Rethinking the Basestock Equation

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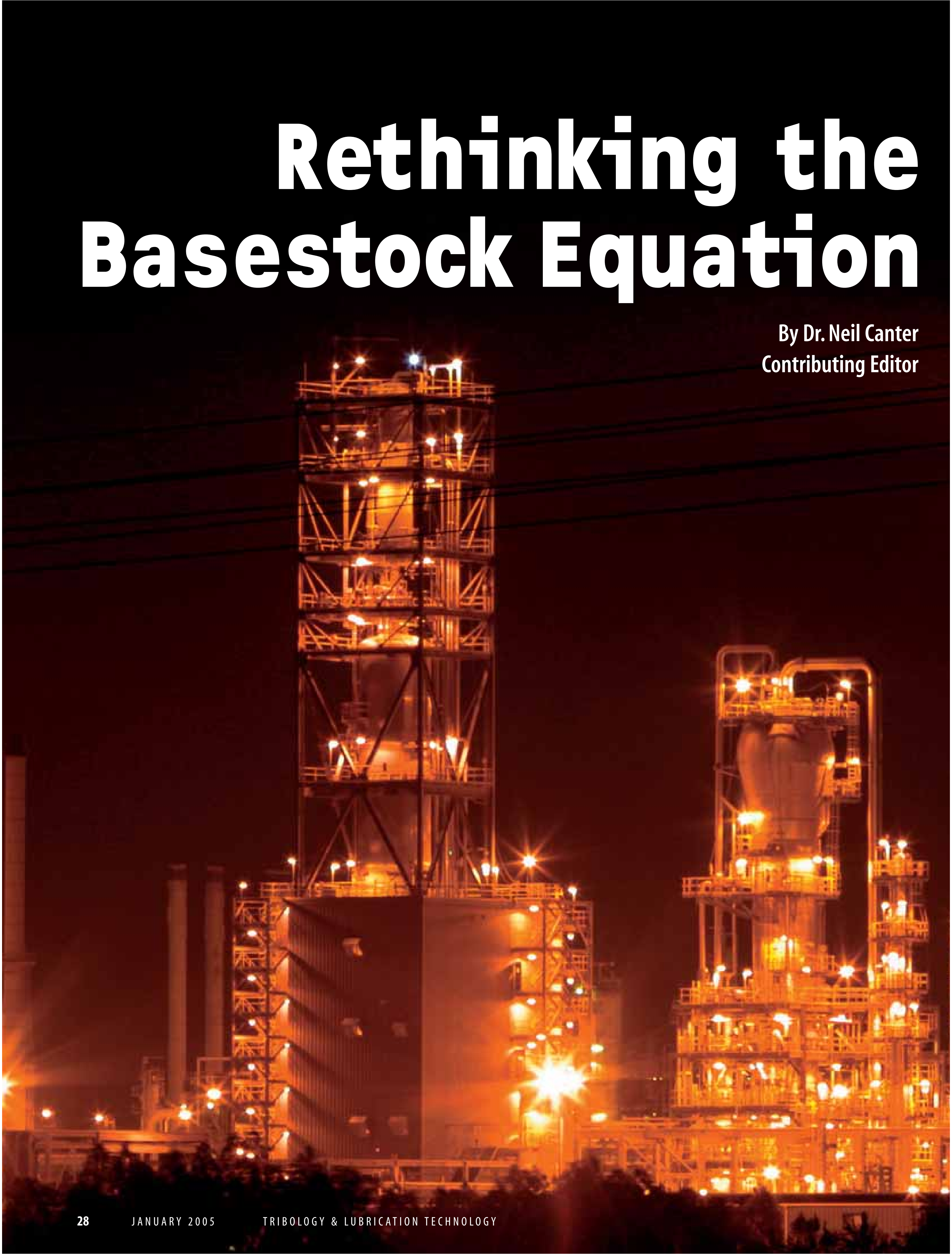

Changing regulations and an evolving marketplace are leading lubricant formulators to make greater use of Group II & III base oils.

