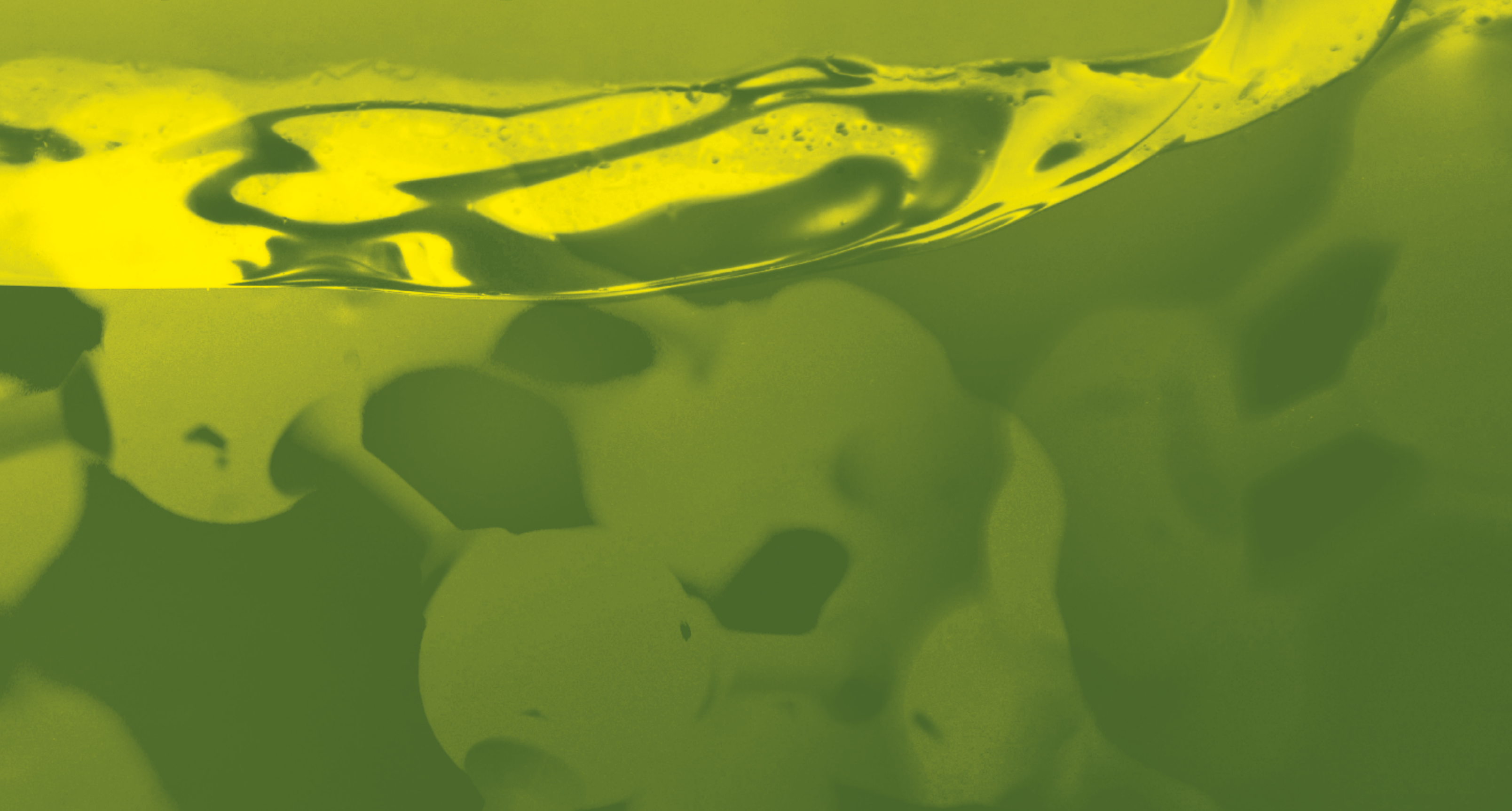
Synthetic Gear Lubricants Go Green

By Jason T. Galary

In addition to being environmentally friendly, synthetic lubricants impart many beneficial qualities to the gears and components they coat and protect.



