Metalworking fluids biocides:
SCIENCE vs. FICTION

Setting the record straight in the U.S. and Europe.

- EPA’s next move on chlorinated paraffins
- What’s ahead for heavy duty diesel engine oils?
- Bearing selection: Balancing reliability with cost
- The perils of global communication
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MADE IN THE USA
The perils of global communication

How STLE is spreading its message and building a worldwide community.

“ENGLAND AND AMERICA ARE TWO COUNTRIES SEPARATED BY A COMMON LANGUAGE.” This famous quote is often attributed to George Bernard Shaw, although whether he actually used these words remains disputed. The nearest equivalent appears in Oscar Wilde’s short story The Canterville Ghost, which includes the line, “We have really everything in common with America nowadays except, of course, language.”

British and American versions of English started drawing apart almost as soon as the first colonists had settled. While the two forms have remained for the most part mutually intelligible, the differences can lead to confusion. When my wife Janet and I arrived in America 26 years ago, we discovered these differences for ourselves, sometimes with potentially disastrous or embarrassing consequences.

The differences occur in many forms. The simplest are those in which words are spelled differently. Examples include color (colour), center (centre), tire (tyre), behavior (behaviour) and numerous cases where an ‘s’ used in the UK is replaced with a ‘z,’ which incidentally is pronounced zed in the UK. It took me awhile to adjust when writing reports, although today our word processors automatically correct to the version of English being used.

In the spoken word, pronunciations also vary, and there have even been songs written celebrating the differences. It took me awhile before I could make myself fully understood when ordering tomatoes in a sandwich or salad. Trickier are the cases in which completely different words are used. Famous examples are the hood and trunk of an automobile, which in the UK are referred to as the bonnet and boot. Furthermore, a British lorry is transformed into a truck, mangetout becomes a snow pea and filling a car with petrol turns into gassing up.

There are many cases in which there is no direct translation for some phrases. For example we initially confused many of our newfound friends by suggesting that we arrange to meet in about a fortnight. We had not realized that this English term for two weeks was not an expression used in the U.S.

However, the direst consequences can occur when the same expression has different meanings. One example that can influence business meetings is the meaning of tabling a discussion. In the UK to table a discussion means to introduce a topic for discussion at the meeting. In the U.S. tabling a motion or topic is used to defer discussion or action for a subsequent meeting. In fact I recall it was during some of my first STLE meetings in which I finally realized how the term was being used differently.

Given the pitfalls that can occur between parties using ostensibly the same language, imagine the potential problems that can occur when communicating between different languages. Business and cultural differences can introduce a further layer of complication. The STLE-sponsored Emerging Trends report confirms that globalization will continue to have a dramatic influence on our industry. Around 20% of our members reside outside of the U.S. Furthermore, many members work for companies that operate globally, and some have significant operations around the world. As part of our Strategic Plan, STLE is creating opportunities to serve our increasingly global membership.

In the January TLT, Executive Director Ed Salek reported on recent events and meetings in China that I participated in. A number of enthusiastic local STLE volunteers presented a highly successful education program that was given in Mandarin for the first time. We also are partnering with a company that specializes in helping associations gain a foothold in different overseas locations. We now have a Chinese version of the STLE Website (www.stle.org.cn) and a local contact office in Beijing. In addition, we have formed a local advisory council that is helping STLE focus its local activities to benefit members and potential members in China.

Like the various versions of English used worldwide, there is much commonality in the needs of the global tribology and lubrication engineering community. It is already apparent that our Connect, Learn, Achieve value proposition resonates well and will form the basis for future events in China. We believe that our approach of engaging with local affiliated organizations and with local member volunteer support will help us avoid potential pitfalls.

This approach most likely will be taken in other countries as we expand our relationships outside of North America. Along the way we will make every effort to fully understand cultural differences and deliver meaningful information on membership benefits in ways that avoid misunderstandings.
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SOME OF THE BEST COMEDY IS PERFORMED WITHOUT WORDS—PANTOMIME. Originating in ancient Egyptian times, performers often relied on schadenfreude (deriving pleasure from the misfortune of others). Harlequin, one of the principle characters from the 16th Century Italian Commedia dell’arte, used a paddle composed of two pieces of wood that slapped together to create a powerful whack using little force. This type of paddle is referred to as a batacchio, which translates to slapstick.

Slapstick comedy, as it is now known, can depend on at least one universal truth: Watching someone else fall down, especially by their own doing, is always funny, and the most popular setup was explained by Cosmo Brown in the movie Singin’ in the Rain, “Just slip on a banana peel; the world’s at your feet.”

Bananas were first imported to New York in 1866 by Carl B. Frank. In 1876, at the first official World’s Fair to be held in the U.S., visitors to the Centennial International Exhibition in Philadelphia were exposed to this new food (wrapped in tin foil and sold for a dime), along with popcorn and Heinz ketchup. Within a few years it became a common street food, eventually replaced by another World’s Fair entry, albeit in Chicago in 1893—the hot dog. I know I digress, but isn’t it odd ketchup was invented before hot dogs?

With a surge in urban migration and a lack of sanitation regulation, people tossing garbage into the streets became a growing concern. Likely due to its large size and distinct color, the banana peel became a symbol of poor manners. By the turn of the century, relying on roaming pigs to dispose of organic matter was no longer reliable. Dan Koeppel’s book Banana: The Fate of the Fruit That Changed the World details the “first large-scale recycling effort in the U.S.” as a public agency headed by a former Civil War colonel, George Waring. His uniformed workers swept the streets of New York and disposed of the waste in public composting facilities.

Relying on the ingrained symbolism, Vaudeville comedians perpetuated the premise that one might still find a banana peel in one’s path, which guaranteed a fall was to follow. The self-proclaimed inventor of the banana-peel pratfall “Sliding” Bill Watson alleged he was inspired by watching a man struggling to maintain his balance after slipping on a peel. This gag was first immortalized on the silver screen by Charlie Chaplin in his 1915 film By The Sea, and later augmented in Buster Keaton’s 1921 film The High Sign, which saw him mockingly step over a banana peel only to slip on a second peel he did not see.

Some evidence suggests that the real slipping hazard in the days of poor sanitation was horse manure, and that the banana peel was simply a visual stand-in contrived for the stage. This has not stopped inquiring minds from performing experiments to confirm the validity of the premise that one can slip on a peel. After all, the June 30, 2002, issue of The Observer stated that Great Britain reported over 300 banana-related accidents in 2001 alone, so there’s got to be some truth in the matter.

The 116th episode of MythBusters, which aired in 2009, tried various experiments with both banana peels and lubricants to test the myth that a banana peel on the ground was guaranteed to cause a fall. The myth was declared busted, but only marginally, since a peel could still prove to be very slippery on a smooth enough surface.

In 2014 Kiyoshi Mabuchi’s team from Kitasato University was awarded the Ig Nobel Prize in the physics category for their paper Frictional Coefficient under Banana Skin, which determined that the coefficient of friction between a banana peel and common floor material is at 0.07 (epidemiological research states the risk of fall exceeds 90% if the frictional coefficient is lower than 0.1). They estimated the dominant factor was the polysaccharide follicular gel (also found in membranes where our bones meet), which becomes a homogeneous sol (a fluid colloidal system) after the peel is crushed. So a fall is possible, just not probable.
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THE EUSTACHIAN TUBE is a narrow passage leading from the pharynx to the cavity of the middle ear, permitting the equalization of pressure on each side of the eardrum. Thank you, Wikipedia, for that definition to get us started on a column that might seem to be veering off on a personal tangent. Bear with me, please.

When one’s Eustachian tubes are working properly, life is good (and so is our hearing). When they are not working properly, we experience muffled hearing and a desire to “un-pop” our ears in order to relieve that annoying rushing sound. Simple things like yawning or chewing gum usually correct the situation. However, after flying home to Chicago a few weeks ago, I experienced this problem and repeatedly tried all the normal remedies. When the conventional treatments didn’t work, I visited our trusted family doctor. This is where things get interesting, especially for those not all that concerned about the state of my Eustachian tubes.

The doctor reassured me that there was nothing serious wrong and gave me some guidance on how to deal with my ear issues. Things improved in about 24 hours. But it was his visual demonstration that created the “a-ha” moment for me.

In addition to telling me about the problem and the solutions, my doctor gave me a quick visual tour of the affected body parts courtesy of an elegant color illustration that he called up via a search engine on his computer. The 16th Century Italian anatomist Eustachius, who inspired the Eustachian tube name, would have been amazed!

This personal experience connects back to a discussion about communications strategy that took place during the STLE winter board of directors meeting. As part of this two-day event, directors participate in a generative session that’s designed to give the group time to think out loud about issues affecting the organization.

At this most recent session, a primary topic was rapidly changing expectations concerning communication and access to information. One of our directors shaped the discussion by talking about the importance of using an illustration, a video or some other form of visual communication to quickly explain a concept—very much like my doctor did to demonstrate the purpose of a Eustachian tube.

STLE’s Website (www.stle.org) has the potential to deliver this sort of experience. Headquarters staff is working with a team of Web content and navigation experts to provide for much greater integration of visual images that are searchable or readily available on the Website. It’s not difficult to see the many applications: to make a point when meeting with a customer, to illustrate a concept for students at a STEM camp or to inform someone who is simply curious about how a lubricant works or why friction can be both good and bad.

Keep your eyes open for more on this expanded functionality in mid-2016.
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### PERFORMANCE PROPERTIES

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- Imparts superior thermo-oxidative stability
- Acts as a bridging solvent - reduces opaqueness
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### IMPROVING THERMO-OXIDATIVE STABILITY

These curves compare five lithium 12-hydroxystearate greases made with different base oils and base oil blends. Oxidation initiates almost immediately at 180°C for the greases made with Group III and PAO.

A small introduction of alkylated naphthalene **NA-LUBE KR-015** into the PAO shows excellent improvement.

50/50 NA-LUBE KR-015 and PAO shows no oxidation after 40 minutes at 180°C under these conditions.

### Formulation Performance

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>93% KR-015</th>
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<td>233°C</td>
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**PDSC - ASTM D 5483**

(500 psi O₂, 180°C)

![PDSC graph](image)
New high-temperature solid lubricant coating

Invented by NASA, PS400 exhibits superior dimensional and oxidation stability.

SOLID LUBRICANTS ARE USED IN EXTREME OPERATING APPLICATIONS where conventional liquid film lubricants cannot provide the lubricity, chemical resistance and corrosion protection required. Among the main types of solid lubri- cants are graphite, molybdenum disulfide and polytetrafluoroethylene.

But these traditional solid lubricants do not exhibit thermal and chemical stability under vacuum conditions, in atmospheric air and in hydrogen. A previous TLT article discusses a new technique for combining two or more solid lubricants to, it is hoped, maxi- mize their benefits and minimize their deficiencies. A heterostructure based on graphene and tungsten disulfide was prepared using a scotch-tape method that literally places one material on top of another.

Another approach that differs from the layered structure is to form com- posites by depositing coatings made from mixed materials.

STLE Fellow Dr. Christopher DellaCorte, senior technologist, Tribology and Rotating Machinery at NASA’s Glenn Research Center in Cleveland, says NASA has developed three distinct families of solid lubricant composite coatings since the 1970s. DellaCorte also is editor of Tribology Transactions, STLE’s peer-reviewed journal.

Says DellaCorte: “The first solid lubricant coating known as PS100 is based on a nickel chromium glass composite that is a soft coating, which was used successfully in the high temperature environment of turbine engines.”

But in the 1980s, a harder binder matrix material was required for use in the high-speed turbine engines. “At that time we developed a nickel-cobalt chrome carbide composite known as PS200 that proved to be effective but had problems with abrasion against soft-metal alloys,” says DellaCorte.

This led to the preparation of the third family known as PS300 that involved using an inexpensive nickel-chromium binder in combination with a chrome oxide hardener. DellaCorte says, “Chrome oxide is not as hard as the chrome carbide used in the second coating family enabling PS300 to be used with softer metals in turbocharger and turbine engine applications.”

But PS300 had some operating deficiencies that included a lack of dimensional stability.

Coatings prepared with PS300 also grew in thickness after 5,000 hours of operating life that unfortunately led to the jamming of clearances in some applica- tions. Thickness levels increased by as much as 7% after exposure of the coating in air to temperatures in excess of 500 °C.

DellaCorte says, “This problem was circumvented through 100 hours of heat treatment in air followed by a final grinding of the coating. But the need to do further processing added...
manufacturing cost and limited potential applications for PS300."

A need existed for a fourth coating family to provide better performance than PS300. Such a solid lubricant coating now has been developed.

**NICKEL MOLYBDENUM ALUMINUM BINDER**

DellaCorte, in collaboration with Brian Edmonds, has now developed a fourth solid lubricant coating known as PS400 that exhibits superior dimensional and oxidation stability compared to PS300. "Incorporation of a nickel-molybdenum-aluminum binder in the coating leads to better creep resistance and an improved bonding to the substrate," says DellaCorte. "Chrome oxide is included in the new solid lubricant coating to contribute strength and wear resistance. The final component is a eutectic mixture of barium fluoride and calcium fluoride blended with silver to act as high and low temperature solid lubricants, respectively."

A common approach for preparing and applying the coating is thermal spray deposition. The individual components can be mixed as powders in a suitable container prior to spray deposition. Once a uniform mixture is achieved, the powder is injected into an argon gas carrier stream that is then subjected to ionized argon gas that provides the temperature needed to melt the powder. Application of the melted powder follows to produce a coating that has a typical thickness of 300 microns.

One of the additional benefits of PS400 is a reduction of the solid lubricant content from 10% to 5% compared to PS300. DellaCorte says, "The decrease in solid lubricant actually improves the new coating’s high temperature strength and could possibly improve its surface finish. The cost of the solid lubricant also is reduced without sacrificing performance. A high volume application can cut the cost of the solid lubricant powder by 20%.

DellaCorte also points out that PS400 can be applied not only by thermal spray deposition but by all commercially available techniques. Tribological testing is conducted on the nickel-based superalloy, Inconel X-750. DellaCorte says, “This alloy is commonly used in foil gas bearings that are being tested in advanced oil-free turbomachinery systems.”

Evaluation of a PS400 shaft coating in a hot section foil bearing contained within a microturbine engine involved 2,200 start-up and shutdown cycles conducted over 8,000 hours of operation at 96,000 rpm and a temperature of 540 C. The shaft was then disassembled and inspected. DellaCorte says, "The coating changed in appearance to a smoothly polished surface that is ideal for strong tribological performance under these extreme temperature conditions. Improved wear performance also is observed as compared to PS300."

Figure 1 shows an engine shaft from a Capstone Microturbine C30 engine coated with PS400 on the surface of the journal shaft.

Besides foil bearings, DellaCorte envisions that PS400 can be used in high temperature components such as furnaces and conveyor bushings. He says, "We believe that PS400 represents a starting point for industrial applications and not the ultimate high temperature coating."

DellaCorte indicates that NASA is interested in licensing the PS400 technology. He says, “Interested parties can contact Amy Hiltabidel, NASA technology manager at amy.hiltabidel@nasa.gov.”

Additional information can be found in a past article2 or by contacting DellaCorte at christopher.dellacorte@nasa.gov.

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**REFERENCES**


Using metal powders as a fuel source

Iron holds the most promise due to its availability, low cost, combustion properties and capacity to be recycled.

THE SEARCH FOR ALTERNATIVE FUELS TO PETROLEUM HAS LED RESEARCHERS to evaluate biofuels, hydrogen and batteries. Each of these options has shown promise but also has operational problems that have not been overcome.

For example, hydrogen is inherently very flammable and difficult to handle. Refueling with hydrogen can potentially lead to explosion hazards. In a previous TLT article, a safer hydrogen storage material known as ammonia borane was discussed. Ammonia borane is a solid material that has a hydrogen density of 19.6%. The article details a new process for converting ammonia borane to hydrogen using a ruthenium catalyst at elevated temperatures without forming byproducts that can be detrimental to the use of hydrogen as a fuel. Batteries are convenient but heavy and take up a lot of space to deliver the same energy as hydrocarbon fuels.

An alternative option is the use of metals, which are the fuel within batteries, as recyclable fuels. Jeffrey Bergthorson, associate professor of mechanical engineering and associate director of the Trottier Institute for Sustainability in Engineering and Design at McGill University in Montreal, Quebec, Canada says, “Metal powders have been known to burn for a long time and are used in fireworks and as propellants. Two applications are in fireworks and as propellants. One very prominent application is the use of aluminum powder at a 16% concentration in the propellant for the space-shuttle solid rocket boosters.”

Research on metal powders has been ongoing at McGill for some time. Bergthorson says, “The group has been evaluating metal powders for use in military applications and also at investigating safety concerns regarding the potential combustion of powders used in industrial processes.”

There are two ways for extracting energy from metal powders. Bergthorson says, “One option is to react metals with water to generate hydrogen. This process is not efficient because the amount of energy captured in the hydrogen is less than the total usable energy stored in the metal. The problem is that, in most cases, the heat produced as a byproduct of the reaction is at low temperatures and is not usable for generating power. The second option is to directly burn the metals with air to produce heat for an engine, just like fossil fuels are used for today in everything from cars to coal-fired power plants.”

One idea that was proposed about 10 years ago was using metal powders as the fuel for an internal combustion engine. Bergthorson says, “We were approached by one of our research partners to explore the concept of using metal powders as a fuel for automobile engines. The problem with this approach is that metal oxides, which are

Metal powders can be used as a fuel in external combustion engines but are not suitable in internal combustion engines.

KEY CONCEPTS

- Metal powders have potential to be used as fuels.
- The challenge is finding the right metal that can efficiently burn and also form big metal oxides upon combustion that can be collected and recycled.
- Iron is the most promising metal to be used as a fuel because of performance and economic considerations.
METAL COMBUSTION PROPERTIES

The rationale for this approach is the potential for developing a metal fuel cycle, powered by clean energy. Bergthorson explains, “Metal powder will be oxidized into solid metal oxides and hydroxides during its use as a fuel in order to produce motive or electrical power on demand. The byproducts, which are oxides of the metal, can be converted back into metal fuel through the use of clean primary energy sources such as solar and wind power. In effect, this process is analogous to charging and discharging a battery, but the “combustible battery” is very compact and lightweight since only the metal fuel needs to be carried. The metal can be filled into a tank at refueling stations just like gasoline or diesel. In this way, the metal becomes a type of recyclable coal. This recyclable fuel can be traded globally, to move clean energy from where it is produced to where it is needed, and can be stored for long periods of time.”

While it has long been known that metals can be burned, our understanding of their combustion properties lags far behind that of our more-common fuels. In general, the rate of oxidation is limited by the ability of the oxidizers to physically get to the metal surface. Bergthorson says, “To be effective as a fuel, a metal must have a high surface to volume ratio either in the form of a particle or a droplet. Ideally, metal particles must have a diameter in the micron size range to efficiently burn.”

But the combustion process for each metal can differ. Bergthorson says, “Aluminum burns with air at 3,000 °C but produces very small aluminum nano oxides that are difficult to collect and reprocess. Iron burns at 2,000 °C, close to the temperatures of typical hydrocarbon flames, and produces bigger oxide particles that are easier to handle.”

Figure 2 shows a comparison between a hydrocarbon flame on the left and an aluminum flame on the right. The ability to use a metal as a fuel is based on how combustion occurs. Bergthorson says, “A key factor is whether a metal will burn as a vapor or as a solid/liquid. For particles whose temperature of combustion is higher than the boiling point of the metal, the metal droplet will burn with a vapor-phase flame surrounding it similar to that for hydrocarbon fuels. In this case, very small metal oxides are formed that are difficult to capture. If the flame temperature is lower than the metal boiling point, the combustion process will occur heterogeneously as a gas-solid/liquid reaction at the surface of the metal particle/droplet. Metals such as iron that burn and produce a solid (porous) metal oxide on the surface of the particle will result in relatively large metal oxide products that are easier to capture for recycling.”

Another factor that the researchers are examining is burning velocity. Bergthorson says, “Burning velocity is a measure of how quickly the combustion reaction occurs. A faster rate is desired to facilitate flame stabilization in a compact combustion system. Metal powders will exhibit high burning velocities if they have small enough particle size and high enough concentrations. But more work is needed to optimize the parameters.”

Bergthorson says, “The most promising metal for use as a recyclable fuel at the moment is iron because it is readily available, has a low cost relative to other metals, produces combustion products that facilitate capture and can be recycled using green energy and existing technologies.” Additional information on the concept of using metal powder as a fuel can be found in a recent review article2 or by contacting Bergthorson at jeff.bergthorson@mcgill.ca.

REFERENCES


Figure 2 | Metal powders such as aluminum can undergo combustion (see flame on the right) and are under evaluation as alternative fuels to hydrocarbons (see flame on the left). (Figure courtesy of McGill University.)
THE CONTINUING EFFORT TO IMPROVE THE PERFORMANCE AND EFFICIENCY of machinery is leading researchers to develop new lightweight alloys and also techniques for better understanding how the structure of these alloys correlate with their physical and mechanical properties and ultimately their performance. For example, much attention has been paid to working with non-ferrous alloys in automobiles in an effort to improve their fuel economy.

A previous TLT article discussed how the presence of oxygen in titanium causes the metal’s physical properties to decline. Typically other components known as solutes are added to metals to improve their properties. In the case of titanium, researchers found that oxygen can accelerate the formation of extra spaces in the metal lattice known as dislocations. This phenomenon causes tangling leading the titanium to become more vulnerable to cracking.

A class of metal alloys that continues to be widely used in many applications in the energy, manufacturing and transportation industries is cast iron. This metal has been used since the 17th Century through a casting process, which involves the use of molten iron and solutes including carbon, silicon, manganese, sulfur and phosphorus. Carbon in particular is a very important solute because its presence will improve the alloy’s hardness and strength but too much will increase the brittleness of cast iron.

Dr. Dileep Singh, group leader of thermal-mechanical research at Argonne National Laboratory’s Center for Transportation Research in Argonne, Ill., says, “The amount of carbon added to iron in the preparation of cast iron controls fatigue, strength and thermal properties. The size and morphology of the graphite phase, resulting from carbon additions, in cast iron has been found to be very important in determining the properties of the alloy formed.”

Making the process more difficult is that the typical method for examining the microstructure of cast iron is using two-dimensional optical microscopy or scanning electron microscopy imaging. Singh says, “The problem with the two-dimensional analysis is that examination of a cross-section of the cast iron does not reveal complete information about the shape and size of the graphite particles formed when the alloy is produced.”

A new technique is needed to analyze cast iron in order to better correlate its microstructure with its properties. Such a technique now has been developed.

SYNCHROTRON X-RAY ANALYSIS
Singh and his colleagues are using synchrotron x-ray analysis at the Advanced Photon Source at Argonne to develop a three-dimensional image of cast iron alloys. He says, “We prepared a sample...
of a cast iron alloy that is two millimeters in diameter and 20 millimeters in height and then conducted a three-dimensional analysis of several segments. A series of radiographic images are taken at 0.2-degree intervals as the segment under evaluation undergoes a 180-degree rotation.

The researchers are able to stitch all of these images together in a similar manner to a CT scan to provide a three-dimensional, volume analysis of the microstructure. The alloy studied is a compacted-graphite iron (CGI) that is used by one of Argonne’s industrial partners in the preparation of heavy-duty engine components.

