Structure Holds Key to Ester Selection

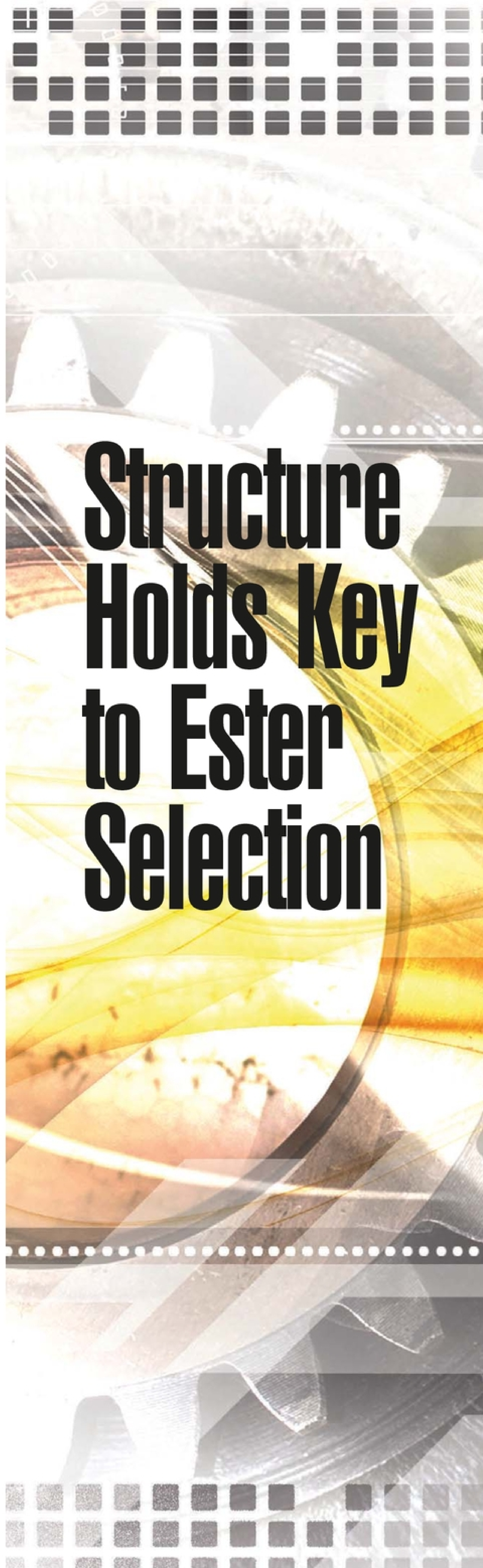


Image: Neliana Kostadinova

By Matthias Hof

Trends in the lubricants industry toward fuel efficiency and "green" products have brought attention to biobased ester base stocks for formulating high performance lubricants. Understanding the frictional properties of esters can allow formulators to take full advantage of these sustainable products.

Esters are based on fatty acids, often derived from renewable sources such as palm oil. When it comes to friction, ester base stocks can vary widely according to their chemical structure. A recent Emery Oleochemicals research study found that branched, oleate and saturated esters exhibit considerably different frictional behavior and film thickness.

While the study confirmed esters' reputation for shear stability, it also found that viscosity grade and operational temperature can have significant effects on the behavior of these fluids. With this in mind, formulators should consider both the required viscosity and application temperatures when selecting an ester base stock.

Why Esters?

One of the most dominant trends in the field of tribology is furthering the contribution lubricants can make to fuel and energy efficiency, according to a survey conducted by the Society of Tribologists and Lubrication Engineers. Thirty-five percent of participants in the 2014 survey named decreasing use of fossil fuels, requirements for lower emissions or energy improvements—such as fuel efficiency—as the single most significant trend for tribology. More than half of respondents said that these industry trends will continue to be significant more than a decade from today.

In the automotive and transportation industry, greater fuel efficiency has been pursued for quite some time, and emissions requirements imposed by governments around the world have pushed this agenda forward. While the industrial sector has been spared such regulations, its operators also seek greater energy efficiency in order to cut costs. To support this objective, more and more lubricant companies and component suppliers have begun to market products with claims of improved efficiency.

Lubricants contribute to energy and fuel efficiency mainly by reducing friction between contact surfaces and

Tested Esters

	ISO VG 20	ISO VG 46	ISO VG 100	ISO VG 150	ISO VG 320
Oleates	x	x		x	x
Branched esters		x	x	x	
Saturated esters	x	x	x		

Source: Emery Oleochemicals

within the lubricant itself. This fact is reflected in the growing use of low viscosity lubricants like 0W and 5W engine oils, and industrial oils such as ISO viscosity grade 32 oils for hydraulic systems.