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Demand for more highly refined basestocks is growing in response to trends requiring better lubricants in the automotive sector. OEMs are looking for lubricants with such properties as extended drain intervals, reduced emissions and better fuel economy.

Specifications such as GF-4 (passenger car motor oils) and the pending PC-10 (heavy duty engine oils) have led lubricant compound/blenders to incorporate base oils with greater purity, lower volatility and longer operating life than those previously used.

For the most part, Group II and III base oils can impart improved oxidative and thermal stability as compared to their Group I counterparts.

This demand has led to the greater use of Group II and III base oils. Compared to the traditional Group I base oils, Group II and III have fewer impurities. Figure 1 is a chart showing the much lower level of aromatics, sulfur and nitrogen-containing compounds in Group II compared to Group I base oils. Group III base oils are even more highly refined.

The American Petroleum Institute (API) categorized these base oils in 1993, as shown in Table 1. There are three other basestock categories. Group IV are polyalphaolefins (PAOs), a specific synthetic lubricant basestock, and Group V are all other stocks not included in the previous four groups. This includes the other synthetic basestocks (diesters, polyalkylene glycols, polyol esters, etc.) and pale oils. Recently, a new synthetic basestock, polyinternalolefins (PIOs), has been developed in Europe and designated as Group VI. Background information on base oils and processing can be found in a three-part series published in 2003 in *Machinery Lubrication* magazine.(1-3)

Table 1. API Base Stock Categories

Group	Sulfur, Weight %		Saturates, Weight %	Viscosity Index (VI)
I	> 0.03	and/or	< 90	80 – 119
II	≤ 0.03	and	≥ 90	80 – 119
III	≤ 0.03	and	≥ 90	≥ 120

Industrial lubricants have been considered to some extent to be of secondary importance compared to the automotive market. With the greater percentages of Group II and III base oils available worldwide, compound/blenders of industrial lubricants have more options at the moment for formulating their products to meet the needs of their customers.

Over the long term, the availability of Group I base oils in North America will decline. Terry Hoffman, director of base oil sales for Valero Corp., says, "U.S.-produced Group I base oils will be significantly rationalized by 2015. Of the seven refineries manufacturing Group I base oils today in the U.S., only three, at most, likely will be operating in 2015."

This change in Group I availability means that the industrial lubricants industry must take a serious look at its options for formulating products to meet the requirements of a wide range of applications (compressor oils, hydraulic oils, metalworking fluids, process oils, refrigeration oils, turbine oils, etc). Group II and III base oils are, in effect, different carrier systems containing much lower levels of aromatics. This leads to an increase in the thermal and oxidative stability of Group II and III base oils as compared to Group I. Yet, the lower levels of sulfur content can reduce the ability of Group II and III base oils to provide inhibition to oxidation as compared to Group I base oils.

This article seeks to provide industrial lubricant formulators with options for formulating the best possible products from Group I, II and III base oils to ultimately meet the needs of the end-users. Discussions were held with representatives from base oil suppliers, compound/blenders of industrial lubricants and additive suppliers to gain their insight into how best to use the available basestocks.

FOCUS ON PERFORMANCE

Dr. Tim Nadasdi, technical advisor of industrial oils for ExxonMobil Lubricants & Specialties says, "The discussion about the specific compositions of the base oil classes has taken attention away from developing well-balanced formulations to meet application needs. We need to take people's attention away from molecules and focus on lubricant performance."

One key issue is the availability of Group II and III basestocks at higher viscosities. Group I base oils range in viscosity up to about 500 cSt at 40 C. This high viscosity material is known as brightstock. The processing used to hydrogenate and hydrocrack basestocks limits the viscosity of Group II and III base oils to 100-110 cSt and 40 cSt at 40 C, respectively. Besides Group I brightstock, other heavy basestock options for the formulator include PAOs (viscosity grades available up to 3,000 cSt at 40 C) and polyisobutylene (PIB).