The value of using x-rays is that they can clearly identify the components in the cast iron graphite microstructure. Singh says, “There is a clear absorption contrast between the graphite and iron in the microstructure. Graphite absorbs less x-ray energy that translates into a darker image as compared to iron, which is brighter.”

Figure 3 shows a three-dimensional model of the graphite particles in the CGI alloy studied. This image shows that synchrotron x-ray analysis can determine the morphology and size distribution of the graphite particles.

Singh says, “Two-dimensional analysis of cast iron does not provide a complete representation of the size and physical shape of the graphite particles present. Our approach can determine if a specific graphite particle is a nodule as opposed to being a CGI.”

For this particular alloy, the researchers found that the nodularity of the sample is 35% and the average diameter of nodular graphite is 12 microns. Singh is hopeful that synchrotron x-ray tomographic analysis can rapidly determine the real 3D structure of cast iron alloys, unlike current time consuming 2D sectioning techniques. He says, “We are hopeful that users of this technique will be able to use the structural information to develop the best possible cast iron alloy for their applications.”

Singh is interested in using synchrotron x-ray analysis to examine the structure of other alloys for structural applications in automotive and aerospace. Additional information can be found in a recent article2 or by contacting Singh at dsingh@anl.gov.

REFERENCES

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Daryl Foley

This manager for Total Lubricants discusses sales dynamics, working in Europe—and why making grease is like Mom’s pie.

DARYL FOLEY – The Quick File

Daryl Foley is the grease manager for Total Lubricants in Paris, France. He has worked in the automotive, motorcycle, heavy-duty and industrial lubricants industries for more than 18 years. Foley previously worked for American AGIP Co. (Eni) in Hainesport, N.J., from 1996-2006 and also was a worldwide general manager (industrial) for Bel-Ray Co. in Farmingdale, N.J., from 2006-2008. Before joining Total Lubricants in Paris, he was vice president of industry and technology for Total Specialties USA in Linden, N.J., from 2008-2014.

Foley received his associate’s of applied science degree in sales and marketing from Camden County Community College. He also received his bachelor’s of science degree in organizational management from University of Phoenix.

In Foley’s spare time he likes to golf, fish and play sports including baseball, tennis and basketball. He also has an interest in motorcycles. Foley lives with his wife and two sons in Garches, France.

TLT: What was your first job in the lubricants industry?

Foley: I answered an advertisement out of a local newspaper for a salesperson and got a job with American AGIP Co. (Eni) as a territory salesperson.

TLT: You’ve had a lot of hands-on experience working with lubricants in the field. Has this been important to your career? How has this helped your career?

Foley: Before starting in the lubricants industry I held two jobs that very much involved the use of lubricants. While going to school I worked part-time as an auto mechanic at a local repair shop and also had a hobby of rebuilding and upgrading old cars and motorcycles. At the same time I held a job as a drill rig operator and mechanic for a local geotechnical engineering firm. Both of these jobs involved the use and understanding of lubrication.

My automotive experience taught me about the importance of lubricants in relation to the maintenance and care of automotive and heavy-duty engines, transmissions and pinion gears. As a drill rig operator I was responsible for the maintenance of my rig and others in our fleet; I was experienced with lubricants and we saved money by doing routine maintenance in-house.

Grease and anti-seize compounds were vital to the operation of a drill rig. It was necessary to apply grease or anti-seize compound to each auger or piece of drill rod before we added it to the rig, so we could disassemble it after we completed a test boring. When the level of lubrication was better—in this case anti-seize compound on the parts of the drill—the operation was more efficient and there was less wear and tear on vital parts of the equipment. The mechanical parts of the rig required constant lubrication in certain demanding operations. We constantly applied lubricant to the main drive and Kelly bar in the rig to prevent wear due to the sliding motion of the rig when the drill rod was pulled up or pushed down.

These experiences have had a big impact on my career because they taught me which characteristics/selling features and benefits are important to end-user customers. I also believe it gave me the ability to speak to all levels of staff and truly understand their constraints, demands and needs. By education I am not a chemist or engineer, but I am able to comprehend complex...
performance demands of machinery and how lubricants satisfy mechanical performance demands in the field.

**TLT: How did you become interested in grease?**

**Foley:** I find grease to be the most interesting part of the lubricants product range for many reasons. From a manufacturing standpoint it is like making Mom’s pie, meaning a grease maker is an artist and can produce a superior product by combining their expertise with select ingredients. I think the complex nature of grease is very interesting. Making grease involves much more than just blending base oils and additives. It takes a lot of skill to create unique and complex chemistries in general. However, when it comes to greases, chemists combine special raw materials and react them to form a thickener, which is like a network in the oil that gives grease its semi-solid consistency. Then we adjust each batch with base oil and additives to meet performance specifications.

**TLT: Do you have a favorite grease?**

**Foley:** I get a lot of satisfaction from selling calcium sulfonate complex greases (CSCGs) because they are a unique technology and provide special benefits to our end-users. They are unique because they are formulated with not one but two thickeners. We formulate CSCGs with gelled calcium sulfonate (like in calcium sulfonate grease) plus soap-type thickener (like in calcium grease). When we mix these two thickeners they form a special structure inside our CSCGs. This provides many benefits: excellent water resistance, good extreme pressure and antiwear properties, high dropping point and good shear stability. Our customers like to use our CSCGs in steel-making applications, pulp and paper mills, mining and construction equipment, automotive applications, etc. We formulate certain CSCGs for low-temperature applications such as mining. We even have a special line of CSCGs that are registered for food-grade applications. They are very popular in the food and beverage, pharmaceutical and personal care product industries.

**TLT: How did you become interested in sales?**

**Foley:** I like to talk to people and I am a very social person! Many friends and
colleagues will smile when they read this. I like working in sales because it gives me unlimited opportunities to sell, help customers and earn my living. I also love to study the psychology of selling. This means figuring out the reasons that people buy products.

**TLT: What have you learned about sales and selling?**

**Foley:** Customers buy for millions of different reasons. I’ve learned that there is a common thread—the law of self-interest. In some cases customers are motivated to buy products that bring the most benefit to their employers. Sometimes there are other factors such as brand loyalty and cost management. Sometimes you just never know what motivates certain customers.

As a salesperson you must determine as quickly as possible the self-interest of the buyer and present your product or service in a way to sway them and convince them to buy from you. If it’s not possible to provide what the customer needs, then it’s important to leave a good impression and an open channel for the customer to contact you in the future. Also in sales it’s important to pursue as many opportunities as possible; it is a numbers game! After many years of selling lubricants and greases, this is my perspective.

**TLT: What characteristics or behaviors are important for someone to succeed in a sales career?**

**Foley:** Successful sales reps are approachable, perceptive and creative with a relentless hunger to achieve and succeed.

**TLT: What have you learned working for multinational versus domestic companies? Is one easier than the other?**

**Foley:** I have learned many things from working for these two types of companies. When it comes to multinational companies I think for the most part they are more formal and not as agile, but they have tremendous access to resources. You may have a larger range of global human resources and perspectives that broaden the capacity to be competitive on a global—not just a local—scale.

In the U.S. domestic companies must be aggressive because they operate in a competitive environment. Domestic companies tend to be relatively flat, which allows for making quicker decisions and taking more risks. As an employee working in a domestic company you may feel more comfortable, but you may be a bigger fish in a smaller pond. Working in an international firm provides opportunities to learn about global markets, which can be enlightening and open new perspectives. I think that working for domestic or multinational companies can be equally challenging.

**TLT: You’ve been working in Paris this year. What has this been like? Do you miss anything special about working in the U.S.?**

**Foley:** When I arrived in Paris I had only a basic knowledge of the French language. It’s been challenging, but I’ve been improving my ability to understand and speak French. The working environment at my company is great. In France the working environment in some companies tends to have a hierarchical feel. This may have historical roots in French culture.

Americans often perceive the European working environment as easy with long lunches, vacations and short working hours. This is far from reality; I find that the work day tends to be longer than in the U.S. So long vacations are well deserved. Employees are expected to use all of their vacation time. In contrast, I think employees tend to be hesitant about taking their vacation time in the U.S. Working for Total Lubricants, I have learned that it is truly challenging to work as a manager in a global organization, and I appreciate that it is critical to have a diverse staff to be effective in global markets. My employer takes very well-planned steps to ensure that the work force is diverse and this becomes more and more important every day.

**TLT: You have had many experiences riding motorcycles. Do you have a favorite bike? A favorite road or place to ride?**

**Foley:** My favorite motorcycle is the Ducati Desmosedici RR. This is a true piece of engineering brilliance. It is like riding a MotoGP bike, a true racing bike that is legal to ride on the road.

As for my favorite road or place to ride, I still find that the Tail of the Dragon in Deals Gap, N.C., is one of the most beautiful, challenging and motorcycle-friendly roads in the world. Riding down this Smoky Mountain road that has 318 curves over 11 miles of road is a challenge that every motorcyclist should try to carefully experience at least once! TLT

You can reach Daryl Foley at daryl.foley@total.com.

Dr. Mary Moon volunteers as a TLT technical editor and treasurer of the STLE Philadelphia Section. She is a physical chemist with hands-on R&D and management experience in the lubricants industry and she writes professionally for lubricants industry publications. You can reach her at mmmoon@ix.netcom.com or (267) 567-7234.
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The following are descriptions of the four technical certifications:

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STLE’s signature certification is held by more than 1,500 lubrication professionals and remains the industry’s standard for technical excellence. Independent studies show that CLS-certified professionals earn more money, supervise larger staffs and are more likely to receive raises. Designed for technical specialists, CLS also is held by hundreds of sales and marketing reps.

**Certified Oil Monitoring Analyst™ I & II (OMA I and OMA II)**
STLE’s OMA certification is for the predictive maintenance professional and demonstrates proficiency in sampling and analyzing oil properties. OMA I is for the individual taking the oil sample on the shop floor. OMA II is for the person responsible for running the proper tests, interpreting data and managing the lubrication program.

**Certified Metalworking Fluids Specialist™ (CMFS)**
STLE’s CMFS certification verifies knowledge, experience and education in this growing and specialized field. CMFS is for individuals with responsibility for metal-removal or forming management, application and handling of metalworking fluids and related materials.

**CLS**

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Advanced Lubrication Specialties

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PetroChoice

Lukas Andresen  
Caterpillar Motoren GmbH & Co. KG

Ewald Badisch  
Austrian Center of Competence for Tribology

Steffen Basner  
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American Chemical Technologies

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IN THE JANUARY ISSUE OF TLT—AND TO A LESSER EXTENT FEBRUARY AS WELL—we talked about how water and oil can seem to mix or at least form very stable emulsions. We noted that there are all kinds of materials around us that derive some or all of their properties from the use of surfactants: engine oils, metalworking fluids (MWFs), certain other lubricants, a wide variety of face creams, lotions, conditioners and cosmetics, shaving cream, water-based paints and coatings, a wide variety of food products conjured by man and, in fact, almost anything that is a water-based non-solution.

As fascinating as that discussion was, it really only described the tip of the iceberg in terms of what is really involved in making a commercially viable product. So perhaps it will be of use to peel back another layer of the onion to see just what the formulator is faced with when given the assignment to make a particular emulsified product. The formulator will need to apply a mix of science and art, whether the formulator works in the food, cosmetics, pesticides, MWFs or other industry.

First, remember the surfactant is a molecule that typically has a long carbon chain tail with some kind of polar head attached, as shown in Figure 1.

There are literally hundreds and hundreds of emulsifiers to choose from, and, as we will see, they are not all alike. For example, the size and strength of the polar (hydrophilic or water-loving) head can vary as well as the size and strength of the hydrocarbon (lipophilic or water-hating) tail. To make matters worse, the nature of the polar head and hydrocarbon tail also can affect such properties of the final emulsion as:

- Toxicity
- Skin irritation
- Stability
- Resistance to salts
- Acids or alkalis
- Ease of manufacture
- Ease of dilution
- Storage stability
- Whether you get a water-in-oil or oil-in-water emulsion.

Added to that partial list, of course, is cost. Further, the material to be
emulsified will have certain inherent properties that also will affect the decision on which emulsifier to use. Finally, most emulsified products will use more than one emulsifier. Thus, it is easy to see why there are so many commercially available emulsifiers on the market, even from a single company.

So what is the poor formulator to do? The first step is to define what the final product is supposed to do (what it is used for?) and what constitutes a satisfactory emulsion (what properties must the emulsion have?). Additionally, such factors as those listed previously such as storage conditions, temperature in use, viscosity, whether you get oil-in-water or the opposite, etc., are not only listed but defined and specified. Further, the methods for testing to determine whether those properties have been achieved and the necessary quality assurance requirements must all be defined and specified as well. Once this step is completed, many potential emulsifiers can be eliminated and certain chemical classes of emulsifiers will emerge as having the highest probability of success. The next part of the process is a blend of the formulator’s science and art.

Table 1 | Emulsifiers and Their Published HLBs

<table>
<thead>
<tr>
<th>Emulsifier</th>
<th>HLB value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycerol monostearate</td>
<td>3.8</td>
</tr>
<tr>
<td>Diglycerol monostearate</td>
<td>5.5</td>
</tr>
<tr>
<td>Tetraglycerol monostearate</td>
<td>9.1</td>
</tr>
<tr>
<td>Succinic acid ester of monoglycerides</td>
<td>5.3</td>
</tr>
<tr>
<td>Diacetyl tartaric acid ester of monoglycerides</td>
<td>9.2</td>
</tr>
<tr>
<td>Sodium stearoyl-2-lactylate</td>
<td>21.0</td>
</tr>
<tr>
<td>Sorbitan tristerate</td>
<td>2.1</td>
</tr>
<tr>
<td>Sorbitan monostearate</td>
<td>4.7</td>
</tr>
<tr>
<td>Sorbitan monooleate</td>
<td>4.3</td>
</tr>
<tr>
<td>Polyoxyethylene sorbitan monostearate</td>
<td>14.9</td>
</tr>
<tr>
<td>Propylene glycol monostearate</td>
<td>3.4</td>
</tr>
<tr>
<td>Polyoxyethylene sorbitan monooleate</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Part of this elimination process also will involve the so-called Bancroft rule, which defines oil-in-water and water-in-oil emulsions. Remember in typical emulsions, there are tiny particles (discrete phase) suspended in a liquid (continuous phase). In an oil-in-water emulsion, oil is the discrete phase while water is the continuous phase. What the Bancroft rule states is that, perhaps contrary to common sense, what makes an oil-in-water or water-in-oil emulsion is not the relative percentages of oil or water but in which phase the emulsifier is more soluble. So even though there may be a formula that’s 60% oil and 40% water, if the emulsifier chosen is more soluble in water, it will create an oil-in-water system. Naturally there are some exceptions, but it’s a very useful rule of thumb for most systems.

The next step is to apply the so-called hydrophilic-lipophilic balance (HLB) system to the problem of emulsifier selection and formulation development. The HLB system was developed in the 1940s by William C. Griffin of the Atlas Powder Co., which later became the company we know today as Imperial Chemical Industries and is also a corporate member of STLE.

The HLB system enables the formulator to assign a number to the ingredient or blend of ingredients to be emulsified. Many ingredients have already published HLBs, and blends can be determined by calculation. However, if the HLBs have not been defined, they can be estimated by making a series of trial-and-error emulsions of HLB known emulsifiers to see which works best.

For example, suppose we wanted to emulsify a 65/35 blend of soybean oil and mineral oil to make an oil-in-water emulsion. We start with soybean oil, which has a required HLB of 7 and mineral oil, which has an HLB of 10.5. And our oil blend is 22% of the total formulation. Then:

- Soybean oil 0.65 × 7 = 4.55
- Mineral oil 0.35 × 10.5 = 3.67
- Blend 4.55 + 3.67 = 8.22

Oil-in-water emulsions use emulsifying agents that are more soluble in water than in oil (high-HLB surfactants). Water-in-oil emulsions use emulsifying agents that are more soluble in oil than in water (low-HLB surfactants). So we can also see how some ingredients, perhaps with a high HLB, may not make very good water-in-oil emulsions or at least will pose a more difficult problem for the formulator. Further, most emulsion systems tend to be blends of higher and lower HLB emulsifiers to get better stability. Most emulsifiers have published HLBs like in Table 1.

So let’s see how this might work. The first step is to define the HLB of the ingredient or blend of ingredients to be emulsified.
Thus, we need an emulsifier system that has an HLB of 8.22 +/- 1.

Suppose for example, we select these as emulsifiers:
- Glyceryl stearate [HLB = 3.8 ± 1]
- Polysorbate 80 [HLB = 15 ± 1]

We need to find a blend that will equal 8.22 +/- 1. So we calculate: 8.22 = (100-X%/100) × 3.8 + (X%/100) × 15. Thus, polysorbate 80 = X = 64% and glyceryl stearate = 100-X = 36%.

Coincidently our blend of emulsifiers is similar to the oil blend of 65/35.

So to build a formula, most systems contain a water phase, oil phase and a miscellaneous “stuff” phase. Now in our formulation we said our oil phase is 22% and let’s say, for example, the miscellaneous stuff phase is 3%. So what is the needed HLB at that concentration? We know that 22% of the formula is equal to 100% of the oil phase, and since the oil phase is 65% soybean oil and 35% mineral oil, X = conc. soybean oil = (65/100)/(22/100) = 14.3% of the formula, and (22% – X) = conc. mineral oil = 7.7%.

Now to determine the required HLB for the formula: soybean oil (HLB 7) = (14.3%/100) × 7 = 1.00 and mineral oil (HLB 10.5) = (7.7%/100) × 10.5 = 0.81. Thus, the required HLB is 1.81 for the formula or 1.81% of the formula will be our emulsifier blend.

This is where the art comes in. Remember part of the miscellaneous stuff phase also will compete for the emulsifier. So as a rule of thumb, we might start by using 2% of our emulsifier blend in the formula and mix and test for the needed stability. If it’s not the needed stability, we simply add a little more and retest.

This has been a pretty simplified explanation, but I hope you can see that the various emulsions we encounter in our daily life, including those formulated by Mother Nature and certain types of MWFs in particular, are a pretty sophisticated blend of science and art. 

Bob Gresham is STLE’s director of professional development. You can reach him at rgresham@stle.org.
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KEY CONCEPTS
- For PC-11s, high temperature/high shear viscosity is the main determinant in fuel economy performance.
- One of the primary challenges with lower viscosity fuel efficient lubricants is providing adequate engine protection.
- Analysis of used PC-11 oil is important to ensure the correct oil is being used and to monitor wear metals, an issue with PC-11B oils in older engines.

20 MPG in a heavy duty truck? It’s do-able.

IN 2010 THE NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION announced regulations to reduce the level of greenhouse gas (GHG) (CO₂) emissions and mandate fuel economy improvements for medium and heavy duty (HD) engines and vehicles (see Emission and Fuel Efficiency Targets). For on-road diesel vehicles, the new regulations—which are being phased in from 2014-2018—impose fuel-efficiency targets that are based on the vehicle's size and weight. Stricter GHG regulations will be enforced in 2017.

This article is based on an STLE University-sponsored Webinar presented Oct. 14, 2015, by Shawn McCarthy, an outside sales representative for Ocean State Oil. See Meet the Presenter for details on the Webinar and how you can download a version.

The American Petroleum Institute’s (API) Proposed Category 11 (PC-11) refers to a new generation of heavy duty engine oils that will facilitate compliance with the new regulations (see Links to PC-11 Information on page 31). The proposed date of first license for PC-11 oils is late 2016 and first availability is expected in December.
To comply with these new regulations, significant diesel engine design changes include:

- Diesel engine downsizing—15 L to 13 L
- Down speeding—1,600 rpm to 1,200 rpm
- Advanced combustion design
- Active oil temperature control
- Variable valve timing
- Start/stop technology

The new PC-11 diesel engine oils will play a pivotal role in supporting new design changes and complying with new regulations by enabling these design advancements, increasing fuel economy through lower viscosity grades and friction modifiers and improving engine durability through advanced additive formulations and careful base oil selection.

There is no fuel economy test for PC-11. Since the fuel economy savings will be derived primarily from lower viscosity oil, the challenge for oil formulators is developing low-viscosity oils that still provide the necessary engine protection (see Benefits of Low-Viscosity Oils on page 30). But oxidation stability will be the main performance upgrade because the oil also must be thermally stable in order to prevent oxidation, which leads to deposit formation and reduced fuel economy (see The Oxidation Process on page 31).

**EMISSIONS AND FUEL EFFICIENCY TARGETS**

- 2017 models must reduce CO₂ emissions by 10%-20% over their 2010 baseline.
- 2017 class 7 and class 8 trucks must save four more gallons of fuel for every 100 miles traveled over their 2010 baseline.
- EPA is targeting a 9%-23% improvement in fuel economy and carbon emissions for larger trucks and a 6%-9% improvement in vocational and medium-duty trucks.
- The national and global goal for fuel efficiency in HD trucks is an average of about 20 MPG in the next 15-35 years.

**PC-11 CATEGORIES AND TESTS**

For the first time, PC-11 will be split into two categories: PC-11A and PC-11B. Following are some specifics on each.

**PC-11 A**

- Licenses as API CK-4 on Dec. 1, 2016
- Is backward compatible with API CJ-4, API CI-4+, etc.
- Covers W-40 and W-30 viscosity grades
- Minimum 3.5 centipoise high temperature/high shear (cPHT/HS)
- Has the same limits on sulfur, phosphorus and sulfated ash as CJ-4
- Is compatible with after-treatment systems

**PC-11 B**

- Licenses as API FA-4 on Dec. 1, 2016
- Has limited or no backward compatibility—any backward compatibility depends on the OEM
- Covers only W-30 viscosity grade
- Has a viscosity range between 2.9-3.2 cPHT/HS
- Has improved fuel economy compared to API CJ-4 and PC-11A oils
- Has the same limits on sulfur, phosphorus and sulfated ash as CJ-4
- Is compatible with after-treatment systems

Right now there are nine engine oil tests; the first seven are legacy tests and
the last two, Volvo T-13 and Cat C13-A, are new (see Figure 1):

- **Cat 1N.** Tests for aluminum piston deposits.
- **GM 6.5L.** Tests for valve train wear.
- **Cummins ISB.** Tests for valve train wear.
- **Cummins ISM.** Tests for valve train wear, sludge and filter plugging.
- **Cat C13.** Tests for steel piston deposits in oil consumption.
- **Mack T-11.** Tests for soot dispersants.
- **Mack T-12.** Tests for ring liner wear, protection of lead alloy bearings and measures oxidation resistance.
- **Volvo T-13.** Tests for oxidation and bearing corrosion.
- **Cat C13-A.** Tests for aeration; PC-11 oils need to have better aeration properties to support new engine designs.

### BASE OIL AND BOI/VGRA

Base oil interchange (BOI) is the process of interchanging one base oil for another without having to test the formulation again as long as it has the same basic additive package. Viscosity grade read across (VGRA) is a guideline used to test a formulation in one viscosity grade and apply the results to a different grade without additional engine testing. This is helpful in streamlining multiple formulations. Both BOI and VGRA allow products to get to the market rapidly—benefiting formulators, OEMs and consumers. But there are two concerns with BOI and VGRA:

1. The test data may not support the in-use results, which can create a negative situation for the end-user.
2. The BOI can make it difficult to quantify highly refined oils. Lack of physical and chemical tests to measure the traits that improve performance in the engine have not been identified for BOI in highly refined oils.

PC-11 requires a high-quality, high-VI base oil in one of the three groups in Table 1.