With global industry moving toward environmentally friendly "green" lubricants, some very challenging issues have been created for lubrication in gearing applications. Over the last decade gears have been pushed to design limits as they are required to run at higher speeds, under heavier loads, and for longer periods of time. Along with new materials and improved manufacturing processes, synthetic lubricant technology has helped to achieve these higher industry expectations.

However, before discussing environmentally friendly synthetic lubricants let's first look at the advantages of synthetic lubricants and how to test performance in a gearing application. After this we can look at the viability of synthetic green lubricants in regards to matching the performance requirements of current industry standard lubricants.

BACKGROUND

Synthetic lubricants have found a home in the gearing industry based on several important advantages they possess over conventional petroleum lubricants. Both the petroleum and polyalphaolefin (PAO, the most common synthetic oil) are derived from hydrocarbon feedstocks, and PAO is further refined to purify its molecular weight range and remove any impurities. This additional processing will impart several intrinsic properties onto the PAO like reduced volatility and a lower pour point. These two properties improve both the high- and low-temperature capabilities as they lower the evaporation and increase the lubricant's functionality in colder environments, which is key in automotive gearing applications. In the power tool industry great advances have been made by using synthetic lubricants, as they have been able to optimize the motor efficiency because of the reduced internal drag. This allows for lower wear on the gear and an extended operating life for the tool.

TRIBOLOGY THEORY

Synthetic lubricants also have several tribological advantages over petroleum fluids. The term "tribology" refers to the study of friction, wear, and lubrication film. Friction (μ) is typically characterized as the ratio of frictional force to normal load between two moving bodies:

$$\mu = \frac{F_f}{N}$$

Wear can be defined simply as the reduction of material from a solid surface via mechanical (abrasive/adhesive) or chemical actions. It is characterized by the amount of material (V) removed from a surface over a sliding distance (s) modeled below by the Archards Wear equation [1]:

$$\frac{V}{s} = k.N$$

Lubrication film is also very important to the amount of friction and wear that occur on a surface. There are three distinct types of film—boundary, mixed, and elasto-hydrodynamic—which are determined by the amount of contact between the surfaces. By knowing the roughnesses of the two surfaces (R_{qA} and R_{qB}), as well as the lubricant film thickness (h_0), you can predict which film regime you will be in:

$$\lambda = \frac{h_o}{\sqrt{R_{qA}^2 + R_{qB}^2}}$$

During boundary, lubrication film thickness is very small due to high loads and rubbing of the two surfaces. When in this regime it is important to have a polar fluid (stronger metal affinity and bonding) and to use anti-wear and extreme pres-

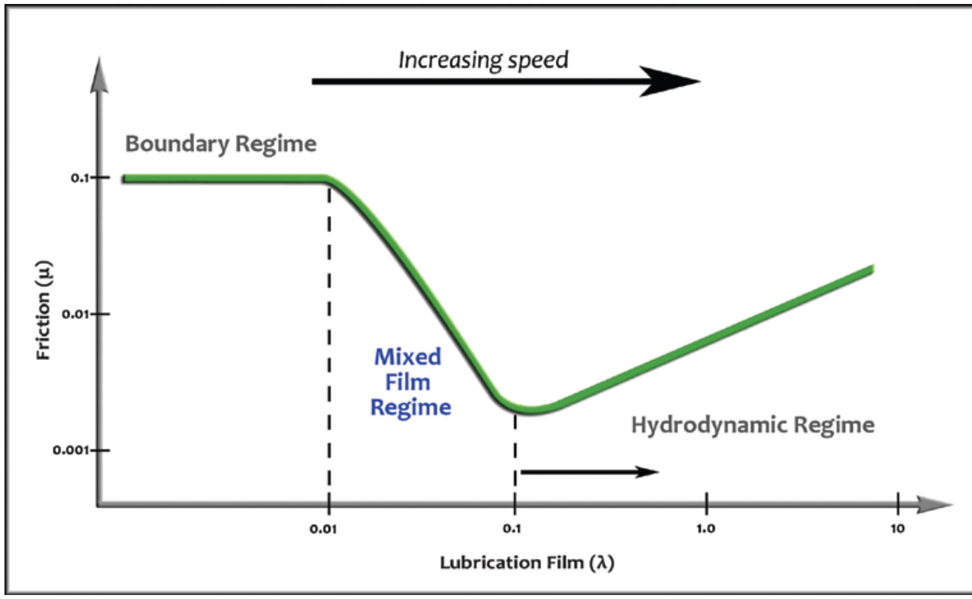


Fig. 1: **Stribeck curve.**

sure additives. It is in these conditions that gearing applications typically fall. As shown in the Stribeck Curve (fig. 1), as we move from boundary lubrication to elasto-hydrodynamic, the coefficient of friction drops as the surfaces separate and a full fluid lubrication film is formed. At this point there is a continuous lubricating film that adheres to the moving part and is drawn in between the two moving surfaces forming a pressure wedge.