The challenge according to Dr. Nadasdi is to provide the best possible basestock combination to formulate a product such as an ISO 320 gear oil. While use of PIB will raise the lubricant's viscosity into the desired range, shear stability and oxidative stability could be sacrificed. Dr. Nadasdi says, "Using PIB to compensate for lower viscosity Group III basestocks in a finished formulation can, in some cases, defeat the purpose of developing a higher performing product."

As a second example, Dr. Nadasdi says, "pour point depressants can improve the cold temperature properties of Group III base oils to a level comparable to some PAOs. However, if higher viscosities are needed and PIB is used, this polymer can reduce the effectiveness of pour point depressants."

A process that can be used to face the challenges of formulating industrial lubricants is the spider diagram. Such an approach is provided in Figure 2.

Dr. Nadasdi says, "Key lubricant performance characteristics are placed on this diagram and rated from a poor rating of 0 to an excellent rating of 10. The objective is to include all the categories in a spider chart that impact the specific application requirements. Contained within the chart is the fact that the lubricant will undergo a specific series of laboratory tests (and sometimes field tests) in the designated categories to mimic the application."

In the hydraulic fluid segment, Dr. Nadasdi has seen companies promoting Group II and III-based lubricants that claim 3,000 to 5,000 hours in the ASTM D 943 Turbine Oil Stability Test (TOST). The setup for running the TOST test is shown in Figure 3.

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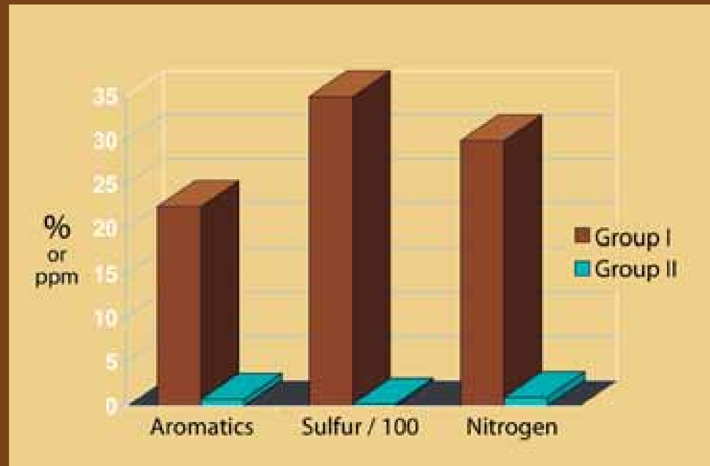
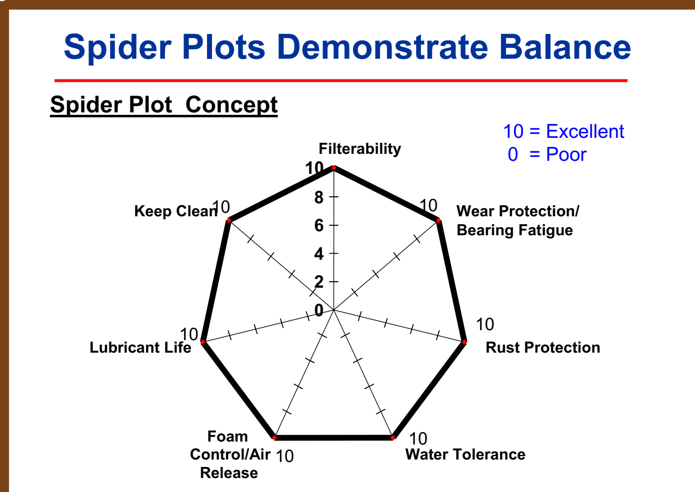
Figure 1. Group II Stocks Have Lower Impurities



(chart courtesy of ChevronTexaco Global Lubricants)

Group II base oils display lower levels of impurities than Group I base oils.

Figure 2.