- **Group II and III** are prevalent. Both groups have advantages over Group I and Group IV (synthetics) and over each other.²
- **Group II** oils have less sulfur, a higher VI, more saturates (better oxidation properties) and a clearer color than Group I. They also have better solvency (soot dispersancy), processing advantages and a lower cost than Group III.
- **Group III** oils have a better pour point, better oxidation and thermal stability, better cold crank performance and a higher VI than Group II. Some also have better additive solubility, antiwear performance, lubricity, pour point and supply and a lower cost than Group IV oil.

### PC-11 ADDITIVES

There is some overlap in additive systems for PC-11A and PC-11B. Most PC-11 oils typically include three primary classes of additives: VI improvers (may be most important), friction modifiers and antioxidants.

#### BENEFITS OF LOW-VISCOSITY OILS

- Approximate 1% fuel savings with SAE 10W-30 oils (over SAE 15W-40)
- Approximate 2% fuel savings with SAE 5W-30 oils (over SAE 15W-40)
- Engine oil drain and durability are equal to SAE 15W-40 engine oils in most cases.

### VI IMPROVERS

These account for 23% of all additive sales. They provide engine protection for low-temperature starts and high-operating temperatures and must have shear stability. The five basic functions of viscosity modifiers include:

1. Reducing viscosity changes with temperature
2. Enabling the engine to start at low temperatures
3. Ensuring engine durability during boundary layer lubrication regimes
4. Providing non-viscometric performance benefits
5. Providing protection and better operation for a secondary usage of engine oil including removing contaminants to the filter, preventing rust and corrosion and in some cases transmitting power.

<table>
<thead>
<tr>
<th>Base oil category</th>
<th>Sulfur %</th>
<th>Viscosity index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>&gt; .03</td>
<td>80-119</td>
</tr>
<tr>
<td>Group II</td>
<td>≤ .03</td>
<td>80-119</td>
</tr>
<tr>
<td>Group III</td>
<td>≤ .03</td>
<td>&gt; 120</td>
</tr>
</tbody>
</table>

![Figure 1](image-url) | The first seven engine oil tests are legacy ones and the last two, Volvo T-13 and Cat C13-A, are new.
For PC-11, high temperature/high shear viscosity is the main determinant of fuel economy performance (see Successes With PC-11).

**FRICTION MODIFIERS**

Friction modifiers (FMs) are crucial during boundary lubrication and reduce the effect of friction on the metal surface. They improve fuel economy of the oil and are an effective performance additive. There are two types of FMs—organic friction modifiers and metal-containing friction modifiers. Both have two segments: a polar group and an oleophilic group.

**ANTIOXIDANTS**

- Sacrificial antioxidants deplete over time. They include UV absorbers, peroxide decomposers, chain-breaking electron donors and chain-breaking electron acceptors.
- Primary antioxidants include phenolic or aromatic amines, chain-breaking antioxidants and free radical-absorbing antioxidants (able to stop more than one free radical).
- Secondary antioxidants include peroxide decomposers (ZDDPs).

In addition to the three primary categories, other major additives include dispersants, detergents, pour point depressants, foam inhibitors and antiwear additives. Following is the range of additive treat rates for HD engine oil:

- Ashless dispersants: 8%-12%
- VI improvers: 0%-10%
- Detergents: 2%-3%
- Antioxidants: 0.3%-1.5%
- Antiwear additives: 1%-1.5%
- Friction modifiers 0.1%-0.5%
- Others: 1%-2%.

**SOME CHALLENGES**

First of all, ZDDPs, while cost effective, contain phosphorus, which has a 1,200 ppm limit (800 ppm for gasoline engines). Ashless antiwear additives improve performance but have limited field results and may need to be supplemented with other additives. Formulators also need to convince end-users that low-viscosity oils perform as well

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**LINKS TO PC-11 INFORMATION**

The following Websites have good information about PC-11 and its integration into the heavy duty vehicle market:

- www.pc-11explained.com
- www.hddeo.com
- www.infineuminsight.com/expertise/heavy-duty-engine-oils
- www.whatispc-11.com

**SUCCESES WITH PC-11**

**Ryder.** Ryder recently switched its fleet of 200,000 trucks and tractors from SAE 15W-40 to SAE 10W-30. They expect 1.5% better fuel economy and a reduction of 110,000 metric tons of CO2 without changing any maintenance procedures.

**Infineum.** Infineum tested 2.1 cPHT/HS viscosity oil in a high-soot-producing Cummins ISX 450 HP. There were no significant differences compared to SAE 15W-40 in terms of oil consumption, used wear metals and parts consumption. They also reported that an engine using SAE 5W-30 with new additive technology in a Cummins ISX 450 successfully completed 1,000,000 miles.

**Shell.** Shell has logged in 22 million miles on 14 engines with PC-11 type oils. The longest running was 800,000 miles. One engine ran 500,000 miles with a 3.0cP 10W-30 oil. Drain intervals were 55,000 miles.

**DID YOU KNOW?**

- Transportation accounts for 41% of the total energy used in the U.S.
- In 2008 HD trucks accounted for 22% of greenhouse gas emissions in the U.S.
- There were 3.6 million class 8 trucks in 2015 with four million projected by 2026.
- Diesel fuel cost accounts for about 40% of the total cost of operating over-the-road class 8 trucks in North America.

**THE OXIDATION PROCESS**

Catalysts for the oxidation process include temperature, wear metals, water-free and dissolved contaminants, UV light and oxygen. There are three stages in the oxidation process:

1. Initiation (when the process begins)
2. Propagation (as the process intensifies)
3. Termination (when the process ends, either positively or negatively).

The consequences of negative reactions include corrosion and wear; an increase in oil viscosity; the formation of sludge and varnish; filter plugging; accelerated wear rates, higher operating temperatures; additive depletion; and base oil breakdown.
as SAE 15W-40 oils. Some PC-11s may no longer carry gasoline approvals, and end-users may need to stock additional oil inventory as they purchase new trucks (see Did You Know? on page 31).

These are all challenges, but ensuring that correct oils are used is a major challenge that, if not carried out, can have consequences leading to engine failure.

So what can be done to ensure that the wrong oil is not used? The primary tool is education. A number of Web-sites provide excellent resources (see Links to PC-11 Information on page 31). Another critical source of information is the oil label—on the container and/or the storage tank (see Figure 2).

**OIL ANALYSIS**

So what is all of this going to mean for oil analysis providers? Used oil analysis will be even more beneficial for two reasons:

- To ensure that the correct oil is being used
- To test for wear metals (low-viscosity PC-11s in older engines have the potential to cause premature wear).

The biggest concern end-users have is how well low-viscosity oils are going to hold up. Because of this and other factors, it will take the market a while to accept these oils. But lower viscosity oils are here to stay. CAT, John Deere, Volvo and Kenworth currently factory fill with SAE 10W-30, which is projected to gain 28% of the market share by 2021 and 50% of the market share by 2025 (see Figure 3).

According to the Shell PC-11 Website, if every truck increased fuel economy by just 1%, it would result in an annual reduction of four million tons of carbon dioxide emissions, the equivalent of removing 23,000 trucks from the road each year.
Figure 3  |  Fuel cost savings using PC-11 oils.

<table>
<thead>
<tr>
<th>ABC Company</th>
<th>Miles/Year</th>
<th>Fuel Costs/Yr (6 mpg, $4/gal)</th>
<th>CK-4 10W30 $$$ Savings/Yr (1% FE Rdctn)</th>
<th>FA-4 10W30 $$$ Savings/Yr (1.7% FE Rdctn)</th>
<th>CK-4 SAE 5W30 $ Savings/Yr (2% FE Rdctn)</th>
<th>FA-4 5W30 $$$ Savings/Yr (2.7% FE Rdctn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Class 8 Truck</td>
<td>125,000</td>
<td>$83333</td>
<td>$833</td>
<td>$1417</td>
<td>$1,667</td>
<td>$2,250</td>
</tr>
<tr>
<td>Fleet (50 Trucks)</td>
<td>6,250,000</td>
<td>$4,166,650</td>
<td>$41,666</td>
<td>$70,833</td>
<td>$83,333</td>
<td>$112,500</td>
</tr>
</tbody>
</table>


REFERENCES
2. PC-11s with synthetic base oil are expected to make up only a very small percentage of the PC-11 market, but as technologies evolve that may change.

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CHLORINATED PARAFFINS ARE THE MOST WIDELY USED EXTREME PRESSURE (EP) additive in the marketplace. They were introduced in the 1930s and are available in varying degrees of carbon chain length and chlorine content.1

Chlorinated paraffins are prepared from the reaction of chlorine with a paraffin or olefin of a specific chain length (see Figure 1). The current types of chlorinated paraffins are distinguished by chain length ranges and are shown in Table 1.

Regulation of chlorinated paraffins started in the 1980s with the reporting of a U.S. National Toxicology Program study on a specific short-chain chlorinated paraffin (SCCP) and long-chain chlorinated paraffin (LCCP). A historical perspective on the regulation of chlorinated paraffins can be found in a recent STLE Webinar2 that was summarized in the February 2016 TLT.

In 2012 the U.S. Environmental Protection Agency (EPA) required, via a consent decree, that the chlorinated paraffin producers submit premanufacturing notifications (PMNs) for medium- and long-chain chlorinated paraffins.3 As part of this arrangement, manufacturing and importation of SCCPs in the U.S. ceased. The metalworking fluid (MWF) industry had previously started to move away from this specific chlorinated paraffin chain in the mid-1990s when EPA ordered SCCPs to be subjected to Toxic Release Inventory reporting and mainly switched to medium-chain chlorinated paraffins (MCCPs).4

The PMN process in the U.S. enables EPA to review “new substances” that companies want to introduce commercially and be listed on the TSCA Inventory. EPA indicated that in 2012 the chlorinated paraffin suppliers agreed to have medium- and long-chain chlorinated paraffins treated as new substances under TSCA section 5.

The big concern for EPA is that the currently used CAS numbers on the end will probably end at some point in the future.

Combinations of alternatives are needed because no single alternative works in every case.

Will their use be restricted? And what are the alternatives?

Preparation of Medium-Chain Chlorinated Paraffin - (MCCP)

Figure 1 | Chlorinated paraffins are produced through the reaction of chlorine with a paraffin or olefin as shown for an MCCP. (Figure courtesy of Qualice LLC.)
Current Types of Chlorinated Paraffins

<table>
<thead>
<tr>
<th>Chlorinated paraffin type</th>
<th>Chain length</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCCP</td>
<td>C10-13</td>
</tr>
<tr>
<td>MCCP</td>
<td>C14-17</td>
</tr>
<tr>
<td>LCCP</td>
<td>C18-20</td>
</tr>
<tr>
<td>vLCCP</td>
<td>C21-30</td>
</tr>
</tbody>
</table>

TSCA database for chlorinated paraffins are too general (see Table 2). EPA believes that any chlorinated paraffins approved for use now and in the future must have CAS numbers with more specific chemical structure descriptions.

In 2012 and based on PMN submissions, EPA initiated a further risk assessment of MCCPs and LCCPs that was completed in November 2014. A redacted version of EPA’s risk assessment is now available through a link on the Independent Lubricant Manufacturer’s Association’s (ILMA) website. EPA’s preliminary conclusions are that MCCPs and LCCPs “present acute and chronic risks to aquatic organisms” and “may be very persistent and bioaccumulative.”

For these reasons, EPA in January 2015 gave chlorinated paraffin producers two options:

1. Stop selling MCCPs and LCCPs immediately.
2. Not produce or import MCCPs and LCCPs after May 31, 2016.

In effect, EPA will be impacting 99% of the chlorinated paraffins sold in the marketplace to the metalworking fluid industry. As part of a presentation from Dr. Maria Doa of EPA in September 2015, the agency has now decided to delay the stoppage of production and importation of MCCPs and LCCPs to mid-2017.

An important consideration is that no deadline has been established for when usage of MCCPs and LCCPs in the U.S. must cease. The metalworking fluid industry is waiting for EPA to develop a Significant New Use Rule (SNUR) to deal with the issue of critical applications for which acceptable substitutes are not available by the eventual ban date.

EPA is willing to obtain industry input on “critical uses” for MCCPs and LCCPs that might impact the agency’s final approach for dealing with these two additives. In December 2015, EPA published a notice in the Federal Register requesting new data for them to use in evaluation of the risk assessments for MCCPs and LCCPs. Interested parties were asked to respond back with data and/or comments by Feb. 22, 2016.

A coalition of industry organizations has now been organized to respond to EPA’s action in (1.) withdrawing the general CAS numbers and descriptions for the chlorinated paraffins now on the TSCA Inventory and (2.) requiring producers and importers to submit PMNs so that they can be placed back on the TSCA Inventory under more specific CAS numbers and descriptions.

There is general chemical industry concern that EPA may use this approach on other chemical substances currently used commercially. The lead industry organizations working with EPA are the American Chemistry Council and ILMA. They are proposing three alternatives for EPA to consider in dealing with MCCPs and LCCPs.

1. Complete the ongoing review of MCCPs and LCCPs under the TSCA work plan and if scientifically justified proceed with a TSCA section 6 rulemaking to impose disposal restrictions.
2. After an opportunity for industry input, promote an SNUR imposing appropriate disposal restrictions.
3. Obtain peer review of the draft risk assessment and issue a request for information on appropriate risk management controls for MCCPs and LCCPs.

As of the end of January 2016, the goal of the industry coalition remains to have EPA review MCCPs and LCCPs under the TSCA work plan and if scientifically justified proceed with a TSCA section 6 rulemaking to impose disposal restrictions.

As of the end of January 2016, it is unclear exactly what will occur except that the MWF industry should realize that use of MCCPs and LCCPs will probably end at some point in the future.

This means that MWF formulators must reformulate their products to replace MCCPs and LCCPs with viable alternatives.

**Table 1** | The current types of chlorinated paraffins are defined by specific chain length ranges. (Table courtesy of Chemical Solutions.)

<table>
<thead>
<tr>
<th>CAS #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>61788-76-9</td>
<td>Alkanes, chloro</td>
</tr>
<tr>
<td>63440-39-8</td>
<td>Paraffin waxes and hydrocarbon waxes, chlorinated</td>
</tr>
<tr>
<td>68920-70-7</td>
<td>Alkanes, C6 -18, chloro</td>
</tr>
<tr>
<td>71011-12-6</td>
<td>Alkanes, C12-13, chloro</td>
</tr>
</tbody>
</table>

**Table 2** | The currently listed CAS numbers for chlorinated paraffins on the TSCA database are very general in description. (Table courtesy of Chemical Solutions.)

<table>
<thead>
<tr>
<th>CAS #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1401974-24-0</td>
<td>Alkanes, C22-30, branched and linear, chloro</td>
</tr>
<tr>
<td>1417900-96-9</td>
<td>Alkanes, C21-34, branched and linear, chloro</td>
</tr>
<tr>
<td>1402738-52-6</td>
<td>Alkanes, C24-28, chloro</td>
</tr>
</tbody>
</table>

**vLCCPs Cleared by EPA**

**Table 3** | The CAS numbers for vLCCPs listed on the TSCA database are defined by much more specific descriptions. (Table courtesy of Chemical Solutions.)
alternatives. As a follow-up to a past article on chlorinated paraffins, the following companies were contacted again to provide updates on alternatives to chlorinated paraffins:

- Afton Chemical Corp.
- Croda Inc.
- DIC Corp.
- The Elco Corp.
- The Lubrizol Corp.
- Qualice LLC.

**vLCCP**

An example of EPA’s new approach on chlorinated paraffins is the recently commercialized very long-chain chlorinated paraffins (vLCCPs, see Figure 2). As shown in Table 1, vLCCPs cover chlorinated paraffins with chain lengths between C21 and C30. STLE-member James MacNeil, product manager for Qualice LLC in Hamlet, N.C., says, “The paraffins used to prepare vLCCPs cannot contain more than 1% of a carbon chain length below C21.”

The vLCCPs currently cleared by EPA and commercialized are shown by CAS number and description in Table 3 on page 35. These compounds are characterized by specific carbon chain lengths in contrast to the CAS numbers for the other chlorinated paraffins shown in Table 2.

MacNeil says, “vLCCPs are fully registered under TSCA and are not under EPA risk assessment at this time.”

While comparable to MCCPs and LCCPs in chemical composition, vLCCPs exhibit higher molecular weights and as a consequence higher viscosities. MacNeil says, “vLCCPs have higher viscosities than mid-chain and long-chain chlorinated paraffins at equal chlorine content due to the length of the carbon chain. The phenomenon is familiar to compounders of metalworking fluids as a similar effect occurs in base oils.”

Formulating with vLCCPs can present some new challenges to the metalworking fluid formulator due to their higher chain length. MacNeil says,
“vLCCPs have comparable solubility in oil for neat oil formulations as compared to MCCPs and LCCPs and also can be emulsified to create water-based metalworking fluids.”

An example of a sample emulsifiable oil formulation containing vLCCPs used at a treat rate of 10% is shown in Figure 3. MacNeil says, “We developed the formulation known as 94A with the additives shown using naphthenic oil as the base stock. The formulation is stable at a 5% dilution in 200 ppm and 400 ppm hard water as shown.”

MacNeil considers vLCCPs to be a useful tool for the MWF formulator to consider as an alternative to LCCPs and MCCPs. He adds, “Some care in formulating will be needed with the higher viscosity of vLCCPs. Though the higher viscosity of vLCCPs dictates that their maximum chlorine content be around 50% by weight as opposed to 60% for an MCCP, the difference is quite small in a formulated product. At a treat rate of 20% in a formulated metalworking fluid, the 10% difference in chlorine content translates into a 2% difference if both chlorinated paraffins are used at a treat rate of 20% in the formulation.”

**ALTERNATIVE CHLORINE-FREE EP ADDITIVES**

There are a number of alternative chlorine-free EP additives that can be substituted for MCCPs and LCCPs in the main metalworking fluid types (neat oils, emulsifiable oils and semisynthetic fluids) where chlorinated paraffins are used. Most of the respondents list the following types as possibilities:

- boundary lubricity additives (complex esters, polymeric esters and polyalkylene glycols)
- phosphorous containing additives (phosphate esters, phosphites and phosphonates)
- sulfur-based additives (sulfurized olefins, sulfurized fats, oils and esters)
- overbased calcium sulfonates.

One of the challenges faced by metalworking fluid formulators is making sure that under a given set of operating conditions the chlorinated paraffin alternatives will exhibit comparable performance. In assessing boundary lubricity additives and extreme pressure additives, formulators must realize that they operate within different temperature ranges as shown in Figure 4.

**BENEFITS**

Anthony Jarvis, R&D manager, global MWF product development for Afton Chemical Corp. in Manchester, UK, indicates that alternatives to chlorinated paraffins offer advantages such as having regulatory approval for use, being able to be biodegradable, having greater ease of disposal, having a more favorable image from an environmental standpoint and having no chloride-based corrosion issues that chlorinated paraffins can face during application.

In the latter case, Jarvis says, “Chlorinated paraffin alternatives do not liberate hydrogen chloride during use, which reduces fumes and staining.”

But these alternatives also have some disadvantages. Jarvis says, “Alternatives for chlorinated paraffins can be less flexible in terms of applications and the choice of carrier base stocks (mineral oils and water) used in formulating them, have more difficulty in developing stable formulations, have less hard water stability and be more expensive.”

STLE-member Ben Faber, metalworking product manager for The Lubrizol Corp. in Wickliffe, Ohio, says, “Chlorinated paraffins undoubtedly provide great extreme pressure lubrication, but there are other alternatives that do not have the associated environmental and regulatory concerns.”

Faber believes that by switching to chlorine-free alternatives, formulators can achieve greater flexibility with their fluids. Extreme pressure additives can be combined to activate at broader temperatures that allows fluids to be used in more applications. In general, phosphorus additives activate at a lower temperature and sulfur additives activate at a higher temperature relative to chlorine.

“As part of this flexibility, formulators also may be able to use lower treat rates of additives such as sulfurized olefins and polymeric esters,” says STLE-member Gabe Kirsch, metalworking product manager for The Lubrizol Corp. He continues, “Some chlorine replacement chemistries are more compatible with use in water-based fluids, especially polymeric esters and phosphorus additives. Some additives require no emulsifier whatsoever and can allow for synthetics with improved lubricity.”

One other advantage for chlorinated paraffin alternatives cited by Kirsch is...
fewer staining and residue problems. He explains, “Through the machining process, chlorinated paraffin residues can cause undesirable ferrous corrosion, which is often overcome with non-chlorinated additives. In addition, chlorinated paraffin residues are notoriously difficult to remove in some applications, whereas chlorine-free alternatives are typically easier to clean off of a surface.”

STLE-member Larisa Marmerstein, R&D chemist for Elco Corp. in Cleveland, says, “Besides an improved environmental profile, chlorinated paraffin-free alternatives when used in metalworking fluids can contribute better tool life and finish on metal parts, easier cleaning and the ability to keep the cutting tool cooler especially in an emulsifiable oil.”

The last benefit is seen in a 4-ball EP ramp test (ASTM D2783) where the load is increased from 10 to 160 kgf over a period of 20 minutes. No heat is applied during the test.

Marmerstein says, “We evaluated an emulsifiable oil based on a polymeric phosphate ester versus an emulsifiable oil based on a chlorinated paraffin. The temperature changes over the 20-minute time frame. Figure 5 shows that the temperature of the chlorinated paraffin-free alternative fluid is more than 10 F lower than for the chlorinated paraffin-based fluid by the end of the test. The gap between the two fluids is as much as 40 F more than halfway through the test.”

Hiroshi Sakata, manager polymer technical group for DIC Corp. in Chiba, Japan, believes that active and inactive sulfurized additives can provide benefits for formulators as chlorinated paraffin alternatives. He says, “For metal cutting applications, an inactive 30% sulfurized olefin can be effective in drilling, milling and turning operations in both neat oils and water dilutable fluids. In such metal forming applications as cold forming, stamping and fine blanking, the inactive 30% sulfurized olefin also can be effective. If the metal forming applications are compatible, a low-temperature, active 30% sulfurized olefin also can be useful because it performs well at keeping friction low over a wide range of loading.”

REPLACEMENT STEPS

STLE-member Mandi McElwain, lead application scientist-lubricants for Croda Inc. in New Castle, Del., provides guidance on how MWF formulators can move forward with replacing MC-CPs and LCCPs. She says, “Formulators can start by directly replacing the chlorinated paraffins they are using with one of the alternatives. The next step is to evaluate the performance of their chlorinated paraffin-free formulation with modern and meaningful test methods such as the Microtap and the Twist Compression Test.

Depending on the application, it may be useful to evaluate the performance with more than one metal. In our experience, when certain complex esters are combined with phosphate esters or sulfurized olefins, synergies are present. So the formulator could similarly evaluate formulations containing more than one EP alternative.”

For example, Figure 6 shows Microtap data from the evaluation of cutting fluids.
Additives to Transform Lubricant Technologies

DOVER CHEMICAL is helping industries transform their technologies to meet evolving global regulations and make products people need in a greener world. We offer metalworking formulators and blenders 12 additive chemistries to replace chlorinated paraffins:

Mayfree® 133 — Phosphated Amide
Doverlube® NCEP — Patented Nitrated Vegetable Oil
Doverphos® 253 — Phosphite Ester

High EP and AW performance
for difficult-to-machine metals and alloys

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oils containing various additives on 1018 steel using forming taps. The treat rate for the various additives is shown on the left. McElwain says, “We found in this specific study that the combination of a complex ester with a phosphate ester displayed 14% lower torque at a lower treat rate than a cutting oil formulated with chlorinated paraffin.”