PERFORMANCE AND WEAR

Comments often heard from gear design engineers are that they would really like some way to predict how a lubricant will work in their application. Outside of the FZG gear tests—ASTM D-5182 for load and ASTM D-4998 for wear—which are very expensive, there are not many industry focused test methods that can provide hard data for gearing applications outside of testing an actual gearbox. This is where one of Nye's strengths can be found, as we have a long history of performing application and pre-qualification testing for customers. Our applications group is made up of design engineers from a variety of industries that provides us with the ability to develop new test equipment and methods to help service the gearing industry.

Through the use of an SRV 4 tribometer (fig. 2) from Optimol Instruments we developed a test method that uses an 11mm 52100 sweeping cylinder on 52100 steel disc (fig. 3). The load, speed, temperature, and stroke of the test can all be modified as well as the orientation of the mating surfaces, lubricant delivery, and many other variables in order to recreate the conditions of a specific application as closely as possible. Although we used 52100 steel in the original development project, which is a standard grade for the SRV instrument, we also have balls, pins, cylinders, and discs that can be made out of almost any material a customer requires including

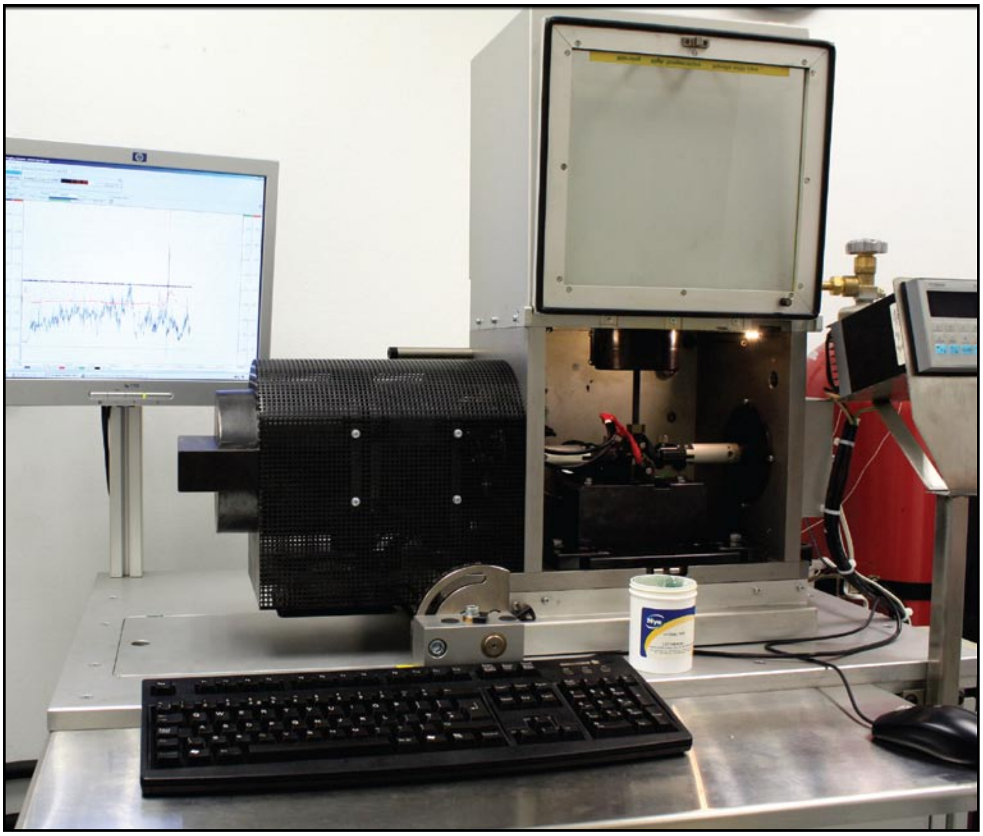


Fig. 2: **SRV 4 tribometer.**

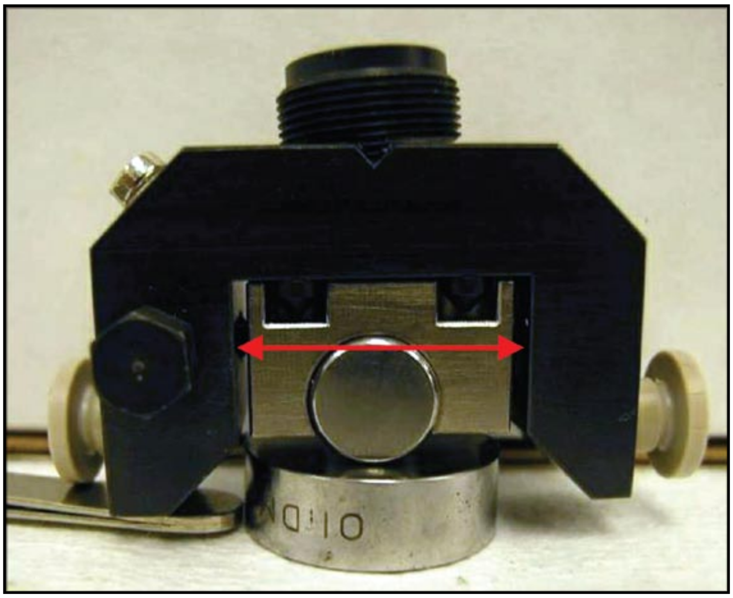
many grades of plastic, FZG gear grade steel, etc. This truly allows for simulation of an application's environment.

For extreme simulation of scuffing and wear on gears, a more rigorous test could be employed. By setting up the tribometer in a pin on disk configuration, or using a small contact bearing, contact pressures up to 10 GPa can be achieved. This allows for many variable situations to be created where different lubricant film regimes can be tested to help a design engineer more easily understand the dynamics of friction and wear occurring in their gears.

TRENDS TO WATCH

Synthetic lubricants have shown that they offer better wear protection, last up to five times longer, and have less probability of creating carbon deposits than petroleum products. They also have higher viscosity indexes, which are an indication of how the fluid viscosity characteristics of the oil will change across a