(chart courtesy of ExxonMobil Lubricants & Specialties)

A spider diagram can be used to assist the compound/blender with formulating the right product for a specific application.

Figure 3.

(photo courtesy of RheinChemie Corp.)

Setup for running the ASTM D 943 Turbine Oil Stability Test (TOST).

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However, focus on this single dimension of product performance has led to problems in other areas such as deposit control. This has led to a pullback of this product type in lieu of hydraulic fluids blended with combinations of Group I, II and III basestocks.

BASE OIL SUPPLIER PERSPECTIVE

Hoffman of Valero has found that the marketplace is not necessarily looking to replace Group I basestocks in favor of Group II and III alternatives. He says, "We have seen mixed reviews with base oils. Some customers rely on the sulfur present in Group I base oils to provide natural inhibition properties in general industrial and metalworking applications. In fact, Group II maybe too highly refined a base oil for some applications."

Solubility is also a consideration as lower levels of aromatics can lead to incompatibility problems with the additives used in industrial lubricant formulations. Hoffman says, "The aromatic content in Group I base oils is needed in rubber process oils to ensure that some components do not bleed out of the finished formulation. A similar situation also applies to diluent oils that require a certain level of aromatics to ensure that all the additives in the formulation remain in solution."

With the greater percentages of Group II and III base oils available worldwide, compound/blenders of industrial lubricants have more options at the moment for formulating their products to meet the needs of their customers.

COMPOUND/BLENDER PERSPECTIVE

Dave Kramer, global manager of industrial oil technology for ChevronTexaco Global Lubricants, indicates that there are a number of different applications where the benefits of using Group II and Group III base oils can lead to performance enhancements. Says Kramer, "Incorporation of Group II base oils in metalworking fluid and refrigeration lubricant applications has led to superior characteristics as compared to these fluid types formulated with Group I or naphthenic oils."

Metalworking fluids are prepared with a large concentration of additives needed for a number of functions. Kramer indicated that traditional components such as animal fat derivatives are not soluble in Group II base oils. He pointed out, "Our approach was to utilize alternative additives that are compatible with Group II base oils in the development of straight oils."

Group II-based metalworking fluids display lighter color and lower volatility than corresponding lubricants prepared from naphthenic oils. Noack volatility levels for straight oils prepared from both Group I and II base oils are shown in Figure 4 for oils with comparable viscosities. The biggest performance difference was observed with the 23 cSt at 40 C oils because of the much higher level of volatile components in the Group I basestocks used to prepare this specific metalworking fluid.

Lubricants in ammonia refrigeration systems face the challenge of dealing with a basic refrigerant that can combine with acidic lubricant degradation products to form sludge and varnish. Low volatility and good immiscibility with ammonia are needed for this application.

A comparison showing the appearance of a Group II oil-based fluid vs. a traditional naphthenic derived refrigeration lubricant that were used in a real world compressor application is shown in Figure 5. The Group II oil is initially shown after 24 hours of operation. It contains approximately 10% of the previous lubricant. Continuous operation up to 10,000 hours does not lead to much of a color change. In contrast, a new naphthenic oil will seriously degrade during the same time period.

Kramer contends that Group II-based ammonia refrigeration oils display lower volatility, lower oil consumption, better low temperature performance and better immiscibility than naphthenic oil-based products. This translates into superior operating performance over a longer operating time frame.

Group II-based hydraulic oils also have become very attractive for performance and environmental reasons. Kramer points out, "Hydraulic oils formulated with Group II basestocks display three times the TOST life of comparable lubricants blended with Group I base oils." This feature coupled with the clean, clear and low toxicity profile of Group II base oils enables the product to be safer to the environment and the workers using the product.

Harji Gill, vice president and technical director for Pinnacle Oil, also has seen performance benefits with using Group II base oils in antiwear hydraulic fluids. He says, "We are able to offer products that can operate for 5,000 hours in the TOST test. Outstanding performance also has been seen with turbine oils prepared with Group II base oils," Gill explains, "TOST data on turbine oils formulated with a rust and oxidation additive package can exceed 10,000 hours."