Sakata focuses on replacing chlorinated paraffins with sulfurized additives. He says, “The most important difference between sulfurized EP additives and chlorinated paraffins is the operating temperature of these additives. Since chlorinated paraffins react with metal surfaces at lower temperatures than sulfurized additives (see Figure 4), chlorinated paraffins start to work at a lower treat rate than a cutting oil formulated with chlorinated paraffin.”

Sakata continues by recommending specific additives that can work synergistically with sulfurized additives. He says, “For neat oils, overbased calcium sulfonate is an additive typically used with sulfurized additives. In forming fluids, several kinds of additives such as sulfurized fatty additives, non-sulfurized fatty additives, overbased calcium sulfonates, phosphate esters, etc., are added. It is very important for metalworking formulators to know what kind of synergistic effect can be obtained by mixing several additives to replace chlorinated paraffin.”

Figure 7 contains a tapping torque study done comparing the performance of 30% and 40% active sulfurized additives at a treat rate of 2.5% with 50% chlorinated paraffin at a comparable treat rate. Sakata says, “We evaluated the cutting oils on carbon steel and an aluminum alloy used in die casting. With both metal alloys, the 30%, low-temperature active sulfurized additive displays superior performance compared to the 50% chlorinated paraffin and the 40% sulfurized additive.”

Faber offers five steps that a formulator should take to replace chlorinated paraffins in a specific application. He says, “The first step is for the formulator to find a lubrication test or tests that replicate the intended application. Then the next step is to identify the most effective chlorine replacement alternatives, and do not forget synergistic combinations of additives. In the case of water-based fluids, make sure that the emulsifier performance is balanced and the formulation makes a stable emulsion (adjust if necessary). The fourth step is to use laboratory bench tests to discriminate performance, and lastly lab tests should be confirmed with either in-house computerized numerical control machine testing or field trial testing that matches the intended application.”

Jarvis provides some guidelines for assisting formulators with replacing chlorinated paraffins. He says, “Generally if a system containing ≤10% chlorinated paraffin is being replaced, then for metal removal and forming processes this can be achieved with a reasonable degree of confidence. However, higher chlorinated paraffin-containing formulations become more difficult to predict.”

Jarvis continues, “Replacing chlorinated paraffins will probably require the formulator to completely re-examine all aspects of the formulation. It will require a complete matrix including various levels of EP and film strength additives.”

DIFFERENTIATE THE PERFORMANCE OF CHLORINE-FREE EP ADDITIVES

Marmerstein recommends that the formulator evaluate chlorinated paraffin-free formulations using a wide variety of tests. She says, “In addition to standard tests, we often use a modified 4-ball test, where the load on the ball is slowly increasing over a 20-minute period. This test is more severe than the regular 4-ball wear test and allows for better differentiation of additive effects in the fluids (see Figure 5).”

Jarvis believes that lab-based tests should be performed on rudimentary oil/water emulsions to assess the inher-
ent performance of the alternative additive compared to the chlorinated paraffin it is replacing. He adds, “A wide range of laboratory tests are available to evaluate the lubricity and EP characteristics of a fluid. Some examples include the Draw-Bead, Reichert, High Frequency Reciprocating Rig and the Hille Press.”

Figures 8 and 9 demonstrate the capabilities of the Hille Press test. Jarvis says, “This test involves the use of a laboratory scale deep drawing machine in which test blanks are coated with a lubricant, clamped at a fixed pressure and extruded through the use of a traveling punch. As shown in Figure 8, punch pressure (or resistance to deformation) is measured versus punch displacement until failure is reached. The objective is to find the lowest additive treat rate that displays the best combination of lowest punch pressure and highest punch displacement.”

Typically an additive candidate is evaluated at treat rates of 0.5%, 2.5%, 7.5% and 20% in base oil and applied to the stainless steel blank (see Figure 9). Jarvis says, “We use MCCP (additive 1) and two polymeric lubricant additives (additives 2 and 3) as industry standards. The remaining 16 additives are taken from a range of MWFs and other lubricants. High-performing additives display superior boundary lubrication and interact very effectively with metal surfaces.”

Kirsch says, “In addition to the tests previously described, we are investigating the use of traditional tribological tests including the mini traction machine and Cameron Plint to determine how best to evaluate alternatives to chlorinated paraffins.”

McElwain indicates that formulators need to evaluate other properties besides boundary lubricity and extreme pressure characteristics to determine if chlorinated paraffin-free alternatives will provide comparable performance. She says, “Formulators should evaluate such properties as concentrate stability, foam, tramp oil rejection and emulsion stability. If results from these bench tests and from lubricity tests are promising, then field performance will test the real-life viability of these chlorinated paraffin-free alternatives.”

**EVALUATING SYNERGISTIC COMBINATIONS**

Kirsch maintains that the MWF fluid industry has speculated for many years on the exact mechanism behind the synergies seen with various additive combinations. He says, “Extreme pressure additive performance can often be enhanced through synergy with other similar additives. By using materials that broadly function between 200-1,000 °C, many to most metalworking and metal forming operations will gain improved tool life and processing speeds.”

Various synergisms are evaluated in a tapping torque test conducted on 1018 carbon steel. Five additive combinations are tested with LCCP being the reference. As shown in Figure 10, a combination of sulfurized olefin, overbased sulfonate and sulfurized fat displays the best performance.

McElwain says, “We believe that certain additives have a higher propensity to bond ionically to the metal surface. This relative affinity may be impacted by temperature, explaining why EP additives ‘activate’ at different temperatures. When additives are used in combination, each additive may perform independent of the other or synergistically.”

Marmerstein says, “Phosphite esters work synergistically with sulfurized olefins and triglycerides, showing significant improvement in extreme pressure and tapping torque results.”

Jarvis cautions that further research must be done to clearly identify additive synergisms. He says, “More work is
required on the mechanisms by which certain chlorinated paraffin replacement technologies work synergistically when in combination with each other.”

FORMULATOR PERSPECTIVE

With many options to choose to replace chlorinated paraffins, metalworking fluid formulators are faced with a major challenge in replacing MCCPs and LCCPs in their products. Former STLE President Jerry Byers, now an independent consultant in The Villages, Fla., says, “Formulators that typically have at least 200 products are faced with having to deal with formulations that can contain between 15-20 ingredients.”

Regulations are restricting the number of ingredients available to the formulator due to restrictions in ingredient availability. “In effect, it is like trying to write a novel with fewer and fewer letters in the alphabet,” says Byers, editor of Metalworking Fluids, Second Edition (available at www.stle.org). See Figure 11. 

MCCPs and LCCPs exhibit a great degree of flexibility that enables them to be used in a wide range of fluids and applications. While replacing them with alternative EP additives is do-able in most cases, Byers points out that there are applications that need chlorinated paraffins. He says, “Operations where chlorinated paraffins are needed include military applications (such as aviation fasteners), heavy-duty stamping and drawing, fine blanking, forming high strength, heavy gauge steels, older dyes, heavy-duty broaching and machining stainless steel. In the latter case, chlorinated paraffins are the only effective EP additive for this particular class of metal alloys.”

Alternative additives available to the formulator are listed in Table 4 on page 44 by metalworking fluid type. While there appears to be a wide choice of options, each alternative additive exhibits some weaknesses.

Byers says, “Sulfurized EP additives can generate odors that are objectionable and even dangerous since they can originate from the presence of hydrogen sulfide. This additive type also can stimulate microbial growth, cause ferrous corrosion, foam and stain copper alloys. Use of sulfurized additives with nickel-based alloys should be avoided because of the danger of forming a low melting point eutectic that weakens the metal surface.”

The main phosphorus-based EP additive is phosphate esters, which are known to stimulate microbial growth and generate foam in water-based metalworking fluids. Byers says, “Phosphate esters also can be too reactive with other components in the formulation and create problems when used in straight oils, including causing hydrolysis if water contamination is present, act to emulsify water and require high maintenance.”

Other alternative additives also have weaknesses including fatty esters that can readily hydrolyze in the alkaline environment of metalworking fluids, forming metal soaps that can lead to foaming and concentrate instability over time.

Byers sums up the challenges facing formulators: “Combinations of alternative additives will be needed because no single alternative will work in every case and each of the alternatives has problems. Product costs will increase by as much as 50%. But formulators should expect shorter sump life, higher disposal volumes and higher biocide usage.”

Additional details on the formulator’s perspective can be found in a recent presentation.9

FUTURE FOR ALTERNATIVE EP ADDITIVES

As the metalworking fluid industry turns to finding alternatives for MCCPs and LCCPs, the respondents were asked to predict what extreme pressure

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**Figure 10** | Five additive combinations blended in Group I base oil are evaluated with LCCP as the reference on 1018 carbon steel in a tapping torque test. (Figure courtesy of The Lubrizol Corp.)

**Figure 11** | The analogy can be drawn that the fewer ingredients available to formulators due to regulations is comparable to writing a novel without a complete alphabet. (Figure courtesy of Jerry Byers.)
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additives will be available for formulators in the future.

McElwain says, “Formulators will need to rely on existing chlorinated paraffin-free extreme pressure additives in the near future. New product introductions will take place in more of an evolutionary as opposed to revolutionary manner as the metalworking fluid industry gains a better handle on what applications will need better upgrades from MCCPs and LCCPs.”

Kirsch feels that finding additive synergies will be the key to replacing MCCPs and LCCPs. He says, “As machining and stamping operations increase in operational severity (e.g., higher pressures, faster speeds and feeds, etc.), fluids need to respond to this demand without compromising part and tooling integrity. Many extreme pressure additive alternatives to chlorinated paraffins are already available to the formulator. Synergies between these additives can often provide effective solutions for the formulator.”

Jarvis sees the future from the short/medium- and long-term perspectives. He says, “Over the short/medium-term, the current chlorinated paraffin-free EP additives will need to be used. Additive suppliers will be utilizing their R&D programs to develop newer approaches over the long term.”

Marmerstein predicts that formulators will be working with combinations of various types of chlorinated paraffin-free EP additives. She says, “Various sulfur, phosphorus and nitrogen components will be used in combination. For severe applications, formulators will work with active sulfurized olefins and fats in combination with phosphorus and amine chemistries to achieve improved lubricity, antiwear and lower friction.”

The current uncertainty about when MCCPs and LCCPs will be phased out is not stopping formulators from seeking and evaluating alternatives. This process will continue now and in the near future at a steady pace that may need to be accelerated depending upon when the use of main chlorinated paraffin types must cease in the U.S. TLT

Table 4 | Alternative additives available to the formulator are listed by metalworking fluid type. (Table courtesy of Jerry Byers.)

![Table 4 | Alternative additives available to the formulator are listed by metalworking fluid type.](image)

### REFERENCES

4. In December 2014, EPA issued a notice requiring any future use of SCCPs required an SNUR.
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Science vs. Fiction

KEY CONCEPTS

• The health risks associated with formaldehyde-condensate have been conflated with those associated with formaldehyde and are not supported by scientific data.

• Formaldehyde-condensate microbicides are an essential part of the ever-shrinking list of biocidal products that are approved for use in metalworking fluids.

• Aldehyde-based microbicides are unique in their ability to denature endotoxin and thereby reduce the risk of respiratory disease caused by endotoxin exposure.
In both the U.S. and Europe, examining the research goes a long way toward setting the record straight.

The November 2015 issue of TLT contained an article titled Biocides: Both Problem and Solution. While this timely article addressed a topic that is foremost in the minds of many metalworking fluid (MWF) formulators, resellers, fluid managers and end-users, it only scratched the surface of an issue that is both fascinating for tribologists and under scrutiny by regulatory agencies in the U.S. and other countries.

This follow-up article expands the information in the November article and is based on consensus documents (primarily ASTM standards), peer-reviewed literature and regulatory agency material to provide an update on the current status of U.S. and European regulations affecting the registration and use of microbicides in MWFs.
DDT VERSUS FORMALDEHYDE-CONDENSATE MICROBICIDES

The U.S. EPA and European regulatory agencies have conflated F-C microbicides with formaldehyde based on their erroneous assumption that formaldehyde-condensate molecules will completely hydrolyze to free-formaldehyde plus the other reactive intermediate(s) while in solution.

After decades of use—often applied in aerosol form in the same manner as many agricultural pesticides—Dichlorodiphenyltrichloroethane (DDT) was discovered to be bioresistant (half-life raging to 30 years), bioaccumulative and—because of its adverse impact on eggshell thickness—contributing to marked declines in the populations of various species of birds. The public outrage over DDT’s ecotoxicological properties led to it ultimately being banned by many countries. Despite its effectiveness against the insect vectors of malaria, dengue fever and typhus, DDT became the symbol of indiscriminate pesticide use. Moreover, the unequivocal link between DDT bioaccumulation and near extinction of a variety of bird populations eclipsed DDT’s public health benefits.

In the 1980s, formaldehyde (HCHO) came under regulatory pressure after it was reported that HCHO was associated with an increased cancer rate among workers in 10 high-exposure industries (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 8, 2006, http://monographs.iarc.fr/ENG/Monographs/vol88/index.php).

In this IARC report, the standardized mortality ratio (SMR, a measure of the number of deaths due to all causes or a specific cause among members of a designated [exposed] population relative to the general putatively unexposed population) among HCHO-exposed workers for all cancers was 0.76 (95% confidence interval (CI): 0.69 – 0.84) and for nasopharyngeal cancers was 2.10 (95% CI: 1.05 – 4.21). This means that while the overall incidence of cancer among exposed workers was significantly less than that of the general population, exposed workers were significantly more likely than the background population to develop nasopharyngeal cancers.

The acute toxicity (LD$_{50}$) of HCHO in mice is 42 mg/kg, and its acute inhalation toxicity (LC$_{50}$) is 505 mg/m$^3$ (4h exposure; mice; Nagorny, P.A., Suddakova, Zh. A., and Schablenko, S.M., 1979. On the general toxic and allergic action of formaldehyde. Gig. Tr. Zabol. 1:27-30). Formaldehyde is currently listed by IARC as a probable human carcinogen (classification 2A).

In contrast, the acute oral toxicity of Hexahydro-1,3,5-tris(2-hydroxyethyl)-s-triazine (HTHT – the most commonly used formaldehyde-condensate – F-C – microbicide) is 560±32 mg/kg (rats). Inhalation toxicity testing depends on being able to expose test animals to vapors containing the test substance. In contrast to HCHO (vapor pressure @ 25°C = 519 kPa; 3,890 mm Hg) the vapor pressure of HTHT is <0.01 kPa; <0.1 mmHg @ 25°C. This means that under inhalation test conditions, there is no measurable HTHT in the air. Consequently, the acute inhalation toxicity of HTHT is undeterminable (data from HTHT’s SDS; Troy Chemical Corp.). Moreover, HTHT’s low vapor pressure means that HTHT is unlikely to cause adverse health effects due to inhalation of its vapors.

At present there are currently (as of November 2015) 27 products (biocidal chemistries) with active dossiers under the 2012 EU Biocidal Products Regulation (BPR) under Product Type 13 (Working or cutting fluid preservatives). This list of 27 products includes 11 formaldehyde condensates—including Hexahydro-1,3,5-tris(2-hydroxyethyl)-s-triazine, listed as “2,2’,2”-(hexahydro-1,3,5-triazine-1,3,5-triyl) triethanol.”

There is no evidence that there is an incremental health, safety or environmental risk posed by MWFs treated with F-C microbicides, relative to those that are either treated with alternative microbicides or those putatively formulated to be biocide-free.

There is no evidence of an incremental health, safety or environmental risk posed by MWFs treated with F-C microbicides relative to those treated with alternative microbicides or those putatively formulated to be biocide-free.
Controlling pH does not kill bacteria.
all active ingredients approved for use as antimicrobials in MWFs as of 2012.

In short, although the current focus on F-C microbicides is real, it is driven by emotionalism and misconceptions. It is essential that STLE stakeholders recognize the difference between science and hysteria.

**TYPES OF MWFs**

As stated in ASTM D2881 Standard Classification for Metalworking Fluids and Related Materials, the four main types of MWFs are:

1. **Straight oil.** Contains petroleum oil but essentially no water, is not emulsifiable and can contain functional additives.

2. **Emulsifiable oil.** Frequently referred to as a soluble oil, it generally creates a macroemulsion (average micelle size is greater than 1 micron) when dispersed in water. Primary base stock is petroleum oil and contains little or no water, contains emulsifiers and other functional additives and is blended with water in its end use.

3. **Semisynthetic fluid.** Generally, creates a microemulsion (average micelle size is less than 1 micron) when dispersed in water. Primary base stocks are petroleum oil and water, contains functional additives and is blended with water in its end use.

4. **Synthetic fluids.** This fluid type is further classified in three subcategories: solution synthetic fluid, emulsion synthetic fluid and straight synthetic oils:

   a. **Solution Synthetic Fluid** (also known as a chemical solution): Contains no petroleum oil, contains functional additives, forms a single-phase, true solution (no micelles) when further diluted with water prior to use.

   b. **Emulsion Synthetic Fluid**: EPAred from natural (typically vegetable oils) or synthetic triglycerides, esters or other oil-soluble base stocks, contains emulsifiers and other functional additives but no petroleum oil, produces an emulsion when further diluted with water prior to use.

   c. **Straight Synthetic Oil**: Contains no petroleum oil nor water, formulations typically EPAred with renewable triglycerides, synthetic hydrocarbons, esters or other oil-soluble base stocks, generally combined with oil-soluble additives that contain no water and not intended to be diluted nor dispersed in water in its end use.

As noted, MWFs containing bio-based base stocks are clearly placed by industry consensus in the synthetic fluid category.

Moreover, U.S. EPA has established definitions for biopersistence based on percent of biodegradation in various test systems and by various test methods. Given that there are several approved methods and that biopersistence also depends on the environment (aerobic, anaerobic, etc.), its definition is test-method specific. For example: OECD 301 states that to qualify as readily biodegradable, a substance must be degraded by >60% within the 28-day test period. Additionally, >60% of the substance's maximum degradation must occur within 10 days after 10% biodegradation is observed.

**MICROBIAL ECOLOGY OF MWFs**


Microbes require macronutrients that contain carbon, hydrogen, nitrogen, oxygen, sulfur and phosphorous. These macronutrient elements are provided in MWF base stocks and the various performance additives formulated into finished MWFs. Given that watermiscible MWFs are diluted to end-use concentrations ranging from 2% by volume to 10% by volume in water, the diluted MWFs provide a superb medium for microbial growth. Moreover, the turbulent flow conditions that are characteristic of recirculating MWF systems provide optimal conditions for the growth and proliferation of aerobic microbes—bacteria and fungi that require oxygen. In systems with stagnant zones, anaerobic bacteria—bacteria that only grow in oxygen-free environments—feed off of the waste products produced by aerobes and off of particularly biodegradable MWF components.

The malodorous gases—commonly referred to as Monday morning odor—are invariably released after system recirculating pumps that have been left idle for the weekend are turned back on. During normal operations, microbially generated noxious gases (for example: hydrogen sulfide, low molecular weight fatty acids and various sulfur-containing alcohols) are oxidized as they diffuse through well-aerated, recirculating MWFs. When systems are left idle, these gases accumulate. Their rapid release upon restoration of recirculation—generally on Monday mornings—overwhelms the system’s ability to oxidize them before they are expelled into the facility’s atmosphere. The result is the overwhelming aroma of swamp gas. The most cost effective tactic for preventing Monday morning odor is to control microbial contamination effectively.

Make-up water is the primary source of MWF microbial contamination. It is also the primary source of the various inorganic macronutrients microbes need in addition to the aforementioned macronutrients. Conse-
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Formulators must resist the urge to formulate with toxic molecules that serve no other function than to suppress microbial growth.

Currently, the quality of water used to dilute MWFs has a major impact on microbial contamination in MWFs. Although all MWF components are made from two or more of the macronutrients listed above, more complex molecules tend to resist microbial attack better than less complex molecules do.

In recent years, an increasing number of bioreistant functional additives have been introduced to the market. A credible, bioreistant additive demonstrates one or more performance properties other than microbial contamination control. If added to a heavily contaminated MWF, it will not have any immediate effect on the microbial population. However, it will typically improve the finished formulation’s ability to withstand microbial challenges.

**BIOCIDES**

Biocides are products designed to control or kill one or more pests. Microbicides (antimicrobial pesticides) are biocidal products that are designed to specifically target microorganisms.

Any product that has an immediate kill effect on MWF microbial populations but does not have any other demonstrable function is a biocide. In the U.S., all industrial microbicides must be registered with U.S. EPA’s Office of Pesticide Programs. In the EU, microbicides must be registered in accordance with the Biocidal Product Regulation (BPR, EU No 528/2012). ASTM E2275 Standard Practice for Evaluating Water-Miscible Metalworking Fluid Bioreistance and Antimicrobial Pesticide Performance (DOI: 10.1520/E2275-14, [www.ASTM.org](http://www.ASTM.org)) provides guidance on how to evaluate the biocidal or bioreistance performance properties of MWF components or finished formulations.

It is incorrect to assume that the substantially larger portfolio of toxicological data needed to support microbicide registration applications reflects greater hazard. Any chemical or device intended to be used to control one or more types of pests must be registered with U.S. EPA’s OPP. OPP approvals are site-specific (pest and end-use application) specific. There are countless chemistries that are not intended for use as pesticides that are considerably more toxic than microbicides. The basis for requiring pesticides to have more complete toxicological data sets than other chemicals is primarily economic and political rather than logical. People handling concentrated inorganic acids such as hydrochloric or sulfuric acids are exposed to substantially greater risk than those handling F-C microbicides. The implementation of REACh in Europe recognizes and attempts to address this discrepancy.

A perfect example of this is a 0.5% solution of sodium hypochlorite. When purchased in the grocery section as bleach, the product has a label with minimal health and safety information. When the same product is purchased in the MWF in a 10,000 keg, it will have a much more detailed label that lists numerous health and safety considerations, provides detailed information for safe handling and use, and includes a summary of the product’s toxicological profile. However, when purchased as an algaecide, it comes with a fold-out label that lists many health and safety considerations, provides detailed information for safe handling and use, and includes a summary of the product’s toxicological profile. The only difference is the sodium hypochlorite’s intended use.

As noted above, microbicides are approved for use in specific products against specific pests. The three primary factors affecting application approvals are toxicity, exposure and efficacy. Historically, U.S. EPA has not required efficacy data, but that has changed with the 2012 revision to 40CFR158 Subpart W-Antimicrobial Pesticide Data Requirements. The BPR has always required performance efficacy data. A major challenge to the development of reliable performance data is that for many end-use sites, there are no consensus methods for testing microbicide efficacy.

The health risk associated with microbicide use is a function of toxicity and exposure. The U.S. EPA bases microbicide approvals on the risk posed to those using the products; the EU considers only toxicity. Risk decisions are inherently more complex. For example, should permissible dose concentrations be based on the potential (or likely) exposure of personnel handling microbicide concentrate or on likely exposures of personnel working in the metalworking environment? Should exposure risk be based on worst case scenarios or most common conditions? How should microbicide exposure risk be balanced against disease and biodeterioration risks associated with not using microbicides? These are complex issues that are well beyond the scope of this article. Important here is the recognition that the use of hazardous, non-microbicidal products should raise similar questions.