Fig. 3: 11mm sweeping cylinder on 52100 steel disc.



temperature range. The major synthetic lubricant families that have been used in modern gearing applications include PAO, ester, polyglycol, polyphenylether (PPE), silicone, and perfluoropolyether (PFPE). Each of these lubricant families has specific attributes (fig. 5). A Nye Lubricant specialist can help you determine which lubricant will bring the largest benefit to your specific design.

Most of these lubricants do not readily biodegrade (fig. 4) and would not be considered green. Synthetic esters, however, do have very good biodegradability as well as low toxicity, which makes them desirable as a green lubricant. But would they be a good lubricant for gearing applications?

Natural esters were the primary lubricants used prior to the 19th century in the form of animal fats—sperm whale oil, lard, etc.—and vegetable oils such as rapeseed, castor, and jojoba. Following World War II there was a need for more-refined lubricants, and synthetic esters were born. From their humble start as a primary low temperature lubricant solution, they quickly found their way into gas turbines in the aviation industry. Today synthetic esters can be found in applications including sintered bearings, engine oils, hydraulic fluids, and supercharger gears.

Synthetic esters offer an alternative to conventional oils, with strong environmental benefits such as biodegradability and renewability. They are synthesized through a chemical reaction of an alcohol and a fatty acid. This process can be done either thermally, or with the more popular use of a catalyst. The characteristics of the synthetic ester—such as viscosity, pour point, lubricity, and oxidative stability—can all be altered and controlled through the selection of the alcohol and fatty acid.

One of the great strengths of esters is that they have very high polarity, or affinity for metal, which separates them from mineral oils and PAO's, both of which are very non-polar. Polar lubricants are very effective in the boundary lubricant regime, as they tend to form strong bonds with metal surfaces that will reduce friction and wear. If the lubricant is going to be used in mixed or elasto-hydrodynamic regimes where the contact pressure is much higher, anti-wear and extreme pressure additives need to be considered.