Gill sees better thermal and oxidative stability and better cold flow properties as the main reasons for switching to Group II and III base oils. The one concern he has is additive solvency. Gill says, "Formulators must take care to find and use the appropriate additives with Group II and III base oils to minimize incompatibilities."

GROUP III APPLICATION

Bob Begland, president and technical director for Ultrachem, Inc., has used Group III base oils in compressor oils for the past three years. While PAO-based compressor oils still display superior performance, Group III lubricants of this type exhibit operating lifetimes that are close to comparable PAO products.

Begland says, "Under good operating conditions, PAO-formulated compressor oils operate for 8,000 hours while comparable lubricants prepared with Group III base oils can last between 6,000 and 7,000 hours. Oil analysis is conducted every 2,000 hours, and product failure is reached when the acid number exceeds 1.0 and/or product viscosity increases by 20% from its original figure."

Begland revealed that approximately 10% diester is included in both products to ensure that the additive package remains compatible with both basestocks. He noted that Ultrachem, Inc., uses the same additive chemistry in both basestocks with the only exception being that a pour point depressant is added to the Group III products.

Kramer of ChevronTexaco has also seen success with formulating Group III base oils into compressor oils. One concern that customers can face is seal compatibility. Different basestocks can have distinct compatibility issues with elastomers. Kramer is hesitant to add seal swelling agents or aromatic solvents to a Group III base oil. He says, "The biggest benefit in moving from a Group I to Group II basestock is the improvement in thermal and oxidative stability of the lubricant. Adding aromatics or solvents will

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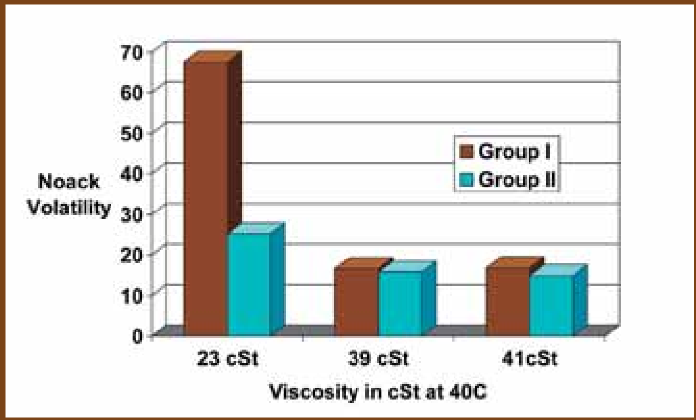
Figure 4. Noack Volatility Levels for Straight Oils Prepared with Group I and II Base Oils



(Data courtesy of ChevronTexaco Global Lubricants

Noack volatility levels for metalworking straight oils prepared with Group I and Group II base oils at comparable viscosities.

Figure 5. Ammonia Refrigeration Oil Field Demonstration

(photo courtesy of ChevronTexaco Global Lubricants)

Difference in performance between a naphthenic and a Group II-based ammonia refrigeration oil.

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nullify that improvement."

The best way to handle this issue is to educate the end-user. Kramer recommends that his company's customers replace old seals with new ones when switching from a Group I to a Group III compressor oil. Following this procedure will enable the basestock to have no impact on the elastomer and easily control any seal issues.

ADDITIVE PERSPECTIVE

STLE-member Dr. Ian Macpherson, marketing manager of industrial lubricants for Afton Chemical, differentiates between Group I and Group II/III when discussing additive needs. He says, "The same additive chemistries used in Group I base oils cannot be applied without testing in Group II/III basestocks. Problems have been encountered in Group II/III base oils particularly in the areas of de-emulsification and foam inhibition. These problems probably reflect the different solubility characteristics of some additives in different base oils. Fortunately, these issues have been overcome through new additive chemistries."

Over the long term, the one main concern with switching to Group II and III base oils is dealing with formulating high viscosity products.