MWF microbicide performance is generally tested against microbes in the bulk fluid (planktonic microbes). It is important to keep in mind that only a fraction of the total microbial biomass in any MWF system is present in the recirculating fluid. For every microbe/mL in the MWF there are likely to be 1,000 microbes/cm² of system surface. These surface-associated (sessile) microbes are invariably found with biofilms. Biofilm communities share many properties in common with fixed-film biological reactors, commonly used in biotechnology to convert organic feedstocks into products. Inadequate control of biofilm communities can result in apparently cryptic, fluid stability and performance problems when the biofilm burden in recirculating MWFs is below detection limits but all other test results indicate biodeterioration. For more information about MWF system biofilms, read “Emerging Issues in Metalworking Fluid Microbiology: Biofilm Control,” available on the Webinar section of [www.stle.org](http://www.stle.org).
CLARIFICATION OF BIOCIDE TYPES

There is some confusion regarding the terms formaldehyde-condensate, formaldehyde releasing and formaldehyde-condensate, formaldehyde non-releasing. For example, the theory that nitromorpholine does not release HCHO is most likely an artifact of experimental design. As part of his doctoral thesis research, Mohammad Sondossi compared the ability of test microbes to become formaldehyde resistant after exposure to increasing concentrations of either formaldehyde or formaldehyde-condensate microbicides. Microbes exposed to either 2-(hydroxymethyl)-2-nitro-1,3-propanediol (TRIS NITRO®) or nitrobutylmorpholine did not develop formaldehyde resistance. Those exposed to formaldehyde or other F-C microbicides became formaldehyde-resistant. The flaw in the study was that TRIS NITRO is well known to hydrolyze under MWF conditions. Free-formaldehyde can be detected quickly after TRIS NITRO is added to end-use diluted MWF. If TRIS NITRO did not select for formaldehyde resistance, the assumption that nitrobutylmorpholine does not release formaldehyde is questionable. We are unaware of actual C¹³-NMR studies on nitrobutylmorpholine hydrolysis in MWFs. Consequently, the statement “nitrobutylmorpholine does not release formaldehyde” is at best speculative.

Benzisothiazolin-3-one (BIT) and other non-F-C microbicides can be effective, but they are much more formulation sensitive. Prof. Ed Bennett used to routinely test microbicide performance in >200 different MWF formulations. He often reported his results in Lubrication Engineering, TLT’s predecessor magazine. Regardless of the product, invariably there would be MWFs in which the microbicide-treated formulation would be less bioreistant than the control. In other MWFs the microbicide would have no significant effect, and in others the microbicide would be effective. The microbicides that became commercially successful were those that were effective in the greatest percentage of MWFs. The range of MWFs in which BIT is effective is substantially less than the range in which F-C products are effective.

OTHER MWF CONCEPTS

Earlier in this article, the most commonly used F-C-microbicide was listed under the chemical name Hexahydro-1,3,5-tris(2-hydroxyethyl)-s-triazine (HTHT). This biocide is not referred to as 1,3,5-triazine nor cyanuric chloride. No chlorine is present in HTHT.

Formaldehyde is also known under additional synonyms including formic aldehyde, methanal, methyl aldehyde, oxo-methane and oxymethylene. Formaldehyde is not methanol, as formaldehyde is chemically known as a member of

* TRIS NITRO is a registered trademark of Dow Chemical Co., Midland, Mich.
the aldehyde class, and methanol is a member of the alcohol class. It also is incorrect to refer to formaldehyde as formalin. In actuality, formalin is a 37% solution of formaldehyde gas in water usually stabilized with methanol to prevent polymerization.

**ADDITIVES IN WATER-BASED MWFs**

Water-based (also known as water-dilutable and water-miscible) MWFs contain a large number of specific additives due to the many functions that the fluid needs to perform. The additive classes found in the water dilutable MWF known as emulsifiable oils, semi-synthetic fluids and synthetic fluids are shown below in alphabetical order:

- Antifoam additives
- Antimicrobial pesticides (biocides)
- Boundary lubricity additives
- Corrosion inhibitors
- Coupling agents
- Dyes
- Emulsifiers
- Extreme pressure agents
- Metal deactivators
- Reserve alkalinity boosters (mainly alkanolamines)
- Wetting agents


**NON-CHEMICAL AND NON-BIOCIDAL MICROBIAL CONTAMINATION CONTROL STRATEGIES**

Pasteurization and other point-source biocidal measures are inadequate. In an MWF with 10⁶ microbes/mL, even 99.99% kill leaves 10³ survivors/mL. A percentage of these survivors are likely to settle on MWF system surfaces, proliferate and recontaminate the bulk MWFs. Point-source decontamination systems have been evaluated for >40 years. Some perform well under controlled laboratory conditions, but to date none has worked well in application.

Controlling pH does not kill bacteria. MWFs running at pH 9.2 are as likely to have high bioburdens as those running at pH 8.5. The source of this myth is unclear, but it has been pervasive since as early as the mid-1970s. It is a myth that is most likely based on culture test data. Too often culture tests are terminated after 36 to 48 hours. Many MWF microbes require 5-15 days to form visible colonies. Consequently, culture tests are commonly misinterpreted.

Fluid management best practices (for example, see Foltz, G., J., Metalworking Fluid Management and Troubleshooting, Chapter 11. In J. P. Byers, Ed. Metalworking Fluids, 2nd Ed., CRC Press, New York, pp: 253-278; 2006) reduce but do not eliminate microbial contamination control problems. Use of quality MWFs, good water, effective condition monitoring and timely, data-driven actions are the best means for minimizing biodeterioration.
and microbe-associated health risks in the metalworking environment.

BIOSTABLE MWFs

As noted above, ASTM E2275 Standard Practice for Evaluating Water-Miscible Metalworking Fluid Biore sistance and Antimicrobial Pesticide Performance provides protocols for testing quick-kill and biore sistance properties of MWFs and MWF additives. It is not uncommon for a functional additive to exhibit quick-kill performance (causes the microbial population density to drop precipitously in a matter of hours). If that additive is not used for its antimicrobial properties, it can be formulated into an MWF without having a pesticide registration. However, it is misleading to suggest that substitution of a micro bicide with such a product reduces the health and safety risks associated with use of MWFs.

Formulators must resist the urge to formulate with toxic molecules that serve no other function than to suppress microbial growth. There are an increasing number of molecules available that have well-documented, non antimicrobial performance properties, do not kill microbial populations (per E2275) when added to heavily contaminated MWFs but provide good biore sistance (≥ 6 weeks of biore sistance by E2275). Additives that meet these latter three criteria are appropriate for use in formulating bioreistant MWFs. This is critical guidance to both formulators and end-users.

MEASURING MICROBES

The types of microbes most commonly recovered from MWFs include bacte ria and fungi. The focus on these two groups is linked to their well-documented biodeteriogenic activity. Given that make-up water is the primary source of microbes in MWFs, it is not unlikely that algae, archaea, protozoa and viruses would also be detected if sought for. Bacteria and Archaea are kingdoms on the current, phylogenetic tree of life. Algae, fungi and protozoa are all branches of the kingdom Eukaryota. Viruses are believed to have either degenerated from bacteria or to have developed from nucleic acids (see below) that survived outside the microbes from which they originated. The term microbe is the diminutive form of the word microorganism. The ASTM consensus definition of microbe is: “bacteria and other organisms that require the aid of a microscope to be seen.”

To detect microbes in MWF and metalworking systems, one must have reliable test methods. The first chal lenge is to obtain a suitable sample. Although ASTM D7464 (Standard Practice for Manual Sampling of Liquid Fuels, Associated Materials and Fuel System Components for Microbiologi cal Testing; DOI: 10.1520/D7464-14, www.ASTM.org) specifically addresses fuel system sampling, the general principles it explains are equally valid for MWFs. Current industry practice is to test for microbial contamination with an agar-coated dipslide or paddle. Most commercially available paddles have two different types of growth media. A medium for growing bacteria is on one side and a medium for growing fungi is on the other side. These dipslides are a simplified version of standard plate count methods (see D5465 Standard Practice for Determining Microbial Colony Counts from Waters Analyzed by Plating Methods; DOI: 10.1520/D5465-93R12, www.ASTM.org). In order for microbes to be detected by culture testing, they must be able to proliferate (form colonies) on the growth medium under the test conditions (incubation temperature, oxygen availability, incubation period) used. Consequently, any single culture test will only detect a fraction of the total microbial community in an MWF sample.

Although all test methods have inherent limitations, non-culture methods typically detect larger proportions of the total population. For example, the catalase test (Gannon, J. and Ben nett, E.O. (1981), “A Rapid Method for Determining Microbial Loads in Metalworking Fluids,” Tribology 14: 3–6.) detects most aerobic bacteria and all metabolically active fungi but does not detect anaerobic bacteria or those aerobic bacteria that do not have a complete catalase enzyme. Endotoxin testing (ASTM E2144 Standard Practice for Personal Sampling and Analysis of Endotoxin in Metalworking Fluid Aerosols in Workplace Atmospheres; DOI: 10.1520/E2144-01, and E2657 Standard Test Method for Determination of Endotoxin Concentrations in Water-Miscible Metalworking Fluids; DOI:10.1520/E2657-11, www.ASTM.org) detects the presence of whole or disintegrated Gram-negative bacteria, but does not detect Gram-positive bacteria or fungi. Adenosine triphosphate (ATP) testing (ASTM E2694 Standard Test Method for Measurement of Adenosine Triphosphate in Water-Miscible Metalworking Fluids, DOI: 10.1520/E2694-11, www.ASTM.org) detects all metabolically active microbes but does not detect dormant cells. Recent advances in ATP testing have made it possible to differentiate between bacterial and fungal contamination (Passman, F.J. and Kuenzi, P., “A Differential Adenosine Triphosphate Test Method for Differentiating between Bacterial and Fungal Contamination in Water-Miscible Metalworking Fluids” International Biodeterioration & Biodegradation; 2014, http://dx.doi.org/10.1016/j.ibiod.2015.01.006 0964-8305.)

No individual test method can provide all of the microbiological information that might be helpful for MWF management. Method selection should be based on careful consideration of the type of information needed and the importance of timeliness. Other con-
such as environmental shotgun sequencing (ESS) have been developed (Tyson GW, Chapman J, Hugenholtz P, Allen EE, Ram RJ, et al., “Community structure and metabolism through reconstruction of microbial genomes from the environment,” Nature, 2004; 428:37-43). Rather than depending on rRNA primers, these methods capture a much broader range of genes, thereby providing much more intimate information about the contaminant population.

Having better information about what types of microbes make up the structure of MWF microbial populations is important, but the real question is: “What is the population doing?” This is where proteomics offers promise. Proteomic methods provide a profile of gene expression in samples by detecting enzymatic proteins. Except for the special case in which biomass accumulation plugs filters and lines, biodeterioration is the result of enzymatic activity.

By understanding the relationship between MWF conditions and gene expression, it might be possible to formulate MWFs that inhibit the expression of genes that play major roles in biodeterioration. Both metagenomics and proteomics are in their respective infancies. Moreover, in an industry accustomed to investing <$5 U.S./test, the cost of obtaining metagenomic data ($150 to $300/test) or proteomic data (thousands of U.S. dollars per test) is still prohibitive for them to be used outside limited research studies. In the future, the information that can be obtained from these emergent technologies might well change how we control microbial contamination in MWFs.

HEALTH EFFECTS OF MWF MICROBES

The earliest research on MWF microbiology was focused on the recovery of pathogenic microbes (Bennett, E.O. and Wheeler, H.O. (1954), “Survival of Bacteria in Cutting Oils.” Appl. Microbiol. 2, pp. 368-371). By the mid-1970s it was apparent that although potentially pathogenic microbes were recovered from MWFs routinely, they were not causing infectious diseases among workers (Rossmoore, H.W. (1979), “Do Metalworking Fluid Microbes Cause Disease?” The Lubricator 6(3)).

Few frankly pathogenic microbes are found in MWFs. Putatively, any microbe can become an opportunistic pathogen. The human microbiome project has reported that there are approximately 10 times as many microbial cells as there are human cells in and on the average human adult. Emerging research is beginning to show how perturbations to either the population profile or environmental niches of skin, gut, respiratory microbiomes can result in a disease state. This is different from infection—pathogenicity—by frank pathogens such as Vibrio cholerae, etc. Moreover, Ed Bennett found that dermatitis was invariably a reaction to MWF chemicals, not symptomatic of microbial infection. This issue is addressed in both Passman and Rossmoore (op. cit.) and Passman, 2008 (op. cit.). We’d cite Prof. Bennett’s papers directly, but they all predate STLE’s electronic archive.

In terms of serious infections from untreated cuts or abrasions, there are only two documented cases of necrotizing...
fasciitis among machinists. Given that there are an estimated 1 to 1.5 million person-years exposure to MWFs annually, the incremental risk to machinists is immeasurably small. Moreover, the risk is comparable to that posed by leaving any cut or puncture wound untreated.

This is not to say that MWF microbes are not associated with disease. The effects of endotoxin exposure are well documented (see Passman, 2008, op. cit.). Between 1990 and 2000, there were several clusters of workers diagnosed with the allergenic respiratory disease, hypersensitivity pneumonitis. During that period, nearly 250 cases were reported. The total incidence of HP among machinists has yet to reach 300 cases. While HP clusters were being reported frequently, it was speculated that the microbe *Mycobacterium immunogenum* was the causative agent. It was also speculated that F-C microbicides either enriched for *M. immunogenum* or stimulated its growth by suppressing the microbes that were more commonly found in MWFs. Both speculations have subsequently been disproven.

As reported in Passman, 2008 op. cit., although *Mycobacterium immunogenum* undoubtedly caused HP, it is only one of a dozen MWF microbes known to do so. Speculation that *Mycobacterium immunogenum* was the only microbe responsible for HP among machinists discounted reports that linked HP-clusters to exposure to any of the dozen other microbes that are both routinely recovered from MWFs and known to cause HP (for example: *Alternaria* species, *Aspergillus* species, *Aureobasidium pullulans*, *Bacillus subtilis*, *Bacillus cereus*, *Acremonium* (formerly *Cephalosporium*) species, *Cryptostroma corticale*, *Enterobacter agglomerans*, *Penicillium* species, *Mycobacterium immunogenum* species, and *Thermoactinomyces* species; Passman, EJ. and H.W. Rossmore. “Reassessing the Health Risks Associated with Employee Exposure to Metalworking Fluid Microbes.” Lub. Eng. 58 (7): pp: 30-38; 2002).

The apparent inverse relationship between *M. immunogenum* and other common MWF microbes turned out to be an artifact of test methodology. Although *M. immunogenum* is considered to be a fast-growing mycobacterium, its generation time is >4x longer than that of many other MWF microbes. It takes seven to 10 days for an *M. immunogenum* colony to appear on culture media. When faster growing microbes are present, their colonies expand to form a uniform covering over the growth medium (confluent growth). This masks *M. immunogenum* colonies that might develop later. Subsequent research demonstrated that the presence or absence of *M. immunogenum* was unrelated to the presence or absence of other microbes (Passman, EJ., Rossmoore, K. and Rossmoore, L. “Relationship between the Presence of Mycobacteria and Non-mycobacteria in Metalworking Fluids.” Tribol. Lub. Technol. 65(3): 52-55; 2009). By extension, this research proved false the hypothesis that F-C microbicides either enriched or selected for *M. immunogenum* proliferation in MWFs.

**MWF AEROSOL EXPOSURE**

Before the 1990s it would not have been inaccurate to report that workers are often in close proximity to the mist for an entire shift. Although mist is invariably created at the tool-workpiece interface and is often generated as used MWFs flow turbulent through return sluices/troughs, industry practices during the past 20 years have reduced employee exposure dramatically. In NIOSH-sponsored surveys, median MWF aerosol exposures fall well below the 0.5 mg/m³ REL which, in turn, is 10% of the PEL (REL: recommended exposure limit; PEL: permissible exposure limit).

**CONCLUSIONS**

As a family of chemicals, microbicides are diverse. They differ in their respective toxicological profiles (for example: Bro-nopol (BNPD) is used as a preservative for antacid tablets), modes of action, compatibilities with other MWF components, spectrum of microbes against which they are effective and persistence when used in MWFs. The F-C microbicides also are quite varied in their chemical and toxicological properties (BNPD is an F-C). Toxicologically, F-C are quite distinct from free-formaldehyde. Moreover, F-C microbicides are unlikely to hydrolyze substantially when used in MWFs. It is true that F-C microbicides are under increasing regulatory pressure. Regrettably, this regulatory pressure is not based on any sound science. TLT

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STLE honors two key tribology anniversaries

March is the month when STLE was formed and the ‘Jost Report’ was issued. We start the celebrations by listing The 12 Greatest Events in Tribology History.

POPC THE CORKS! The lubrication industry is celebrating two critical anniversaries this month.

On March 3, 1944, the organization that would eventually come to be known as the Society of Tribologists and Lubrication Engineers (STLE) was incorporated. For the first time, those companies involved in the lubricants industry coalesced into one entity with the power to provide technical information, create education opportunities, increase professional development and offer international networking experiences. STLE also made it easier for the many and diverse companies in the lubricants industry to conduct business with each other and their customers.

Twenty-two years later on March 9, 1966, the British study known as the “Jost Report” (after committee chair Dr. H. Peter Jost) was released. For the first time the monetary effects of proper lubrication procedures were documented, and the importance of lubrication, until then an afterthought for many machinery manufacturers and plant managers, became a global concern.

On March 2 a celebration of the 50th anniversary of the Jost Report is happening at Buckingham Palace in London. Representatives from STLE, including President Martin Webster and Vice President Ali Erdemir, are attending. TLT will cover the event and offer a more comprehensive article on the Jost Report in the May issue. STLE is promoting the anniversary industry wide with articles, press releases and a 50% discount on prerecorded STLE Webinars on March 9. Use promo code “tribology50.”

TLT kicks off the celebrations with this list of The 12 Greatest Events in Tribology History as selected by TLT readers. Enjoy.

The 12 Greatest Events in Tribology History

1. FIRST LUBRICANTS
Prehistoric man first uses natural materials like plant oils and animal fat to overcome friction. The ancient Egyptians develop sophisticated methods of applying such materials and become the first lubrication engineers.

2. THE WHEEL
Rolling technologies such as pebbles, logs and ultimately the wheel and ball bearings are used to facilitate motion. Ancient Egypt again leads the way, developing elegant means of overcoming friction by rolling motion.

3. LAWS OF FRICTION
The theories, deductions and experiments of scientific geniuses Leonard da Vinci (1452-1519), Isaac Newton (1643-1727), Guillaume Amontons (1663-1705) and Charles Coulomb (1736-1806) give the world its first intellectual insights into the world of friction.

4. DRAKE’S WELL
On Aug. 27, 1859, Col. Edwin Drake and partner Billy Smith, ignoring the naysayers, use a steam-powered engine to drill the first oil well nearly 70 feet deep in Titusville, Pa., a step that leads to the eventual dominance of lubricants made from crude oil.
5. HYDRODYNAMIC LUBRICATION
The Industrial Revolution spurs advances in tribological science. Using a specially constructed test rig for journal bearings, Beauchamp Tower discovers hydrodynamic lubrication in 1883. Three years later, Osborne Reynolds (above) publishes a differential equation describing the pressure buildup in an oil film.

6. SYNTHETIC LUBRICANTS
Frans Fischer and Hans Tropsch in 1923 develop a successful process for converting methane into synthetic substitutes for petroleum products. While other chemistries also are created, synthetic hydrocarbons such as polyalphaolefins come to dominate the synthetic lubricant market.

7. ADDITIVES
Chemistry booms during the early 1900s, and by the ‘30s and ‘40s lubricant additives are created at breakneck speed. Zinc dithiophosphate, whose use would eventually be threatened, bursts onto the scene in 1941 and becomes the additive of choice for anticorrosion, antioxidant and antiwear capability.

8. TRIBOTESTING
The Pin and Vee Block tester debuts in 1927, ushering in an era of standardized machines that allow reliable, reproducible test results on lubricants. Engineers now can quantify and specify the performance of lubricants for specific applications. Organizations like ASME, ASTM and STLE formalize committees that agree on standard tests for engine efficiency, fuel octane, lubricant performance and more.

9. ELASTOHYDRODYNAMIC LUBRICATION
Tribologists use the Stribeck curve to study the transition between boundary and hydrodynamic regimes and, around the middle of the 20th Century, elucidate the principles of elastohydrodynamic lubrication. This leads to improvements in the design and protection of rolling-element bearings and related high-contact stress applications such as automobiles, steel mills and turbomachinery.

10. SELF-LUBRICATING MATERIALS
Although the use of carbon as a solid lubricant was mentioned in 1906, it isn’t until the 1930s and ‘40s that self-lubricating materials such as molybdenum disulfide and polytetrafluoroethylene are formulated, allowing lubrication in extreme conditions.

11. STLE FORMED
On March 3, 1944, articles of incorporation are filed in the state of Illinois for the American Society of Lubrication Engineers. For the first time the lubrication industry’s many players are united. The name is changed to STLE in 1987.

12. THE JOST REPORT RELEASED
Lord Bowen of Chesterfield, England’s Minister of Education and Science, forms the Committee on Tribology to investigate the current state and future needs of industrial lubrication practices. Released March 9, 1966, the Jost Report documents the billions in savings that can be realized by proper lubrication procedures.
On a New Method to Determine the Yield Stress in Lubricating Grease

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3SKF Engineering & Research Centre, Nieuwegein, 3439 MT, The Netherlands

ABSTRACT

An experimental study using both a controlled stress and a controlled strain rheometer has been undertaken to characterize lubricating grease in shear, creep, stress relaxation, and oscillatory flow, with a main focus on determining the yield stress. The yield stress was examined using a cone–plate and parallel-plate system with smooth and rough surfaces. Clear discrepancies were observed in the yield stress values obtained using different techniques where oscillatory strain sweep measurements seem to be the best choice. This technique is less sensitive to wall slip, shows good reproducibility, and is relatively easy to perform. The method also shows that the yield stress is a function of the imposed frequency and therefore of the time domain. At lower values of shear—that is, in the linear viscoelastic regime—there is no structural breakdown and the rheology of the grease can be described by the Maxwell model where the stress and the strain are almost proportional to each other. Based on this observation, a novel method to determine the yield stress is proposed: “The yield stress can be determined from the point where this linearity no longer applies.” This method is compared to those that are commonly used. The yield stress was found to depend exponentially on temperature and linearly on frequency.

INTRODUCTION

Lubricating greases are generally highly structured materials consisting of a dispersion of a thickener in mineral or synthetic oil (Ehrlich (1)). The rheological behavior of lubricating grease strongly determines its performance in rolling bearings (Lugt (2)). Most of the functional properties (reservoir formation and ability to maintain a lubricant film in the bearing) of lubricating greases are related to their ability to flow under mechanical stress and their shear stability, which depends on their chemistry and microstructure (Adhvaryu, et al. (3)). Grease exhibits viscoelastic, time-dependent (thixotropy), and shear thinning (non-Newtonian) behavior. The high viscosity in the absence of shear prevents the grease from leaking out of the bearing and provides the bearing with a lubricant reservoir. During the initial operation of the bearing, macroscopic flow (churning) takes place and a fraction of grease ends up next to the running track and another fraction finds its way inside the bearing such as under

KEY WORDS

Maxwell Model; Oscillatory Strain Sweep; Arrhenius Behavior

Editor’s Note: The definition for yield stress as it applies to grease is not as clear as it could be, and that is partly due to greases not having an ideal elastic-plastic behavior. Various methods for measuring yield stress exist and the results vary in part due to the varying definition of yield stress. This month’s Editor’s Choice paper seeks to evaluate multiple methods to find a robust and efficient method. Some of the subsequent finds regarding rheology in general are quite interesting and worth a read.