All components required to formulate a finished lubricant should contribute to the final target of reducing energy consumption during operation. In order to achieve the required performance levels for a lubricant, a combined approach should ideally be used, including advanced formulation technology, high-performance additives and superior base stock chemistry.

It is generally accepted that the high performance of petrochemical based lubricants stems from various surface-active additives. Because API Group II, Group III and Group IV base stocks are nonpolar, improving frictional behavior and wear protection must be achieved with additives that can more easily cling to metal surfaces.

Synthetic Group V base stocks, such as esters and polyalkylene glycols, are much more polar and can adsorb on metal surfaces, providing a high degree of lubrication even without additives. This behavior depends to a great extent on the chemical nature as well as on the viscosity grade of the Group V fluid.

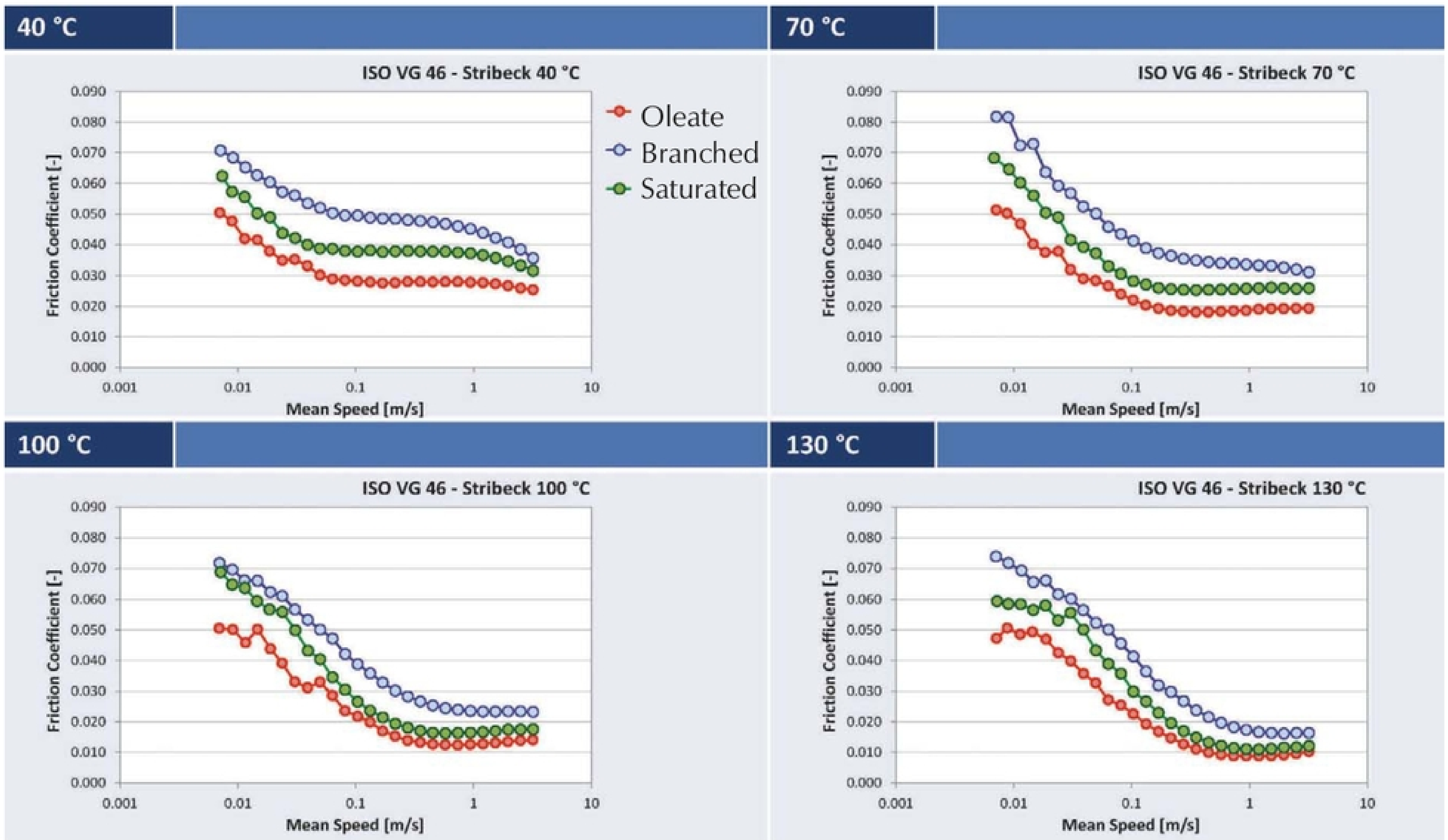
Testing the Boundaries

A total of 10 ester base stocks, including oleates, branched and saturated esters, were studied in depth to determine their frictional properties. These 10 base stocks cover five ISO viscosity grades ranging from 20 to 320.