For the most part, Group II and III base oils can impart improved oxidative and thermal stability as compared to their Group I counterparts. Additive solubility can be a concern with Group II and Group III basestocks according to Macpherson.

He notes, "Where solubility problems occur, they are often not seen right away after blending an industrial lubricant formulation. A very, subtle dropout occurs slowly which leads to the formation of slight turbidity in the mixture. This phenomenon is best seen with a flashlight. Again, additive chemistries optimized for Group II base oils have largely overcome this problem."

In the case of most Group II base oils, no co-solvent is typically used for most applications, as there are aromatic species still present in the base stocks. Macpherson recommends that 5% of an adipate or other ester be considered with a Group III basestock to ensure no additive incompatibilities. Other co-solvents such as alkylated naphthalene (AN) may also be used, depending on the application.

Macpherson also cited problems with leaking seals in the industry several years ago. He believes that generally industrial fluids based on Group I base oil will have a tendency to slightly swell seals over time. These slightly swollen seals may wear slightly. Industrial fluids that are based on Group II base oil have less of a tendency to swell seals and may even shrink them a little. Seal leakage is a consideration when converting plants using predominantly Group I-based industrial fluids to fluids based on Group II base oils.

Macpherson says, "There are few seal tests routinely used to determine the impact of a specific lubricant on elastomers. It is usually left up to the lubricant compound/blenders as to whether a seal swell agent should be added to the industrial formulation."

Over the long-term, the one main concern with switching to Group II and III base oils is dealing with formulating high-viscosity products. Macpherson foresees that the supply of Group I brightstock will decline as Group I refineries close. This could lead to some performance difficulties, as potential replacements such as PIB and polymethacrylates have downsides. The former displays inferior oxidation and low temperature properties while the latter may only achieve the right shear stability at very high cost.

One of the best industrial applications showcasing the value of Group II base oils vs. Group I basestocks is turbine oils. ASTM D 943 (TOST) data was run on a number of different turbine oil formulations at two viscosity ranges (ISO 32 and ISO 46). The averaged results in Figure 6 clearly show that Group II base oils respond better to certain antioxidants in this test.

Macpherson says, "General Electric has developed a turbine oil specification that requires the lubricant to last in the ASTM D 943 procedure for at least 7,000 hours. This result is relatively easy to achieve using Group II base oil in combination with the appropriate antioxidant package. Group I-based formulations can be more challenging in this test."

STLE-member Thomas O'Brien, manager of applications development lubricant additives for the lubricant oil additives division of Rhein Chemie, believes that the main benefits of Group II and III base oils are improved thermal and oxidative stability and better surface viscometrics (superior cold temperature properties). He says, "Group II base oils exhibit, in general, 20 C-lower pour points and VI's that are 30 points higher than Group I basestocks."

Additive solubility is one of the biggest issues facing the users of Group II and III base oils. O'Brien says, "The different compositions of Group II and III base oils mean that new additives need to be developed to work well with these basestocks. Treat rates for these additives sometimes need to be reduced in order to ensure compatibility and solubility with the Group II and III base oils."

As an example, O'Brien cites that conventional additive packages for hydraulic oils are recommended at a 3% to 5% treat rate in Group I oils. The percentage in the corresponding Group II & III-based hydraulic oils may be as much as 50% lower.

Additive packages display different responses to different base oils according to O'Brien. He cites a study assessing the impact of six different additive packages on five specific basestocks. The procedure used was the European oxidation stability test known as IP 280, which measures the tendency for a lubricant to generate sludge and/or solid oxidation byproducts.

In this procedure, a soluble metal catalyst is added to the lubricant and the mixture is heated at 120 C for 164 hours while being subjected to a constant one-liter/hour flow of oxygen. Once the test is completed, the oil is filtered and the sludge isolated and weighed. The additive package treat rate was 0.4%.