Evan Zabawski, CLS
Editor
Other animals can see parts of the spectrum that humans can’t. For example, a large number of insects can see UV light.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Methodology</th>
<th>Yield Stress</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lincoln Ventimeter (Conley, et al. (4); Rotter and Wegmann (13))</td>
<td>The grease in a pipe is first pressurized (12.4 MPa) and subsequently relieved from pressure on one side after 30 s</td>
<td>( \tau = \frac{D\rho_v}{4L} ), where ( \rho_v ) is the venting pressure, ( D ) is the diameter, and ( L ) is the length of the pipe</td>
<td>Simplicity/robustness</td>
<td>Results can be influenced by waiting time, entrapped air in the grease, and wall slip</td>
</tr>
<tr>
<td>Cone penetration test (ISO 2137/ASTM D217; Rebinder and Semenenko (14))</td>
<td>A standard cone is allowed to sink into grease for 5 s</td>
<td>( \tau = \frac{KM}{h} ), where ( M ) is the mass of the cone, ( h ) is the depth of penetration at equilibrium, and ( K ) is a constant depending on the cone angle ( 2\alpha )</td>
<td>Very simple method to estimate yield stress</td>
<td>Yield stress found to be 1.5-2.5 times higher than obtained by other methods; limited temperature range</td>
</tr>
</tbody>
</table>

**Measures using commercial rheometers**

| Flow curve (Radulescu and Radulescu (5); Nguyen and Boger (15); Yeong, et al. (16)) | \( \tau \) is plotted against \( \dot{\gamma} \) | Yield stress is obtained from the extrapolation of flow curve to zero shear rate by using models for, for example, Herschel-Bulkley, Casson, Sisko, Palacios, etc. | Simple and easy to perform | The presence of apparent wall slip at low shear rates makes it difficult to determine the yield stress |
| Creep (Magnin and Piau (10); Whittingstall and Shah (17)) | Constant stress is applied and strain is recorded as function of time | Yield stress is the stress corresponding to the transition from viscoelastic solid to liquid behavior | Free from artifacts of thixotropy; very sensitive to the transition from linear to nonlinear viscoelasticity and thus for determining yield stress accurately | A number of creep curves are required; time consuming; susceptible to wall slip |
| Stress growth and relaxation (Magnin and Piau (10); Whittingstall and Shah (17); Whittingstall (18)) | A step strain deformation is applied and stress is monitored over time | Non-zero steady-state stress at a given strain rate corresponds to yield stress | Simple method to obtain yield stress; measures the true yield stress as it is measured at zero shear rates | Wall slip found to influence the yield stress |
| Oscillatory strain sweep (Balan and Franco (19); Couronne, et al. (20); Salomonsson, et al. (21); Yoshimura and Prud’homme (22)) | Sinusoidal strain deformation is applied at constant frequency and the resultant stress is monitored | With an increase in amplitude the elastic component in the stress will decrease, which could be the measure of yield stress | Less influence of wall slip within the LVE; robust | Frequency dependence |

The Maxwell equation in scalar form is given by

\[
\tau = - \frac{\eta}{G} \frac{d\epsilon}{dt} + \eta \dot{\gamma}, \tag{1}
\]

where \( G \) is the elastic modulus, \( \eta \) is the viscosity, and \( \tau \) and \( \dot{\gamma} \) are the stress and strain rate, respectively. The timescale of the problem is given by the ratio \( \frac{\eta}{G} \), the so-called characteristic time. If this characteristic time is short compared to the time of observation, then the grease behaves as a fluid; if it is long, the grease behaves like a solid (Morrison (6)).

The yield stress of such a semisolid material may be defined as the minimum stress required to produce a flow.
Hence, the yield stress marks the transition from predominant elastic to viscous behavior (Houwink and De Decker (7); Green (8)). The structure of grease consisting of base oil and thickener deforms predominantly elastically as long as the stress is below the yield stress and ruptures when the stress exceeds the yield stress. The structure may or may not be regenerated, depending on the duration and magnitude of the shear (Bondi and Eirich (9)). This is characteristic for many materials showing a similarity to grease, such as suspensions, emulsions, gels, foams, and pastes (Magnin and Piau (11)). However, it may be argued that the yield stress is an engineering approach. It was shown by Barnes and Walters (10) that the yield stress associated with Bingham plastic materials does not really exist. They showed that such materials, which flow at high stresses, would also flow at lower stresses but at a much lower rate. The viscosity may be very high at low shear rates, though, giving the material an apparent yield stress. Based on this hypothesis, they assert that no one has ever measured the yield stress, because it is obtained by extrapolation.

Though yield stress may very well be an engineering concept that can be considered as an idealization or empiricism based on various models, estimating the yield stress is a good practice for determining the ability to provide the bearing with a grease reservoir and prevent leakage (Lugt (2); Lugt, et al. (12)). It is also essential for the design of lubrication, they are less suited (especially if timescale is included). Therefore, it was chosen to evaluate the rheological methodologies making use of a parallel-plate rheometer and define a method for measuring the yield stress for lubricating greases that would be physically acceptable but also robust and illustrate this by means of yield stress measurements on lubricating greases for rolling bearings with the most commonly used thickeners and base oil.

**MATERIALS AND METHODS**

Seven types of commercially available grease were tested, the characteristics of which are summarized in Table 2. Dynamic and steady-state rheology experiments were carried out using both a controlled stress (AR 1000, TA Instruments) and a controlled strain rheometer (MCR 501, Anton Paar). Because it is known that wall slip may occur in these types of measurements, different geometries were used to characterize the grease, including (1) 25-mm smooth parallel plate ($R_a = 0.40 \mu m$), (2) 25-mm sand-blasted rough parallel plate ($R_a = 2.87 \mu m$), (3) 25-mm cone plate with cone angles of 1 and 2° ($R_a = 0.40 \mu m$). A major concern regarding rheological measurements is the effect of load history (influence of sample loading on the geometry). In order to reduce the influence of loading history on the results, the same thermal and mechanical protocol was used for all of the rheological tests. A small quantity of sample ($\approx 0.5–1.5$ g) was loaded onto the lower plate and the gap was closed by controlling the normal force, which otherwise can increase the formation of an oil layer between the plate and sample. The excess sample was trimmed using a microspatula after lowering the upper plate to a gap that is offset 0.025 mm from the required gap setting. This was performed to prevent edge effects that otherwise can contribute to the shear stress and shear rates, which are highest at the rim in the case of a parallel-plate configuration.

### Table 2 | Physical and Chemical Properties of Lubricating Greases Studied

<table>
<thead>
<tr>
<th>Grease</th>
<th>NLGI</th>
<th>Thickener</th>
<th>Shape and Average Size of Thickener</th>
<th>Base Oil</th>
<th>Base Oil Viscosity, 40/100°C (mm²/s)</th>
<th>Consistency (60 Strokes)</th>
<th>Maximum Temperature (HTPL) (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca/S/MS</td>
<td>1–2</td>
<td>Complex calcium sulfonate</td>
<td>Spherical $D \approx 0.3 \mu m$</td>
<td>Mixed mineral/synthetic oil</td>
<td>80/8.6</td>
<td>300 mm/10</td>
<td>110</td>
</tr>
<tr>
<td>Ca/S/M</td>
<td>2</td>
<td>Complex calcium sulfonate</td>
<td>Spherical $D \approx 0.3 \mu m$</td>
<td>Mineral oil</td>
<td>420/26.5</td>
<td>275 mm/10</td>
<td>150</td>
</tr>
<tr>
<td>Ca/PAO</td>
<td>2–3</td>
<td>Calcium complex</td>
<td>Fibers $L \approx 0.8 \mu m$</td>
<td>Synthetic PAO</td>
<td>130/15.5</td>
<td>260 mm/10</td>
<td>160</td>
</tr>
<tr>
<td>PU/E</td>
<td>2–3</td>
<td>Polyurea</td>
<td>Platelets $L \approx 0.6 \mu m$</td>
<td>Synthetic ester</td>
<td>70/9.4</td>
<td>283 mm/10</td>
<td>160</td>
</tr>
<tr>
<td>Li/M</td>
<td>3</td>
<td>Lithium</td>
<td>Twisted fibers $L \approx 2 \mu m$</td>
<td>Mineral oil</td>
<td>99.9/10</td>
<td>207 mm/10</td>
<td>130</td>
</tr>
<tr>
<td>Li/SS</td>
<td>2</td>
<td>Lithium</td>
<td>Twisted fibers $L \approx 2 \mu m$</td>
<td>Mineral (semisynthetic)</td>
<td>41.9/7.5</td>
<td>270 mm/10</td>
<td>140</td>
</tr>
<tr>
<td>LiC/PAO</td>
<td>2–3</td>
<td>Lithium complex</td>
<td>Fibers $L \approx 0.4 \mu m$</td>
<td>PAO</td>
<td>191/22</td>
<td>255 mm/10</td>
<td>160</td>
</tr>
</tbody>
</table>

After loading the sample, a rest time of 20 min, which was sufficient for the normal force to relax at the test temperature, was introduced before performing the measurements.

The following test were performed: steady-state flow (flow curve), step shear (stress relaxation or creep), and oscillatory shear measurements. The flow curve measurements (viscosity vs. shear rate) were carried out using a controlled strain rheometer in the range of shear rates between 10^-8 and 100 s^-1 at a temperature of 25°C. The creep and recovery experiments (strain vs. time at constant stress) were carried out using a controlled stress rheometer in the range of shear stresses of 25–1,600 Pa to assess the creep method. Constant shear rate experiments from a strain of 0.001 to 10 s^-1, in steps of a decade, were performed by using a controlled strain rheometer to assess the stress growth and relaxation method (stress vs. time at constant strain rate).

Finally, oscillatory strain sweep measurements were carried out. These measurements rely on the fact that viscoelastic materials show a response to oscillating shear (\( \dot{\gamma} = \gamma_0 e^{i\omega t} \)) that contain both in-phase (\( \frac{\tau_0}{\gamma_0} \cos \delta \gamma_0 e^{i\omega t} \)) and out-of-phase (\( \frac{\tau_0}{\gamma_0} \sin \delta \gamma_0 e^{i\omega t} \)) contributions. This is quantified by a so-called storage modulus, \( G'(\omega) = \frac{\tau_0}{\gamma_0} \cos \delta \), which is in phase with the shear, and the loss modulus, \( G''(\omega) = \frac{\tau_0}{\gamma_0} \sin \delta \), which is 90° out of phase with the shear and represents the viscous part (Yoshimura and Prud’homme (22), Macosko (23)). These measurements were carried out from a strain of 0.001 to 1000% at a frequency of 1 Hz on all samples using the controlled strain rheometer. Because this measurement method proved to be robust, additional experiments were carried out in a temperature window from -25 to 100°C in steps of 25°C with a precision of 0.5°C on a selected number of samples to investigate the effect of temperature on yield stress. To investigate the effect of timescale, the frequency of oscillation was varied for measurements at 25°C using 0.1, 0.5, 1, and 2 Hz.

### RESULTS AND DISCUSSION

#### Flow Curve Measurements

Yield stress is connected to flow by definition; it is commonly determined using standard flow curve experiments (De Graef, et al. (24)) where the viscosity is plotted as a function of shear stress or where the shear stress is plotted as a function of shear rate (Figures 1a and 1b). The flow curve shows a high viscosity region at low shear rates, followed by a shear thinning region characterized by a drop of five to six decades in viscosity. This flow behavior can be related to a dramatic structural breakdown and structural rearrangement induced by shear (Walls, et al. (25)). In this section, results obtained from steady-state measurements are described and the results are analyzed using the Herschel-Bulkley model. The main objective was to determine the influence of wall slip on yield stress and, more generally, testing conditions/parameters. This was done by varying the gap between the plates and by changing the roughness of the parallel-plate geometry.

<table>
<thead>
<tr>
<th>Grease</th>
<th>Geometry</th>
<th>Gap between Plates (mm)</th>
<th>Yield Stress (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca/MS</td>
<td>Rough plate</td>
<td>1</td>
<td>410</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5</td>
<td>347</td>
</tr>
<tr>
<td>Ca/PAO</td>
<td>Rough plate</td>
<td>1</td>
<td>694</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5</td>
<td>611</td>
</tr>
<tr>
<td>Li/SS</td>
<td>Rough plate</td>
<td>1</td>
<td>532</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5</td>
<td>591</td>
</tr>
<tr>
<td></td>
<td>Smooth plate</td>
<td>1</td>
<td>376</td>
</tr>
</tbody>
</table>

Figure 1 | (a) Flow curve obtained for Li/SS using a smooth and rough plate at a gap of 1 mm between the plates and (b) shear stress–shear rate measurement fitted using the Herschel-Bulkley model for Li/SS using rough and smooth plates.
The yield stress can be obtained from a stress–strain rate flow curve by determining the stress at zero shear rates through extrapolation. However, at very low/intermediate values of shear rate, the shear is dominated by wall slip, making it difficult to obtain a reliable value for the yield stress (Figure 1b). Problems concerning wall slip in lubricating grease measurements are commonly known in this regime and have been reported by, for example, Magnin and Piau (10), (26). Two mechanisms for wall slip have been proposed for lubricating greases. Foster, et al. (27) claimed that internal slip between the fibers will be responsible for wall slip. In contrast, Czarny (28) stated that wall slip is caused by a layer with a high concentration of oil due to the thickener concentration gradient, which is caused by the adhesion of polar thickener particles on the wall. This gradient causes slip to take place in the weakest location within the layer, which is the location with the highest concentration of base oil. Wall slip is found to be more pronounced at stresses near the yield point (Barnes (29)). Though the mechanism of wall slip is not completely understood, it has been measured for lubricating grease in a steady-state flow (Westerberg, et al. (30)) and seriously disturbs the measurements in rheometers (Magnin and Piau (10), (26); Barnes (29)).

In order to avoid wall slip effects, extrapolation should be done from measurements above shear rates of approximately 1 s\(^{-1}\) (Yeong, et al. (16)). Another countermeasure to reduce the occurrence of wall slip is using rough plates. Walls, et al. (25) found a reduction of 60% in yield stress using smooth plates compared to serrated plates for colloidal silica gels. Smooth geometries and a small gap between the plates were found to give lower values of yield stress and exhibited a low-stress Newtonian plateau in a plot of shear stress versus shear rate (Rebinder and Semenenko (14)).

Extrapolation of the shear rate–stress flow measurements to zero shear rate can be obtained by fitting the data to the Herschel-Bulkley model (Figure 1b). This viscoplastic model merges the theoretical and practical aspects of the Bingham and power law models.

The Herschel-Bulkley model reads

\[
\tau = \tau_y + K\dot{\gamma}^n
\]

where \(\tau\) is the shear stress, \(\tau_y\) is the yield point, \(K\) is the consistency index (Pa \cdot s\(^n\)), \(\dot{\gamma}\) is the shear rate (s\(^{-1}\)), and \(n\) is the shear thinning index. Excellent correlation between measurements and the Herschel-Bulkley equation was only found above shear rates of approximately 10\(^{-3}\) s\(^{-1}\). Extrapolation to lower shear rates led to significant errors, which could be at-

Figure 2 | (a) Shear creep and recovery response for CaS/M at 25°C, (b) viscosity deduced from creep compliance plot as a function of imposed stress for CaS/M, (c) influence of the gap between the plates for creep test, and (d) influence of surface roughness on stress growth and relaxation at a strain rate of 0.1 s\(^{-1}\) for CaS/M.
This "rainbow effect" occurs because different colors travel through materials at different speeds, causing them to refract at different angles and separate from each other.

The yield stress obtained for three different greases by varying the gap and surface roughness for the parallel plate geometry, by fitting the Herschel-Bulkley model to shear rate—stress measurements above a minimum shear rate of 10^-3 s^-1, are shown in Table 3 on page 63. Irrespective of the shape and average size of thickeners (Table 2), a strong dependence of yield stress on the roughness and gap is evidenced. This implies that the bulk rheological properties are no longer being accurately measured for viscous flow. This discrepancy in yield stress can be attributed to the presence of a nonhomogeneous velocity field in the grease sample being sheared, as a result of shearing of a small layer of low viscous fluid over the bulk (wall slip). Comparison of yield stress shows that wall slip is more prevalent for a smoother geometry and smaller gap between the plates.

### Creep Measurements

Creep measurements were done by applying steps with constant stress, below a critical stress (\(\tau_c\)) at which grease behaves as a viscoelastic solid with complete recovery. The stress is gradually increased to obtain several creep curves. The hypothesis is that above \(\tau_c\) grease behaves as a viscoplastic liquid and shows partial recovery (Figure 2a). From the plot of creep compliance with time it is possible to deduce viscosity for each applied stress (Whitingstall and Shah (17)). The stress corresponding to a decrease in viscosity can be used as an estimate of yield stress (Figure 2b). The yield stress values obtained using this method are shown in Table 4. This method has the advantage of allowing the sample to fully accommodate a particular stress prior to moving forward; however, it can be damaging to the sample because the stress is applied unidirectionally for a prolonged time (Whitingstall and Shah (17)). Though creep measurements are very sensitive to the transition from linear to nonlinear viscoelasticity and for determining the behavior of grease below the yield stress, it was found to be influenced by different test parameters such as gap setting and plate roughness (Figure 2c). This means that the yield stress measured will be due to the combined effect of wall slip and bulk deformation. Therefore, it was concluded that this method was not the most robust method for determining the yield stress of lubricating greases.

### Stress Growth and Relaxation Measurements

In stress relaxation experiments, a step strain rate deformation is applied to create an instantaneous strain and to monitor the stress decay as the specimen is held over time in the same constrained state. Figure 2d shows the evolution of stress with time for CaS/M measured with a controlled strain rheometer using plates with different roughness. A stress overshoot was followed by a monotonic decrease in stress with time until the steady-state was observed. The shear stress was found to decrease to a nonzero value, which is characteristic of viscoelastic materials. This non-zero stress can be used as an estimate of yield stress as it is measured at zero shear rates (Magnin and Piau (10)). The yield stress obtained was also found to be influenced by wall slip (e.g., for CaS/M the yield stress was found to be 162 and 230 Pa using smooth and rough plates, respectively). Therefore, it was concluded that this method is also not favored for determining yield stress for lubricating greases.

### Oscillatory Strain Sweep Measurements

As the last method to measure yield stress in lubricating greases, oscillatory measurements will be described here. The frequency dependence of yield stress and comparison of yield stress measured using different methodologies, along with the proposed method of measuring yield stress, will be discussed.

Figure 3 shows the evolution of storage and loss modulus with stress at a given frequency in the linear and nonlinear viscoelastic regime for CaS/MS and Li/M. The measurements were found to be unaffected by the geometry (cone vs. parallel plate, not shown), surface roughness (\(R_a = 0.40 \text{ and } 2.87 \mu m\), and gap between the plates (0.5 to 2 mm), irrespective of the

---

**Table 4** Comparison of the Yield Stress (with unit Pa) at a Temperature of 25°C Using Rough Parallel Plates (1 mm gap), Measured Using Different Methodologies and Parameters Obtained from Eq. [3] Using the Proposed Method

<table>
<thead>
<tr>
<th>Grease</th>
<th>Yang’s Yield Stress (Pa)</th>
<th>Crossover Stress (Pa)</th>
<th>De Graaf’s Method (Pa)</th>
<th>Proposed Method (Pa)</th>
<th>Herschel-Buckley (Pa)</th>
<th>Creep (Pa)</th>
<th>(\tau_o) (Pa) at 100°C</th>
<th>b</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaS/MS</td>
<td>390</td>
<td>509</td>
<td>343</td>
<td>196</td>
<td>410</td>
<td>116</td>
<td>30.9 ± 3.5</td>
<td></td>
<td>0.996</td>
</tr>
<tr>
<td>CaS/M</td>
<td>308</td>
<td>567</td>
<td>231</td>
<td>189</td>
<td>318</td>
<td>120</td>
<td>30.1 ± 2.8</td>
<td></td>
<td>0.998</td>
</tr>
<tr>
<td>Ca/PAO</td>
<td>1,626</td>
<td>1,178</td>
<td>342</td>
<td>210</td>
<td>694</td>
<td>350</td>
<td>37.6 ± 2.2</td>
<td></td>
<td>0.998</td>
</tr>
<tr>
<td>PU/E</td>
<td>1,511</td>
<td>1,811</td>
<td>743</td>
<td>270</td>
<td>958</td>
<td>537</td>
<td>86.7 ± 6.6</td>
<td></td>
<td>0.991</td>
</tr>
<tr>
<td>Li/M</td>
<td>1,187</td>
<td>1,407</td>
<td>283</td>
<td>103</td>
<td>917</td>
<td>563</td>
<td>52.2 ± 6.6</td>
<td></td>
<td>0.984</td>
</tr>
<tr>
<td>Li/SS</td>
<td>667</td>
<td>892</td>
<td>257</td>
<td>89</td>
<td>665</td>
<td>445</td>
<td>33.7 ± 3.4</td>
<td></td>
<td>0.985</td>
</tr>
<tr>
<td>LiC/PAO</td>
<td>1,050</td>
<td>676</td>
<td>392</td>
<td>172</td>
<td>1,372</td>
<td>590</td>
<td>54.6 ± 3.6</td>
<td></td>
<td>0.996</td>
</tr>
</tbody>
</table>
frequency. In addition, no significant difference was observed between the output stress waveform using different gaps and surface roughnesses at constant strain, which suggests that the rheological response is mainly due to the bulk properties of the grease. This suggests that wall slip and/or other surface effects are less sensitive when the experiments are carried out under oscillation. Balan and Franco (19) showed for greases that the effect of roughness and type of geometry does not significantly influence the linear viscoelastic parameters if low frequencies are applied. In agreement with Balan and Franco (19), the evolution of storage and loss modulus was found not to be influenced significantly by wall slip within the linear viscoelastic (LVE) range for all greases studied.

Yield Stress from Oscillatory Measurements

It can be seen in Figure 3a that below a critical stress amplitude, the material acts as a solid ($G' > G''$) and $G'$, $G''$ are independent of stress (Franck (31)). In this region (LVE), the stress is so small that the structural integrity of the network is maintained. Above the critical stress, thickener particles are not able to recover elastically, $G'$ decreases, and the material acts as a liquid. At even higher stresses, $G'$ and $G''$ cross and the viscous character will dominate. The shear rate will be so high that the network loses its structural integrity and the resulting stress will be dominated by viscous shear rather than the physical attraction/interaction by the thickener particles. Considering that a structural breakdown is necessary for this viscous flow to initiate, this critical stress could be considered as the yield stress. However, at the crossover stress (Figure 3a), the material will already be in a state of flow. Moreover, a nonlinear, nonsymmetric stress waveform was found beyond the linear viscoelastic range. Hence, although the determination of the crossover point is straightforward, the stress corresponding to the crossover point is too high to be used as an estimate of yield stress.

