and prone to rapid oxidation. The high degree of unsaturation, in fact, leads to increases in viscosity, increases in the total acid number, and fluid aggressiveness toward copper and copper alloys. Taking these deficiencies into account, RLI's specially formulated patented additive technology and selected base stocks have allowed Hydro Safe's line of hydraulic fluids to overcome the shortcomings normally associated with vegetable oil based fluids. Independent laboratory testing and years of field studies in different hydraulic systems have demonstrated that RLI's patented additive technology enable vegetable oils to perform like and sometimes exceed polyol esters. The chemistry in RLI's Technology has been carefully selected and tested and contain rust and oxidation inhibitors, EP and antiwear additives, pour point depressants, metal deactivators, demulsifiers, antifoam and sometimes viscosity index improvers.

For over 20 years, RLI™ has been the leader in developing patented high performance lubricants. To determine whether additive packages could be used to fortify vegetable oils to greatly improve their oxidation stability and thus equal the desired characteristics of synthetic polyol esters, key laboratory comparison tests were conducted during the early years of R&D. The process began with newly hybridized high oleic base stocks (75 to 85% oleic) and then formulated with additives for benchmark comparison against a commercial, premium synthetic polyol ester fluid. When testing was completed, high oleic base oils from sunflower, soybean, and canola oil with todays patented additive technology were found to provide overall comparable performance to the synthetic fluids, including in the following areas:

Pump Testing: The Vickers V-104C (ASTM D-2882, 2000 psi, 1200 rpm, @ 175°F) and 35VQ-25 (ASTM D-2882 @ 3000 psi, 2400 psi, @ 200°F) Vane Pump Tests were utilized. These are considered in the industry as severe, mobile equipment wear tests. The standard test procedure for the Vickers V-104C required the total ring and vanes wear must be below 50 mg. The standard test procedure for the Vickers 35VQ requires that the same charge of fluid be tested with satisfactory results in three successive 50-hour test runs. Total ring and vanes wear for 35VQ-25 must be below 90 mg in each of the three tests. The chosen formulations for commercially available vegetable oil based fluids passed the Vickers

pump tests. Pump Wear was also exceptionally low. Ring and vane loss was less than 12 mg for both pump tests. These results equal high performance polyol ester hydraulic oil formulations.

Oxidative Stability: The Rotary Pressure Vessel Oxidation Test (RPVOT) was applied with these results: life ranged from 55 minutes to 200 minutes for several synthetic polyol esters that were evaluated. The result for canola oil featuring RLI's patented additive technology in a high oleic acid ester base stock was 237 minutes. The US Steel requirement for anti-wear hydraulic fluid is >120 minutes. In addition, tests have shown a direct correlation to improved fire resistant performance with fluids having higher oxidation stability.

Extreme Pressure/Antiwear: When properly formulated, passed FZG stage 12, Shell 4-Ball Wear results (1,800 and 1,200 rpm, 20 and 40 kg., 1 hr.) were 0.30 to 0.40mm.

Hydro Safe® Fire Resistant Fluids: Based on the test results and proven optimized formulations, Hydro Safe® has three hydraulic fluids which are vegetable oils derived fire-resistant hydraulic fluids that meet the Factory Mutual as a less hazardous fluid "Specification Tested" ISO/CD 15029-3 rating HFDU, and ISO/TS 15029-2 Spray Ignition-Ignitability (Class H). Previous studies have provided the expected temperature ranges of Autoignition (ASTM D-2155) @ 752 - 815°F (400 - 435°C) and Manifold Ignition (ISO 20823) @ 824 - 896°F (440 - 480°C).

Physical Properties: Among these three Fire Resistant Hydraulic Fluids, Hydro Safe® ISO VG-32 (FR) provides a Viscosity Index of 201, ASTM D-92 Flash Point of 525°F (274°C) and Fire Point of 610°F (321°C). Hydro Safe® ISO VG-46 (FR) provides a Viscosity Index of 212, ASTM D-92 Flash Point of 554°F (290°C) and Fire Point of 644°F (340°C). Hydro Safe ISO VG-68 (FR) provides a Viscosity Index of 218, ASTM D-92 Flash Point of 570°F (299°C) and Fire Point of 649°F (343°C). ISO VG-32 has a NOACK Volatility of 1% and ISO VG-46 and ISO VG-68 have a NOACK Volatility of less than 1%. Additional required test information can be seen on the RLI™ and Hydro Safe® TDS, SDS, and other technical papers written on the performance of these products. In addition to the excellent lubrication performance, these fire resistant formulas are compatible with the same system materials and components that are designed to operate on mineral oil based fluids. Conversion procedures are much easier and No engineering design changes are necessary for systems designed for mineral based fluids.

The conclusion from these and other tests is that a fire resistant fluid based on naturally occurring triglycerides and RLI's patented technology can be formulated to perform as an equal with synthetic polyol ester fire-resistant fluids. The combination of a growing desire for biodegradability and for renewable, less-costly alternatives suggests that these patented high oleic biobased products offer a practical replacement for synthetic polyol esters, especially in applications where fire resistance is a paramount concern.

For over the past fifteen years, Hydro Safe® Hydraulic Fluids have been successfully marketed, sold and used internationally by major companies and government organizations.

Respectfully submitted,

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Additional information supporting the data in this document can be referenced from the following publications:

Chemical Industries (Synthetics Mineral Oils, and Bio-Based Lubricants Chemistry and Technology, Second Edition under Fire Resistant Hydraulic Fluids),

Not All Biobased/Biodegradable Lubricant Technology is the Same! (See on www.renewablelube.com)

Hydraulic Fluids and Hydraulic System Compatibility with Bio-Ultimax Technology (See on www.renewablelube.com)

STLE Philadelphia, PA May 8, 2007: Balancing Lubrication Properties of Vegetable Oil and PAO Blends, Dr. Ken Hope, (Chevron Phillips Chemical Co.) and William Garmier (Renewable Lubricants Inc.) (See on www.renewablelube.com)

Lubricants & Fluids Technical Advisory Panel in Chicago, IL, September 19, 2006, Title: Balancing Lubrication Properties with Vegetable Oil and PAO Blends, Dr. Ken Hope, (Chevron Phillips Chemical, Co.) and William Garmier (Renewable Lubricants, Inc.)

Lubricants & Fluids Technical Advisory Panel in Chicago, IL, August 20, 1998, Title: High Temperature Stability with Soybean Oil, W.W. Garmier (Renewable Lubricants, Inc.)

89th American Oil Chemists' Society (AOCS) Annual Meeting and Expo, May 10-13, 1998, Chicago, IL. Title: Vegetable Oil Performance in High Temperature Hydraulic and Engine Lubricants, W. W. Garmier (Renewable Lubricants, Inc.)

Lubricants and Fluids Technical Advisory Panel Meeting in Chicago, IL, August 18, 1997, Title: Vegetable Oil Research Studies on Hydraulic Fluids and Engine Oils, J. M. Perez (The Pennsylvania State University) and W. W. Garmier (Renewable Lubricants, Inc.)

50th Annual Society of Tribologists and Lubrication Engineers (STLE) Meeting, May 14-19, 1995, in Chicago, Illinois. Title: Oxidative Stability and Antiwear Properties of High Oleic Vegetable Oils, S. J. Asadauskas, J. M. Perez, and J. L. Duda, (The Pennsylvania State University) STLE Volume 52, 12, 877-882, *Lubrication Engineering* (Dec. 1996).

More STLE and SAE publications can be referenced at www.renewablelube.com