Results are shown in Figure 7. The y axis is provided on a logarithmic scale to ensure that the results all can be included on the same graph. The white line placed across the graph is the specification limit to meet the stringent British Standard 489 for turbine oils.

O'Brien says, "The data shows that different additives will have different performance effects in specific base oils. As the quality of the base oil improves, the tendency for better performance increases to the point that all of the lubricants tested with Group III+ and Group IV base oils meet the British Standard 489."

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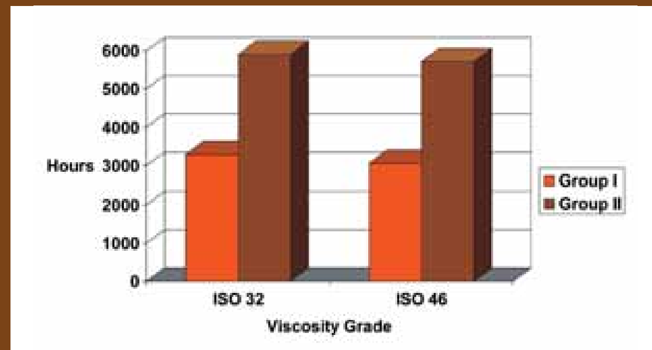
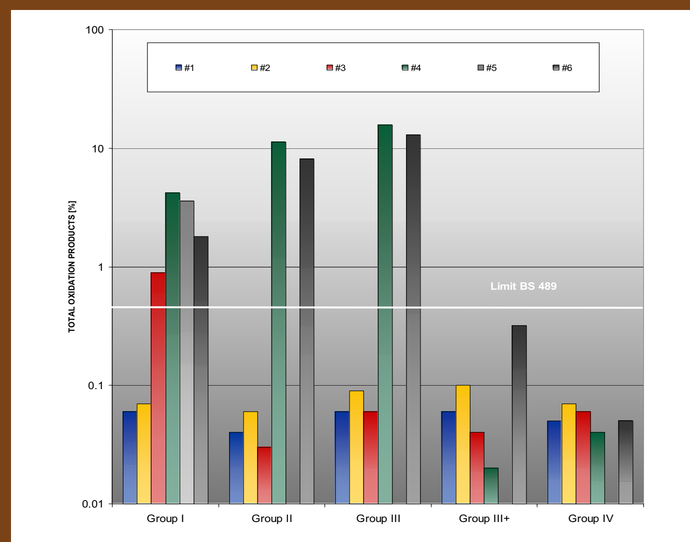
Figure 6. Comparison of TOST Data on Group I and II Based Turbine Oils



(Data courtesy of Afton Chemical)

TOST performance data for Group I and Group II-based turbine oils as measured by the ASTM D 943 test at two different product viscosities.

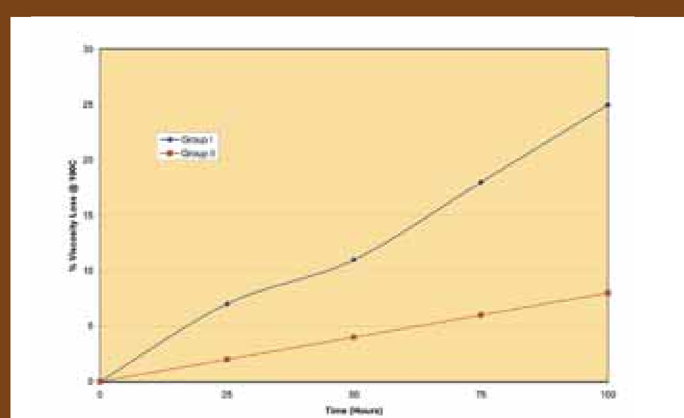
Figure 7. Oxidation Stability IP 280 (CIGRE) 0.4% ADDITIVE in Basic Oil



(Chart courtesy of Rhein Chemie Corp.)

Oxidative stability of 6 different additive packages in 5 different basestocks as measured by the IP 280 test.

Figure 8. PIB Viscosity Loss in Group I and II Base Oils



(Data courtesy of Functional Products, Inc.)