De Graef, et al. (24) estimated the yield stress as the intercept of the tangents of the storage modulus at low and high oscillatory stresses (Figure 3b). The first straight line (Line 1) is determined by (almost constant) storage modulus within the LVE regime, whereas the second straight line (Line 2) is derived from the measured storage modulus for stresses exceeding the LVE. However, there is an ambiguity in choosing the number of points required to obtain Line 2, which reduces the robustness of the method. Yang, et al. (32) used a dynamic strain sweep at a frequency of 0.1 rad/s and replotted the data as the product of the storage modulus ($G'$) and absolute strain (which could be called elastic stress) versus strain. They defined the yield stress as the maximum in this curve. However, their work showed that the maximum in elastic stress lies beyond the LVE range. Hunt and Zukoski (33) found, for latex-type fluids, that the yield stress is proportional to the elastic modulus ($\tau_y = \frac{1}{c} G'$ with $0.015 \leq c \leq 0.03$). Similar values were found by Delgado, et al. (34) for greases, indicating that this is also applicable to lubricating greases. However, in their method, the yield stress is determined by $\tau_y = \gamma_{max} G'$, where $\gamma_{max}$ is the maximum linear elastic strain, which first needs to be defined; thus, this method is also arbitrary in this respect.

The mechanical analog for a viscoelastic liquid is a spring and a dashpot in series (Maxwell element). The Maxwell model is constituted by the sum of the displacements of dashpot and spring (Eq. [1]). The dashpot models the viscous behavior and the spring models elastic behavior. The Maxwell model describes a fluid with elastic properties where imposing a stress results in a continuously increasing displacement. The yield stress could be considered as the stress level at which the Maxwell model is no longer linear. The linearity of the system is measured by measuring stress versus strain (Litters and Koch (35)). In the grease system, the Maxwell model is an idealization in which nonlinearity is very small at small values of strain but will increase with increasing levels of strain. Hence, the nonlinearity will not occur at a single
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well-defined stress level and the yield stress must therefore be
given by a predefined deviation from linear behavior, as is the
case in, for example, steel (0.2 equivalent plastic strain). The
procedure for this is done using an iterative fitting routine in
Matlab (Figure 4). By using this method with a third-order
piecewise polynomial fit, rather than using the discrete mea-
surement points, the sensitivity of the number (and location)
of the measurement points is significantly reduced (Figure 4).
After all, the material will behave according to a continuous
function and, if more points will be included, they will be
close to the obtained polynomial and will only have a limited
influence on the results. Another advantage of the proposed
method is that it can be used for determining the yield stress
at higher temperatures. For other methods, like the flow
curve, at higher temperatures, the centrifugal force will drive
the softened grease outwards, causing severe leakage.

Though the yield stress resulting from the proposed meth-
method was found to be less sensitive to wall slip (Table 5), it was
found to exhibit frequency dependence (Figure 5). In agree-
ment with the yield stress from the proposed method, the
crossover stress also showed a certain frequency dependence.

**Table 5 | % Error Associated with Yield Stress Due to Wall Slip and Other Surface Effects from Different Methods for Ca/PAO at T=25°C**

<table>
<thead>
<tr>
<th>Method</th>
<th>Parallel-Plate Geometry (1 mm Gap)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rough ( (R_a = 2.87 \text{ m}) ) (Pa)</td>
</tr>
<tr>
<td>Flow curve</td>
<td>694</td>
</tr>
<tr>
<td>Creep</td>
<td>350</td>
</tr>
<tr>
<td>Stress growth and relaxation</td>
<td>862</td>
</tr>
<tr>
<td>(strain rate = 0.1 s(^{-1})</td>
<td>Oscillatory strain sweep (1 Hz)</td>
</tr>
<tr>
<td></td>
<td>Crossover stress</td>
</tr>
</tbody>
</table>

---

The branch of physics that studies the properties and behaviors of light is called optics.
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The frequency dependence of yield stress can be illustrated by the Maxwell model from Eq. [1], where yield stress is determined by the point at which the spring is no longer linear. The measurements are done on the full Maxwell system and the presence of the dashpot makes the strain–stress relation time dependent. For example, at very high-frequency displacements (fast displacements, short timescale) the dashpot is very stiff and a large portion of the stress is put on the linear spring, whereas at low frequencies (slow displacements, short timescale) the dashpot is very soft and a large part of the energy is dissipated by the dashpot, which induces time dependency on measured nonlinearity and yield stress. These results show that a unique value for the yield stress does not exist.

With this model, the yield stress is considered as a concept that should be associated with the timescale of the problem to be solved. The breakdown of the thickener network is a function not only of stress and strain but also of the timescale at which the stress or strain acts on its structure. In rolling bearings, this timescale varies throughout its internal geometry. For grease located in the grease reservoirs, only creep will occur and the timescale is therefore very long (low frequency). On the other hand, in the event of high-frequency oscillations (short timescale) the yield stress of lubricating greases will be much larger and it will become apparently stiffer. This is relevant for the prediction of the resistance to flow in the case of vibrations and/or shock loads in bearings.

The yield stress determined from the proposed method is compared with the elastic stress proposed by Yang, et al. (32), the crossover stress, and the De Graef et al. yield stress (De Graef, et al. (24); Table 4). The yield stress obtained was found to be different than that determined by other methods. To illustrate: the yield stress as defined with the present method does not apply to the Herschel-Bulkley model. After all, in the present definition the yield stress is defined as the stress where the grease is no longer viscoelastic, whereas it is defined in the Herschel-Bulkley model as the stress at zero strain rate. Similar arguments hold for the other methods.

### Temperature Dependence of Yield Stress

The temperature dependence of yield stress for all of the greases is studied in the following section to demonstrate the robustness of the proposed method under more extreme conditions. The variation in yield stress with temperature is analyzed using an Arrhenius-type equation.

It is well known that the yield stress, obtained from flow curves, is exponentially dependent on temperature (for an overview, see Lugt (2)). The proposed method for measuring the yield stress shows similar temperature dependence. The yield stress versus temperature of the greases studied at a frequency of 1 Hz is displayed on a semi-log-scale (Figure 6) and is fitted with a straight line. At a temperature of -25°C, a deviation from this Arrhenius behavior was found for a number of greases, except for Ca/PAO, PU/E, and LiC/PAO. This unexpected high yield stress may be caused by phase transitions within the microstructure.

A convenient way to describe the Arrhenius behavior is through

$$
\tau_y = \tau_{y0} \left( \frac{T - T_0}{T_0} \right)^b
$$

where $\tau_{y0}$ is the yield stress at temperature $T = T_0$.

This equation expresses the variation in the yield stress with temperature: the yield stress decreases by half with a temperature increase of $\Delta T = b$. Greases with a small value of $b$ show a high variation in the yield stress with changes in temperature. The different values of $b$ used to fit the data can be found in Table 4.

It is important to note that except for Ca/PAO, PU/E, and LiC/PAO, the measurement points at -25°C were excluded from the curve fitting. At these low temperatures the yield stress is exponentially dependent on temperature (for an overview, see Lugt (2)). The proposed method for measuring the yield stress shows similar temperature dependence. The yield stress versus temperature of the greases studied at a frequency of 1 Hz is displayed on a semi-log-scale (Figure 6) and is fitted with a straight line. At a temperature of -25°C, a deviation from this Arrhenius behavior was found for a number of greases, except for Ca/PAO, PU/E, and LiC/PAO. This unexpected high yield stress may be caused by phase transitions within the microstructure.

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stress does not follow an Arrhenius behavior anymore. Table 4 shows that the yield stresses of lithium grease are less sensitive to temperature compared to other greases studied.

CONCLUSIONS

In this study, different methods for measuring the yield stress of lubricating grease using a commercial rheometer are evaluated. It was found that the type of geometry and surface roughness exert a significant influence on the yield stress obtained with the earlier reported methods. Oscillatory strain sweep measurements seem to be a robust choice to estimate the yield stress as it was found to be less sensitive to wall slip. This method provides reliable and reproducible data, irrespective of the rheometer's geometry, surface roughness, or surface cone/plate material. Generally, the yield stress is defined as the stress at which a solid starts yielding; that is, is no longer elastic.

For lubricating greases the linear elasticity is ascribed to the solid character of the thickener structure. The grease rheology in the viscoelastic regime can be described with the Maxwell model, and the measurements in this article illustrate/confirm that lubricating greases only show this linearity at low levels of strain. There is not a distinct transition from elastic to plastic behavior. An ideal elastic–plastic behavior does not exist. In contrast, the linearity gradually decreases with increasing shear. The yield stress was therefore defined as the stress at which a predefined deviation from the linear behavior at very low strain takes place (0.5%), as is done for steel. By using the proposed method, the influence of the number (and location) of the measurement points can be significantly reduced. The yield stress for seven different greases was measured with six different methods, of which five are well established. The methods give very different results. This is sometimes caused by a different definition of the yield stress.

The interaction of the thickener with the lubricating oil (viscoelasticity) makes the yield stress time dependent. A lubricating grease yields at higher stresses when exposed to shear at higher frequencies than at lower frequencies, a behavior that can be explained by the Maxwell model. Application of the yield stress in grease flow problems should therefore be carefully done. The values that are chosen for the yield stress should be related to the timescale of the flow problem.

The yield stress measurements as a function of temperature show an Arrhenius behavior; that is, the yield stress decreases exponentially with increasing temperature. It was remarkable that all seven grease types tested showed this behavior within a certain temperature window, although the greases...
had clearly different thickener and base oil types. A discrepancy from Arrhenius behavior was noted for a few greases at extremely low temperature. Therefore, there are indications that the yield stress increases at a higher rate with decreasing temperature below this temperature.

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REFERENCES

FUNDING
The authors thank SKF Engineering & Research Centre, Nieuwegein, The Netherlands, for providing the grease samples as well technical and financial support. We would like to extend our sincere gratitude to M2i, the Materials Innovation Institute, Delft, The Netherlands, for funding this study.
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CRODA EXPANDS SINGAPORE ALKYOXYLATION PLANT

Croda International Plc, based in East Yorkshire, UK, celebrates the grand opening of the expansion of alkoxylvation facilities on Jurong Island, Singapore as part of its global strategy to provide innovative solutions closer to customers in the fast growing markets of Asia Pacific.

Capacity will double at the site and it will provide additional flexibility to manufacture new chemistries.

The inauguration ceremony was officiated by Dr. Nick Challoner, president of Croda Asia Pacific, and Ms. Cindy Koh, director of the Energy & Chemicals Group of the Singapore Economic Development Board. The event was attended by participants from various stakeholders including Croda’s customers, the scientific and academic community, suppliers and other key business partners.

“This latest expansion is another step in the execution of Croda’s strategy to develop and supply innovative solutions in Asia for our customers,” says Dr. Challoner.

Croda has had a long presence in Singapore with the opening of its first sales office in the country in 1985. In 1990 Croda Singapore started manufacturing esters and in 1999 moved to Jurong Island to start up its first integrated alkoxylvlation plant in Asia. This most recent expansion is the company’s largest investment in Singapore since the plant was built.

The Singapore expansion has positively impacted the local economy with the design and construction spanning the last two years and the employment of new skilled jobs at the Jurong Island site to run this new facility.

TEKNOR APEX APPOINTS VANDERBILT CHEMICALS AS GLOBAL DISTRIBUTOR

Pawtucket, R.I.-based, Teknor Apex Co. has appointed Vanderbilt Chemicals, based in Norwalk, Conn., as the exclusive global distributor of its TruVis™ line of ester products.

The TruVis Ester product range includes adipate, trimellitate and polyol esters for use as base stocks and additives for the automotive, industrial, metalworking fluid and grease market segments in the lubricant industry. The high lubricity of TruVis Esters, combined with their low- and high-temperature performance, means that they are well positioned to meet the increasing performance demands of synthetic lubricants. Vanderbilt will support these products through customer service, technical service, bench testing, application development and warehousing.

“Teknor Apex has singled out the lubricants market for its high growth potential and will benefit from Vanderbilt’s global reach and extensive experience in the automotive, industrial and grease markets,” says STLE-member Randall Butler, business director for the chemicals division of Teknor Apex. “We will work in close partnership with Vanderbilt whose extensive applications laboratory will provide valuable technical support for our products.”

“Vanderbilt Chemicals is pleased to form this partnership with Teknor Apex, which has been a manufacturer of high-quality esters for over 60 years,” says STLE-member Glenn Mazzamaro, global business manager of Vanderbilt’s petroleum department.
“We have made a multimillion dollar investment in our Petroleum Applications Laboratory in Norwalk, and we will continue to devote resources to expand our technical support capabilities. Our knowledge of the lubricant industry, coupled with Teknor Apex’s manufacturing expertise, will provide great value to our customers.”

**DOW CORNING SCIENTIST ELECTED TO BOARD OF GERMAN TRIBOLOGY GROUP**

At the conference of the German Tribological Society (GfT), a globally recognized Dow Corning lubrication expert was elected to the group’s board of directors. Associate industry scientist and STLE-member Manfred Jungk of Dow Corning’s Molykote® brand was elected to a three-year term on the board after previously serving on the group’s Technical Advisory Committee.

GfT is a technical scientific association serving the lubrication industry in Germany, including both academia and the technical side of the industry. Jungk holds a doctorate in chemistry and has worked for Dow Corning for nearly 30 years.

“Being a part of GfT provides an opportunity to hear early on about trends and challenges in the industry and to help the German market develop solutions and anticipate upcoming technologies,” says Jungk.

GfT has a specific focus on the German lubrication industry, Jungk says, and he hopes his relationships developed through involvement in larger-scale organizations such as the European Lubricating Grease Institute and STLE “can help provide greater networking opportunities and more international exposure” for GfT.

**ASTM TEST METHOD HELPS REDUCE ASPHALTENES IN OIL**

A new ASTM International standard will help to more quickly and accurately detect for contaminants called asphaltenes in a variety of petroleum products.


According to ASTM-member Farshid Mostowfi, Ph.D., asphaltene deposits in the oil production process cost the industry billions of dollars an-
nually. “The asphaltene problem exists deep in reservoirs along transportation networks in refineries and all the way in fuel systems,” says Mostowfi, a principal scientist and program manager at Schlumberger. “Therefore, monitoring asphaltenes and their variations is paramount to avoiding expensive remedial operations.”

Measuring asphaltene deposits has traditionally required bulky glassware, well-ventilated laboratory environments and skilled operators. These techniques take up to two days to perform.

The new test method takes less time and provides increased precision. In addition, the test requires smaller sample and solvent volumes, leading to a smaller environment footprint. Using the standard to monitor asphaltenes throughout the life cycle of a fuel could reduce remediation costs and improve efficiency.

The new standard will cover gas oil, diesel fuel, fuel oils, residual fuel oils, lubricating oil and bitumen, as well as crude oil that uses microfluidics and spectrographic techniques.

**API LAUNCHES CERTIFICATION PROGRAM FOR QUALITY SYSTEMS AUDITORS**

Washington D.C.-based, The American Petroleum Institute’s global industry services department (API Global) has established a new and comprehensive Auditor Certification Program, which is the first to be developed by industry experts.

“API is committed to safety as a core value, and we are pleased to offer this new auditor certification program to help improve the safety and performance of oil and natural gas operations worldwide,” says Lisa Salley, vice president of API Global. “API standards and certifications are the industry gold standard. The program is designed specifically for and by oil and natural gas quality management professionals and draws upon API’s deep industry knowledge and expertise.”

Company personnel and self-employed individuals can register to be trained, tested and certified to audit various quality management programs according to API’s globally recognized standards. The certification of credentialed auditing professionals will play a key role in advancing quality programs, efficiency and safety within the industry.

Certification candidates are required to provide proof of appropriate education, qualifications, training and audit logs as part of the application and pre-qualification process. They must also sit for and pass a 150-question exam administered worldwide at Prometric computer testing centers. The first exams will be offered March 1-15, 2016. API plans to hold three auditor certification exam periods per year.

Each of the three levels of certification can be obtained with a focus on either API Spec Q1 (Specification for Quality Management System Requirements for Manufacturing Organizations) or API Spec Q2 (Specification for Quality Management System Re-
Innovative Corrosion Inhibitor/Emulsifier/EP Components for your water based formulations

Carefree CI-4002 offers proven Rust Protection with excellent hard water compatibility, low foaming tendency, low aquatic toxicity, and ready biodegradability, Water Soluble EP-2302 gives cutting edge EP performance, and Emulsifier EMS-HL is Bio-resistant for your water based formulations
requirements for Service Supply Organizations).

For more information about the Auditor Certification Program, please visit www.apl.org/ICP.

**BASF KAOLIN NAMES HORN GLOBAL DISTRIBUTOR OF THE YEAR**

La Mirada, Calif.-based, HORN, one of North America’s premier distributors of specialty ingredients, chemicals and raw materials, proudly shares its latest accolade, Global Distributor of the Year, as awarded by BASF Kaolin.

By winning the BASF Kaolin Regional Distributor of the Year Award in the Americas, HORN became a contender for the inaugural global distributor recognition and won the award by unanimous vote.

“Our kaolin distributors are key to our success and deserve a special recognition for their outstanding contribution,” says Jan Jeffries, sales director, BASF Kaolin Americas. “By continually delivering results and displaying transparency throughout the year, HORN was selected among our top kaolin distributors for their achievements.”

HORN’s regional recognition from BASF Kaolin was included in the following years: 2014, 2013, 2011, 2007, 2006, 2005, 2004 and 2001. HORN has been representing BASF Kaolin in the Western U.S. for more than 25 years and has a longstanding partnership with the BASF Corp. for more than 45 years.

“We are humbled and honored to accept this inaugural global recognition from our long-time partners at BASF Kaolin,” says Bob Ahn, president, HORN industrial division. “Our partnership continues to flourish and stands the test of time thanks to a commitment to mutual growth and a collaborative effort to serve the industry with innovative solutions and technical excellence.”

**SENTIENT SCIENCE ANNOUNCES WORKING CAPITAL INFUSION**

Buffalo, N.Y.-based, Sentient Science, the leading provider of materials science-based life prediction and extension technology, announces a significant working capital infusion to add new products to its wind turbine operator fleet.

Toba Capital selected Sentient Science as its first investment in materials science-based prediction software. Sentient has initially focused the DigitalClone technology on roller bearing centric, rotating equipment delivering computational testing and asset management. This investment will support accelerated growth through added sales, marketing and product investments, along with international expansion.

Sentient, which recently went to the White House to receive the nation’s highest technology honor, the Tibbetts Award, also will add supplier and logistics services to its rapidly growing fleet of rotating equipment assets. DigitalClone is a fundamental innovation in the market with physical accuracy, high visibility and a low cost, enabling efficient life extension operations and vendor comparisons for mechanical power and drivetrains including bearings, gears and lubrication additives.

“Sentient Science’s DigitalClone software has eliminated the costs and the lengthy process associated with the physical testing of materials, components, systems and fleets,” says STLE-member Ward Thomas, chairman and CEO of Sentient Science. “How would your business be transformed if all of your decisions were tested in real time and virtually for free? Our brilliant team of material scientists, developers and market experts give operators and suppliers simulations of millions of scenarios, tested 24 hours a day, seven days a week, 365 days per year on every component of their rotating assets. Now trillions of dollars in bearing-centric spending decisions can be made based on our predictions, lowering the cost of sales and purchasing for our clients, while improving outcomes equal to 13% of revenues. That is a huge number. We currently have more than 14,700 gearboxes under contract and this financing accelerates that momentum.”

**PROMOTIONS & TRANSITIONS**

**BECHEM LUBRICATION TECHNOLOGY EXPANDS ITS TEAM**

BECHEM Lubrication Technology, based in Chagrin Falls, Ohio, announces that Jillian Jurvelin has joined the BECHEM sales and application engineering team.

After graduating from the University of Detroit with a bachelor’s of arts and master’s degrees in industrial organizational psychology, Jurvelin comes to BECHEM with consulting and sales experience in both automotive and general industry market areas. Jurvelin will be joining the specialty lubricants team for BECHEM that continues to further expand in North America.

“We look forward to having Jill join our team of professional sales and application engineers. She brings another dimension to our group that will blend well with the rest of team as we continue to expand our market penetration in the specialty lubricants market sector,” says STLE-member John Steigerwald, president of BECHEM Lubrication Technology.

**TAUBER INSTITUTE FOR GLOBAL OPERATIONS NAMES INDUSTRY DIRECTOR**

Ann Arbor-based, University of Michigan Tauber Institute for Global Operations welcomes Raymond Muscat as industry director.

The Tauber Institute is a joint venture between the University of Michigan’s Stephen M. Ross School of Business and the College of Engineering, and many industry partners to facilitate cross-disciplinary education in global operations management. In this role Muscat will participate in strategic planning and lead strategic initiatives for the institute.

Muscat’s 37-year corporate career includes global experiences in the automotive, defense electronics, aerospace
and office furniture industries. His expertise spans engineering, manufacturing, program management, mergers and acquisitions, global manufacturing strategy development and execution and the implementation of the Toyota Production System/Lean Manufacturing principles.

Muscat’s career began in 1978 at Ford Motor Co. where he worked in the automotive assembly division. In 1980 he joined Raytheon Co.’s submarine signal division where he held a variety of manufacturing engineering and program management positions for surface ship sonar programs. From 1984-1986 he worked at Ball Aerospace in Boulder, Colo., developing manufacturing operations for military aircraft antennas. He joined Knoll-Shaw/Walker in Muskegon, Mich., in 1986 and held the positions of project engineer, product engineering manager and director of engineering for Midwest operations. Muscat joined Herman Miller in 1991 where he was responsible for engineering, new product development, operations management, etc. Muscat then served as vice president of manufacturing for Cignys, a precision engineered products company in Saginaw, Mich.

Muscat holds a bachelor’s of science in industrial and operations engineering from the University of Michigan and an MBA from the University of Rhode Island.

SENTIENT SCIENCE HIRES CHIEF SCIENTIST

Sentient Science, based in Buffalo, N.Y., announces STLE-member Dr. Nick Weinzapfel has joined its team of scientists as chief scientist for computational bearings.

Weinzapfel will be responsible for the development and application of bearing prognostics tools within DigitalCloneLive for operators and DigitalCloneLive for suppliers. He will re-unite with his colleagues from Purdue University, STLE-members Dr. Nathan Bolander and Dr. Behrooz Jalalahmadi.

“We are ecstatic that Nick has decided to join our team. We’ve admired his work for quite some time, and we are thrilled that we’ll be able to use his expertise in the dynamics and materials science of energy and transportation bearings. We are now engaging bearing suppliers worldwide and making our solutions available to operators across the DigitalClone operator network,” says Dr. Nathan Bolander, chief
technology officer at Sentient Science.

Weinzapfel holds his doctorate in mechanical engineering from Purdue University. He spent the last three and a half years leading R&D of life extension and asset management technologies at Schaeffler Group, a major bearing supplier for the wind energy industry, before coming to Sentient Science to lead the R&D efforts of bearings applications for DigitalClone Solutions. For the past six years he was the associate editor of Tribology Transactions, STLE’s peer-reviewed journal.

“It’s like coming home,” says Weinzapfel. “I have worked with many members of the Sentient team over the last eight years at Purdue University and also as chairman of the Bearing Committee at STLE. Relationships are very important to my success and I invite my long-standing colleagues at Schaeffler, Timken and SKF to participate in my bearing research here at Sentient Science.”

IN MEMORIAM

JEREMIAH MPAGAZEHE

With great sadness TLT reports that Jeremiah Mpagazehe, a resident of Pittsburgh, Pa., passed away suddenly in January. He was 31.