Three different test methods were used to compare the esters' behavior, with each test conducted at 40 degrees Celsius, 70 C, 100 C and 130 C. The first method employed an ultra-shear viscometer to evaluate the shear stability of the base stocks. Shear stability is important in processes with high loads and lots of stress on the lubricant, which might cause viscosity to drop.

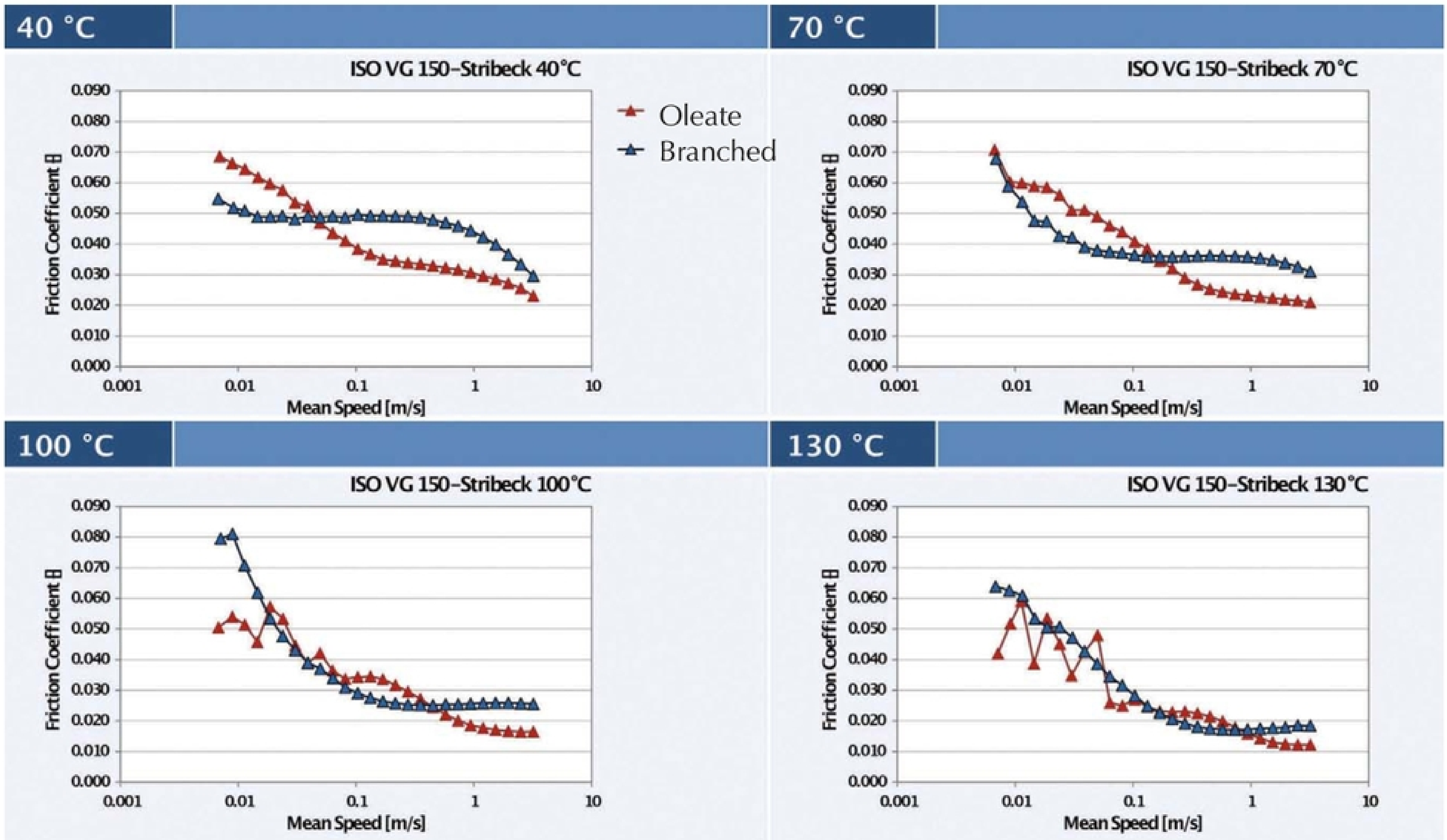
The second test measured lubricant film thickness in an elastohydrodynamic lubrication (EHL) regime. EHL occurs between surfaces that are in rolling contact, such as ball bearings or rolling element bearings. Turbine oils and hydraulic oils, for example, require good EHL performance.