Viscosity loss of a PIB-based solution in both a Group I and a Group II base oil at 100 C over time.

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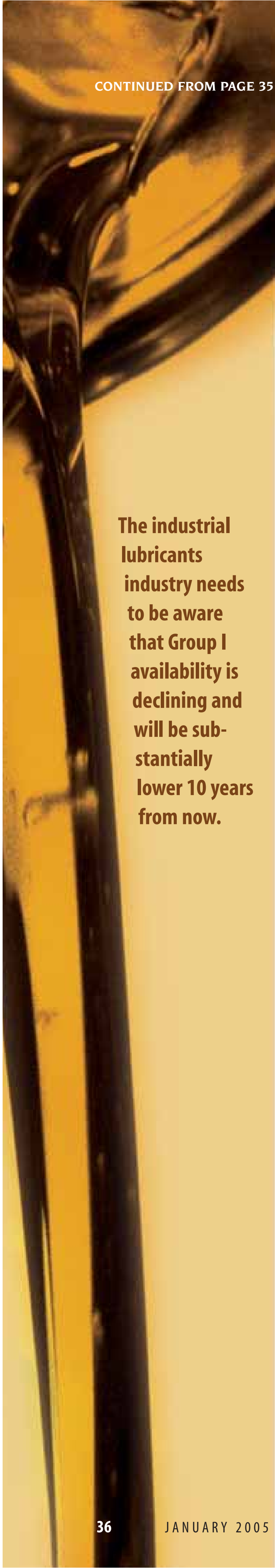

The industrial lubricants industry needs to be aware that Group I availability is declining and will be substantially lower 10 years from now.

O'Brien believes the single biggest benefit to using Group II and III base oils now and in the future is for "seal-for-life" applications. He says, "There is a noticeable trend for end-users to want to extend the operating life of their lubricants and greases as much as possible. Group II and III provide the ability to enable the lubricant to even last for the entire operating period of the specific piece of equipment without the need for a change."

The concern about the thermal stability of PIB has led STLE-member Dr. Victor Levin, lab director at Functional Products, in Macedonia, Ohio, to study the impact of Group I, II and III base oils on this class of polymers.(4) He says, "Solutions of PIB at the same concentration in a Group I and II basestocks display different rates of viscosity loss at 100 C even when formulated with antioxidant. After 100 hours, the viscosity of the Group I base oil drops 25%, while the Group II basestock loses 10% of its viscosity. A chart showing the rate of viscosity loss over the 100-hour test period is shown in Figure 8.

Raising the temperature to 150 C leads to a more rapid viscosity loss. Complete degradation of PIB is observed after an hour in Group I and II base oils. In contrast, no loss of viscosity is detected when a Group III base oil is used after 100 hours at the same temperature.

Even a small amount of Group I has an impact on performance. Preblending PIB in a Group I basestock followed by incorporation in a Group III base oil leads to a viscosity loss. Use of PIB in a preblended Group III oil will eliminate the viscosity loss.

Levin says, "The PIB viscosity loss is directly attributable to the thermal instability of Group I and II base oils. A free radical chain mechanism that involves the formation of peroxy radicals occurs as the base oil undergoes oxidation. The radicals will then degrade the PIB polymer chains leading to the loss of viscosity." Under these conditions, Group III base oils have much better stability and, as a result, preserve the integrity of the PIB chains.

At present, compound/blenders have a range of base oils to choose from for use in the many diverse industrial lubricant applications. Those applications operating under greater temperature extremes, whether it be high temperature (requiring better thermal and oxidative stability) or lower temperature (lower pour points), may require a Group II or Group III base oil. Additive selection remains important as solubility problems can occur, although technology is available to overcome any incompatibility.

The industrial lubricants industry needs to be aware that Group I availability is declining and will be substantially lower 10 years from now. Steps need to be taken to ensure that a viable high viscosity option is available to replace Group I brightstock. **<<**

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