With all of the strengths of synthetic esters, they fit easily into gearing applications with the right considerations placed toward design parameters. The primary reason that may limit the use of esters typically is plastic and elastomer compatibility, including seal material, in gearing applications. Materials that should be verified before use include ABS, polycarbonate, polyester, polystyrene, buna, butyl, natural rubber, and neoprene. These limitations can easily be reduced and/or eliminated with the careful selection of base oil viscosity, additives, or by formulating using synthetic hydrocarbon fluids.

To further improve on the environmentally friendly nature of ester lubricants, advances have been made to reduce their global impact. Through these improvements, increases in biodegradability, very low toxicity, and clean emissions have resulted. These new fluids are called "complex esters" and look to be the future of synthetic lubricants for many applications, including gearing.

Complex esters are comprised of alcohol end-capped complex fluids that typically contain a monofunctional acid and alcohol. These complex polymers can then be polymerized to meet the desired viscosity and polarity. Even in the highest viscosities these fluids still offer 80-plus percent biodegradability using the CEC test that is conducted in water for 28 days, or until CO_2 evolution plateaus. Other advantages include good load carrying capability, excellent viscosity indexes, and low pour points. Because complex esters are shorter chained molecules, even for high viscosities, they tend not to shear into smaller molecules, which means they will provide a consistent lubricant film strength. Also, unlike long chain hydrocarbon fluids, complex esters do not exhibit a temporary loss of viscosity when high contact stresses are exerted. This type of condition happens readily during gear testing.

Overall, the flexibility of ester lubricants fits right in place with both the demanding gearing applications of tomorrow and the green needs of the future. Nye has been hard at work on new developments in this area using synthetic and complex esters, including some new grades that are FDA approved for H1 incidental food contact. With all of these new technologies and the innovation that Nye has illustrated since 1844, we look forward to the future and how we can help the gearing industry with their lubrication needs.

Type of Oil	Percent Biodegraded
Mineral Oil	15-35%
White Mineral Oil	25-45%
Natural & Vegetable Oil	30-100%
PAO	5-30%
Phthalate Ester	5-80%
Trimellitate Ester	5-80%
Polyol Ester	55-100%
Diester	55-100%
Complex Ester	80-100%

Fig. 4: Biodegradability.

Fig. 5: **Lubricant advantages/disadvantages.**

Chemistry	Temp-Range (°C)	Cost	Wear	Volatility	Typical Gear Applications
Petroleum	-20 to 100	$	Good	Fair	General purpose, ambient temperature
PAO	-70 to 140	$-$$	Good	Good	General purpose, drop-in replacement for petroleum
Ester	-75 to 175	$$	Excellent	Excellent	High temperature and/or heavily loaded metal gears
Polyglycol	-40 to 100	$	Fair-Good	Fair	Large heavy loaded worm and planetary gears
Polyphenylether	-50 to 250	$$-$$$	Good	Excellent	Environments with radiation, acid, or chemical exposure
Silicone	-70 to 200	$$-$$$	Poor	Excellent	Lightly loaded (flea power) gears, plastic gears
PFPE	-90 to 250	$$$$	Fair	Excellent	High temperature gears

FUTURE WORK

Nye Lubricants is currently examining the tribofilm formation and the associated degrees of wear that occur in the boundary and mixed lubrication regimes for environmentally friendly biodegradable synthetic lubricants, bio-based materials, and their conventional counterparts. Using an SRV4 rotational tribometer to study wear, friction, and load coefficients, a sliding cylinder contact composed of FZG gear metal will be used in rotational mode with a contact pressure of 1.2 GPa, speeds up to 2,000 rpm, and variable temperatures. Conventional anti-wear additives composed of phosphorus and phosphorus-sulfur will be examined, in addition to neat fluids. The wear surfaces will be analyzed through the use of glow discharge optical emission spectroscopy (GD-OES). This will show the effect of the surface film regime on the wear and friction properties of environmentally friendly biodegradable synthetic lubricants versus conventional lubricants. Based on this work we hope to work on developing a new industry standard test method for measuring friction and wear in gearing applications.

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1) Archard JF: Contact and rubbing of flat surfaces. Journal of Applied Physics 1953; 24:981-988

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