Oleate Esters Produced the Least Friction



Source: Emery Oleochemicals

Pronouced Differences Among VG 150 Esters



Source: Emery Oleochemicals

In the third test, a Mini Traction Machine evaluated frictional behavior in all three lubrication regimes—boundary, mixed and EHL—comparing both the friction coefficient and traction over a range of speeds. Boundary and mixed lubrication are especially important in cutting, forming and rolling operations, gears, screw compressors, ball bearings and other heavy machining or heavy load applications.

A Better Understanding

The research study confirmed the general opinion that ester base stocks, even at high viscosities, are very shear stable compared to lubricants that are formulated with certain polymers, or viscosity modifiers, to achieve target viscosity grades.

For example, in the first test method, the VG 46 oleate ester fluid exhibited largely Newtonian behavior under high shear, and its viscosity was affected very little by the shear rate. Similar behavior was seen among different chemistry groups of the same viscosity: The oleate, saturated and branched esters produced nearly the same results at all tested temperatures and shear rates.

Looking more closely at the differences between the three chemistries, oleate esters showed the highest film thickness under EHL conditions, especially under low speed conditions. For the branched and saturated fluids, film formation depended on viscosity.

Moving on to the second test method, using the EHL device, the researchers found that at 70 C, 100 C and 130 C, all of the VG 46 fluids formed a boundary film. The film was more pronounced for the oleate ester, followed by the branched ester and then the saturated ester.

In tests of the VG 100 fluids, both esters showed boundary film formation at 100 C and 130 C. However, the film thicknesses were reversed—the saturated ester formed a more pronounced boundary film than the branched ester.

One final interesting observation in the EHL tests appeared among the three different branched ester systems at 130 C. The VG 100 fluid showed the strongest boundary film formation—even thicker than the VG 150 equivalent. This demonstrates that, even within the same chemical group, the structure of an ester—not just the type of fatty acid used to make the fluid—can have a significant influence on film formation.

Frictional behavior is even more dependent on the chemistry. The branched esters in this comparison showed the highest friction coefficients within the different viscosity grades (46, 100 and 150). Oleates showed the lowest values, and the saturated esters placed in the middle. It was also found that frictional behavior changes as a function of temperature, even within the same chemistry group.

In this last stage of the study, the Mini Traction Machine was used to evaluate frictional behavior via the Stribeck Curve. Results for the VG 46 fluids were as expected, and some boundary friction effects were observed at 100 C and 130 C.

However, despite having the same viscosity classification, significant differences arose in the fluids' frictional behavior, which can be traced back to their chemical nature. The branched ester had the highest friction coefficient, while the oleate ester had the lowest. The behavior was found at all four temperatures and over the entire speed range.

This finding is surprising when viewed alongside the film thickness evaluation results. In general thinking, a larger film thickness would be connected with higher friction. In the MTM results, however, the oleate—which had the thickest film—provided the lowest friction coefficient.

Chemistry type also had a clear effect within the ISO VG 100 group. As with the VG 46 fluids, the branched ester showed higher friction than the saturated ester at the entire speed range of the Stribeck Curves. The saturated ester also produced lower friction at 100 C and 130 C.

Within the VG 150 group, the different chemistries exhibited even more pronounced differences. In the lower temperature ranges (40 C and 70 C), friction at high speed was significantly greater for the branched ester. By contrast, in the mixed lubrication regime, it was significantly lower than the oleate ester. The effect did not extend to higher temperatures. This particular finding underscores the importance of considering both the chemistry and the intended application temperature when choosing an ester base stock, as both could be important factors affecting performance and efficiency.

While this study only looked at the frictional behavior of ester base stocks, other factors such as stability, low temperature behavior and volatility should be taken into account when determining ester performance.

These test results indicate how esters can contribute to reduction in energy consumption through friction reduction, as a valuable and functional component for the formulation of energy efficient lubricants. ∎

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