Jeremiah was a project scientist who commercialized research in both The Particle Flow & Tribology Lab and the LeDuc Cellular Biomechanics Laboratory at Carnegie Mellon University (CMU). He won the 2012 STLE Student Poster Competition Gold Level Award in St. Louis. He also won STLE’s Young Tribologist Award winner in 2013 at the society’s annual meeting in Detroit. He earned his bachelor’s of science (2006), master’s of science (2010) and doctorate degrees (2013) all in mechanical engineering from CMU.

“A focused young man, he was arguably the most sophisticated and innovative researcher, teacher, mentor and fundraiser of his peer group,” says STLE-member C. Fred Higgs III, professor of mechanical engineering at CMU who also was Jeremiah’s advisor, mentor, business partner and colleague.

“He did everything full speed and at a high level. He has left concrete legacies for CMU and our lab.”

Want to be recognized in TLT?

TLT is interested in hearing from our readers. Let us know what’s happening in your company. If you have news about a new employee or if someone in your company has been recognized with an award or any other interesting items, let us know. Please send us your news releases and photos for publication in Newsmakers to TLT Magazine, Attn: Rachel Fowler, 840 Busse Highway, Park Ridge, IL 60068, rfowler@stle.org.
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Annual Meeting & Exhibition
May 15-19, 2016
Bally’s Las Vegas Hotel
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RE Volvo Quick-Fit™ Housed Units

With the first-of-its-kind angled support pedestal, Timken® Revolvo Quick-Fit™ split cylindrical roller bearings now make installation even easier for change-outs where access is limited. The totally new design can reduce installation time up to 90%, and in many cases one person can complete the installation. The Timken Co. launched Quick-Fit housed units in Europe earlier this year and is now introducing the line in North America. First produced by Revolvo in 2011, the angled pedestal eliminates the need to remove the drive and lift the shaft to replace a solid bearing or to replace the support pedestal of a split bearing. The complete line of Revolvo split-to-the-shaft cylindrical roller bearing housed units allows the bearing to be assembled around the shaft without requiring access to the shaft ends. Once installed, maintenance personnel can easily remove support caps and housing components for quick visual inspection, saving maintenance time. The seven concentric seal designs provide customized options to meet harsh environments requirements, which can extend operational life beyond competitors’ designs. Widely used by mining, power generation, food and beverage, pulp and paper, metals, cement, marine and wastewater operators, these units can quickly reduce maintenance costs and increase plant profitability.

The Timken Co.
North Canton, Ohio
(234) 262-3000
www.timken.com

NYCObase® 9670X HIGH-TEMPERATURE NEOPOLYOL ESTER

NYCO introduces Nycobase® 9670X, a new neopolyol ester with enhanced high-temperature stability and improved lubricity to respond to the ever-increasing demand of thermally stable base stocks driven by the raising severity of lubricant applications. Nycobase 9670X provides high thermal and oxidative stability, low evaporation and coking propensity, high hydrolytic stability and excellent lubricating properties. In particular it will show improved antiwear additive response and will achieve flash points exceeding 300°C when suitably additized. Nycobase 9670X is suitable for the formulation of any high-temperature lubricants such as chain oils and air compressor oils, and will provide optimized performance when mixed with other high-temperature esters from NYCO’s portfolio such as Nycobase 1040X, 1060X or 9600X.

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+33 (0) 1 45 61 50 00
www.nyco.fr/en/

High Viscosity Mobile Filtration Systems

Schoeder Industries, a recognized leader in filtration and fluid conditioning products, releases the High Viscosity Mobile Filtration Systems MFD-MV. The line of high viscosity filtration carts has been expanded with the introduction of the MFD-MV. It is capable of handling fluids of up to 5,000 SUS, at 6 or 10 gpm, bridging the gap between the regular carts and the MFD-HV high viscosity cart for fluids up to 10,000 SUS. The MFD-MV is a compact, self-contained filtration system equipped with high efficiency, high capacity elements capable of removing particulate contamination and/or water quickly, conveniently and economically. It is perfect for cleaning up existing systems as well as for pre-filtering new fluids, since new fluids often have contamination levels significantly higher than that recommended for most hydraulic systems.

Schoeder Industries
Leetsdale, Pa.
(724) 318-1100
www.schooderindustries.com

The world’s longest lasting light bulb, the Centennial Light in Livermore, Calif., has reportedly been burning since 1901 with only a few short shut-offs.
ALL-IN-ONE AUTOMATED LUBRICANT ANALYSIS SYSTEM

Spectro Scientific announces the launch of the new MicroLab® Series all-in-one, automated lubricant analysis systems. The MicroLab platform is used in virtually every industry that operates equipment powered by engines including automotive and trucking, energy, mining and heavy equipment, agricultural and the government sector at all levels from the military to local municipalities. The ability to perform oil analysis on location eliminates the ongoing expense of outside testing services and dramatically reduces the time waiting for the results of those tests. This can save days or weeks, which can be critical, for example, if you are a mechanic trying to diagnose a problem on a vehicle before it leaves the service bay. The systems provide comprehensive results in less than 20 minutes, which enables companies to maintain the readiness of mission-critical assets and improve reliability at remote locations while decreasing downtime and lowering maintenance costs. The MicroLab is a multicomponent analyzer used for engine, generator, gear box, power steering and transmission fluids. It is offered in two versions—the MicroLab 30 provides key properties for oil chemistry, kinematic viscosity and concentration of 10 wear and contamination metals. Additionally the MicroLab 40 version offers an increase to 20 wear, contamination and additive metals along with the addition of a particle counter for analyzing gear and hydraulic oils.

Spectro Scientific
Chelmsford, Mass.
(978) 486-0123
www.spectrosci.com

MULTIMODE 8-HR ATOMIC FORCE MICROSCOPE

Bruker Corp. announces the release of the MultiMode 8-HR Atomic Force Microscope, which brings extensive new capabilities for nanomechanics and higher speed imaging to the world’s highest resolution, most widely used and field-proven scanning probe microscope. The new nanomechanics features of MultiMode 8-HR enable researchers to access the broadest range of ramp frequencies for viscoelastic studies and nanomechanical assessment of a wide range of materials, from soft biological specimens to hard metallic samples. The high resolution and data processing capabilities of the MultiMode 8-HR are the result of its combination of rigid, mechanical design and extremely advanced control electronics. Utilizing Bruker’s NanoScope® V Controller and new Version 8.2 software, the system features unprecedented bandwidth and extremely low-noise data acquisition to enable such proprietary technology advances as ScanAsyst®, Peak Force QNM and FastForce Volume. These features combine to reaffirm the MultiMode 8-HR as the most versatile, highest performance AFM in its class.

Bruker Corp.
Billerica, Mass.
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www.bruker.com

PARTICLE ANALYSIS INSTRUMENT

Anton Paar introduces the Litesizer 500, the next generation in particle analysis instruments. The Litesizer 500 is an instrument for characterizing nano- and microparticles in dispersions and solutions. It determines particle size, zeta potential and molecular mass by measuring dynamic light scattering, electrophoretic light scattering and static light scattering. The Litesizer 500 combines a user-friendly software interface with cutting edge technology to provide a paradigm shift in particle characterization. Experiments can be set up in a few seconds, and you can produce the analyses and reports you need at the touch of a button. It has a robust design that is resistant to dust and vibration.

Anton Paar
Graz, Austria
+43 316 257 0
www.anton-paar.com
When making a recommendation on bearings, how do you balance reliability/durability issues with cost?

Reliability is Job No. 1. That is the message advocated by TLT readers answering this month’s question on bearing selection. “Reliability has to be first,” one reader said. “The cost of labor and downtime far outweighs bearing cost.” A recurring theme among survey respondents is to focus on the total cost of ownership. Many readers recommend documenting the cost of quality parts and proper lubrication regimes versus down time and replacement costs and then taking the analysis to decision makers at the operation. “Usually some additional up-front cost pays large dividends through the life of the equipment,” noted one reader. It’s a message that apparently is resonating with end-users. According to survey respondents, only 25% of end-users make a bearing selection based primarily on cost.

The customer, if educated in tribology, can calculate the ROI of investing in a quality bearing but only if they have implemented best practice lubrication reliability programs that ensure the bearing is lubricated by the correct grease, in the correct quantities/interval and that contamination is excluded. Without such a program, even if the bearing is the best in the world, it is highly likely to fail sooner than wanted or anticipated.

I recommend bearing solutions mainly based on reliability. Reliability means for me that lubrication works and lifetime is reasonable—in this order. Only in very extreme cases do I recommend special bearings.

We always use the OEM-specified bearing.

From an Indian point of view, the durability is much more important than reliability. So here cost plays a vital role. In order to gain confidence on your product, it is very important to prove the durability of the bearing at an effective cost. Reliability is a most important factor for trouble-free running. When it comes to continuous process industries like steel making, reliability is considered above durability. Again, the cost to achieve this matters a lot unless it is a very special product. So depending on the end-user it is very important to take the right balance of reliability and durability issue with the cost.

Total cost of ownership.

Reliability is key in industrial, power plant and commercial vehicle applications.

Reliability and durability are paramount, so we balance by inspecting and testing lower-cost alternatives.

Proper bearing design for load, speed, mounting and operating environment overtakes cost in order to ensure a full bearing life.

In the aviation industry we weigh heavily on the safety of flight.

For end-users making a selection on bearings, do you feel cost is their No. 1 factor?

<table>
<thead>
<tr>
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<th>Yes</th>
<th>No</th>
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<tbody>
<tr>
<td></td>
<td>25%</td>
<td>75%</td>
</tr>
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</table>

Based on responses sent to 13,000 TLT readers.
Customers come to us because we make high-performance synthetic lubricants. We balance things much more toward performance over cost.

It depends on the grade of criticality of the machine to the process.

The key is considering the cost of the total life and function of the bearing (incorporating energy consumption, productivity/downtime, maintenance, lubrication costs, risk of premature failure, expected life) and not just the unit cost of the bearing. Balance is then much easier to achieve.

Reliability is the biggest factor; cost is secondary.

Focus on load capacity balanced with reliability.

What phrase best describes most end-users’ knowledge of bearing selection, maintenance and lubrication?

<table>
<thead>
<tr>
<th>Statement</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>They pretty much know everything they need.</td>
<td>2%</td>
</tr>
<tr>
<td>They’re fairly knowledgeable but need help from a lube engineer.</td>
<td>67%</td>
</tr>
<tr>
<td>They’re just barely competent.</td>
<td>21%</td>
</tr>
<tr>
<td>They’re floundering.</td>
<td>8%</td>
</tr>
<tr>
<td>They’re absolutely clueless.</td>
<td>6%</td>
</tr>
</tbody>
</table>

Based on responses sent to 13,000 TLT readers. Total exceeds 100% because some readers submitted more than one answer.

Go with the reliability and durability. You can usually show the cost savings of longevity and loss of down time.

Cost of maintenance. And down time versus the cost of a premium lubricant.

Try not to offer a solution where cost cannot justify performance.

I would always prefer recommendations from the OEM whether cost effective or not. I would prefer reliability/durability over cost and would tell the customer as much.

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It depends on the level of service and risk of failure.

In my opinion this can only be done with proper selection of the bearing.

Reliability/durability is more important than cost.

Stick to what is formally recommended by the OEM. When that is followed, cost issues go out the window.

Proper lubrication and maintaining the integrity of the fluid and grease is much cheaper than the failed parts, downtime and lost productivity than the expense of the lubricant or cleanliness procedures. Using reliability-based lubrication calculations to get these costs on paper is very effective in solving problems. I always lean toward reliability/durability over cost.

Estimated hours of operation for productivity.

Cost is secondary. Lubricants are there to do a job and sometimes that comes at a price.

Check for speed and type of heat and usage and product being run.

On the typical motor and pillow block bearings, we have done detailed analyses of the largest eight or 10 bearing vendors and found little difference in their quality levels. At times they all have problems, but the proportion is small, especially compared with what North American vendors were producing 40 years ago. On very large bearings—for example more than 400-mm bore—we have seen situations where overseas suppliers have had the bearings in stock for a long time and surface corrosion has occurred. They clean up the corrosion, but the hydrogen damage is still there.

If equipment is process critical, cost is not a factor.

Historical performance versus life expectations in conjunction with cost.

We just focus on performance.

Maintenance for higher productivity looks to be the best basis for a recommendation.

It depends mostly on the service it will see, but the value of reliability will almost always exceed the cost.

Production will always dictate quality. Price is not a determining factor.

Use life cycle cost evaluation to make an educated decision and sell the economics to those that approve spending. Usually some additional up-front cost pays large dividends through the life of the equipment.

Reliability and durability far outweigh cost.

---

When developing bearings for a variety of industrial applications, how important are corrosion issues?

Having the best possible grease applied to the bearing in the correct quantities and rates helps ensure that bearing corrosion is not an issue for the end-user.

Not so important. Usually bearing construction IP-classification meets requirements.

Very important. We’ve had bearings that have arrived “pre-rusted.”

Very important. For example, the food and pharmaceutical industries can process some very corrosive materials and can have aggressive machine-cleaning regimes.

Corrosion prevention by the lubricant is critical, especially in marine applications.

Corrosion issues account for about 30% of failures and is dealt with through improved sealing, lubricants or material options.

Many bearings work in environments where water is present or nearby. Without proper seal technologies, corrosion becomes an issue. Bearings need coatings and proper lubricants to prevent corrosion.

Corrosion is an issue for the bearing shell.

Corrosion can cause bearings to fail rapidly or not work at all. Corrosion prevention should never be overlooked.

Corrosion issues definitely apply to marine applications (exposure to saltwater environment). Land-based applications in humid environments also need consideration of corrosion potential.

Very important, especially in steam turbines.

Corrosion is application specific; so it’s not always a criteria but still needs to be addressed when necessary.
THE SOCIETY OF TRIBOLOGISTS AND LUBRICATION ENGINEERS is seeking student posters for the 71st Annual Meeting & Exhibition at Bally's Las Vegas Hotel and Casino in Las Vegas, Nevada (USA), May 15-19, 2016.

Event organizers are inviting students from all areas of tribology research to participate in a special session dedicated to student posters. The posters must deal with an aspect of tribology research that can be translated into friction, wear and lubrication. Student poster research topics can be co-authored by faculty and other researchers, but only students may exhibit their posters and discuss their work at the session. The posters will be judged by a conference committee, and awards will be given to the best nine posters.

STLE is now accepting abstracts for posters at www.stle.org. The deadline for abstract submissions is March 15, 2016. Notification of acceptance will be sent to students shortly after this date.

THE CRITERIA FOR POSTER SUBMISSIONS ARE AS FOLLOWS:
• The poster must present original work by the student during the 2015-2016 academic year.
• The student may submit only one poster as the lead author.
• As the lead author of the poster, the student should have performed the major portion of the work.
• Lead authors must be full-time graduate or undergraduate students registered during the 2015-2016 academic year.
• Posters can be no larger than 48 x 48 inches.
• Posters must be set Sunday afternoon or Monday morning. The author must be present at the poster display during the judging session Monday, May 16, during lunch and during the scheduled conference break that afternoon.

THREE AWARDS WILL BE GIVEN IN EACH OF THE FOLLOWING CATEGORIES:
Platinum: superior scientific and presentation quality ($300 prize)
Gold: good technical quality ($200 prize)
Silver: overall quality worthy to be encouraged ($100 prize)

Winners will be announced during the Presidents Luncheon Tuesday, May 17.

For additional questions about the student poster session, please contact Merle Hedland, mhedland@stle.org.
Corrosion is a big deal! Per the question, I won’t discuss any marine applications. I’m in the southeast, a very humid environment. There is usually a spot or multiple areas of rust and corrosion on bearing new parts prior to installation. Take care of these new parts. Next, bearings in aggregate plants, paper mills and steel mills are very susceptible to water, dirt ingress and abrasive materials they manufacture. Many users are realizing the importance of cleanliness, utilizing particle count diagnose and breathers to help combat dirt and water ingress. On a smaller scale we’ve helped alleviate $80,000 in losses in productivity annually on one gearbox at a small aggregate company. Imagine the costs of some humongous bearing going down in the states when it’s only made in Europe and replacement is months away.

Customers from various industries stress the importance of bearing corrosion issues when they face problems.

Corrosion is a general concern in process industry such as pulp and paper. Corrosive process fluids can degrade grease, thus affecting re-lube intervals and bearing life.

Corrosion is a factor, albeit secondary to other factors in most applications.

In most of my applications in production lines, corrosion is not the biggest problem.

Extremely important. It’s very simple—if it’s not designed appropriately for the service conditions (with environment being one of those), we’re not buying it.

Corrosion generates hydrogen atoms. Some of those atoms don’t form molecules and, instead, wander through the microstructure looking for a vacancy so they can help create one of the forms of hydrogen damage. With the hardened steels in bearings and their tendency toward hydrogen cracking, my opinion is that even light surface rust is enough to scrap the bearing.

For most applications, corrosion is not a concern unless the equipment is in long-term storage.

Editor’s Note: Sounding Board is based on an email survey of 13,000 TLT readers. Views expressed are those of the respondents and do not reflect the opinions of the Society of Tribologists and Lubrication Engineers. STLE does not vouch for the technical accuracy of opinions expressed in Sounding Board, nor does inclusion of a comment represent an endorsement of the technology by STLE.
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STLE’s 2016 Annual Meeting offers so much programming that keeping track of what’s happening when and where can be a challenge. Our new mobile app lets you plan your itinerary, schedule appointments and stay on top of fast-breaking meeting updates every minute of the day. Download the app—and don’t miss a thing!

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Please mark your calendars for the 2016 TFC, Nov. 13-15 in Chicago’s historic Drake Hotel. We’ll again gather an international community to share tribology’s most cutting-edge research.

March 15 Abstract Deadline
STLE is seeking papers for the following technical tracks:
- Surfaces and Interfaces
- Biotribology
- Fluid Lubrication
- Lubricants
- Machine Elements and Systems
- Energy/Environment/Manufacturing
- Tribochemistry
- Materials Tribology
- Beyond the Cutting Edge

For full details on the technical program, abstract submission process, registration and housing is available on www.stle.org.

Places of Interest • The Art Institute of Chicago • Museum of Science and Industry • Field Museum • Shedd Aquarium • Willis Tower • Lincoln Park Zoo • John Hancock Building • Navy Pier • Millennium Park • Michigan Avenue shopping
ADVANCED NANOMATERIALS AND THEIR APPLICATIONS IN RENEWABLE ENERGY

Authors: Jingbo Louise Liu and Sajid Bashir
Publisher: Elsevier

Advanced Nanomaterials and Their Applications in Renewable Energy presents timely topics related to nanomaterials’ feasible synthesis and characterization and their application in the energy fields. In addition the book provides insights and scientific discoveries in toxicity study with information that is easily understood by a wide audience. Advanced energy materials are important in designing materials that have greater physical, electronic and optical properties. This book emphasizes the fundamental physics and chemistry underlying the techniques used to develop solar and fuel cells with high charge densities and energy conversion efficiencies. New analytical techniques (synchronous x-ray), which probe the interactions of particles and radiation with matter, also are explored, making this book an invaluable reference for practitioners and those interested in the science. Available at www.elsevier.com. List Price: $144.50 (USD).

SUSTAINABLE POWER TECHNOLOGIES AND INFRASTRUCTURE

Authors: Galen J. Suppes and Truman S. Storvick
Publisher: Elsevier

This book presents an overview of current renewable energy sources, challenges and future trends. Drawing from their long-time expertise and deep knowledge of the field, the authors present a critical and well-structured perspective on sustainable power sources and technologies, including solar, wind, hydrogen and nuclear, both in large and small scale. Using accessible language they provide rigorous technological reviews and analyze the main issues of practical usage. The book addresses current questions in this area such as: Is there enough biomass to make a difference in energy needs? Should biomass be used in energy generation? How mature is battery technology? Will it finally become cost effective and will it make a significant difference this next decade? How big a role will small and modular nuclear power generation play in the coming decades? This book is ideal for professionals and students in all areas of energy and power systems as well as those involved in energy planning, management and policy. Available at www.elsevier.com. List Price: $84.96 (USD).

ORGANIC CHEMISTRY, 12TH EDITION

Authors: T.W. Graham Solomons, Craig B. Fryhle and Scott A. Snyder
Publisher: Wiley

In this 12th edition of Organic Chemistry, a central theme of the authors’ approach to organic chemistry is to emphasize the relationship between structure and reactivity. To accomplish this the content is organized in a way that combines the most useful features of a functional group approach with one largely based on reaction mechanisms. The authors’ philosophy is to emphasize mechanisms and their common aspects as often as possible, and at the same time use the unifying features of functional groups as the basis for most chapters. The structural aspects of the authors’ approach show students what organic chemistry is. Mechanistic aspects of their approach show students how it works. Wherever an opportunity arises, the authors’ show students what it does in living systems and the physical world around us. Available at www.wiley.com. List Price: $300.95 for hardcover (USD).
MARCH 2016

STLE Central Illinois Section: Topic TBD (Speaker: Alison D.), March 2, 5:30 p.m. (networking and dinner), 6:30 p.m. (speaker presentation), Golden Corral, 3525 N. University St., Peoria, Ill. Contact: Allison Labraaten, labraaten_allison@cat.com.

STLE Alberta Section: Lubricant Health Monitoring 1 (Speaker: Evan Zabawski, ALS Tribology), March 14, 6 p.m. (hospitality hour), 6:15 p.m. (dinner), 7:15 p.m. (speaker presentation), The Scottish Rite Club of Hamilton, 4 Queen St. South, Hamilton, Ontario, Canada. Contact: Peter Neufeld, pneufeld@suncor.com.

STLE Hamilton Section: Application of Cutting and Metal Removal Fluids (Speaker: Bert Nyenhuis, SKF Lubrication), March 15, 5:15 p.m. (hospitality hour), 6:15 p.m. (dinner), 7:15 p.m. (speaker presentation), STLE Chicago Section: Technical Seminar, March 16-17. The Chicago Section is offering a two-day technical seminar March 16-17 designed for maintenance professionals who have responsibility for lubricant selection, evaluation, safety and rotation equipment reliability. The course will address many of the topics needed for the Certified Lubrication Specialist™ (CLS) certification. The optional CLS, Certified Oil Monitoring Analyst™ (OMA) and Certified Metalworking Fluids Specialist™ (CMFS) exams will be offered Friday, March 18, for those looking to obtain these certifications. Attendees are also invited to register for the STLE Chicago Section monthly meeting immediately following the program on Wednesday for networking, dinner and a technical presentation. Fee is $295 for STLE members and $375 for nonmembers. Fee includes lunches, continental breakfast and the two-day course. Argonne National Laboratory, 9700 S. Cass Ave., Argonne, Ill. Contact: Brian Holtkamp, Holtkamp@nyelubricants.com or (847) 978-8568.


STLE North Texas and Oklahoma Sections: Joint Education Seminar, March 23-24. Topics include PC-11, EAL/VGP and hydraulics and industrial gear. Speakers TBD. Fee is $200 and includes breakfast and lunch for both days. WinStar World Casino and Resort, 777 Casino Ave., Thackerville, Okla. Contact: Paul Salter (pauls@royalmfq.com) or Daniel Roberts (D.Roberts@le-inc.com).

STLE Pittsburgh Section: Dry Film Lubricants/Silicone Lubricants (Speaker: Gary Weber and Yifeng Liao, Dow Corning), March 23, 4:30 p.m. (registration), 6 p.m. (speaker presentation), 6:30 p.m. (dinner), Powers Court Building, Green Glass Building, 17199 N. Laurel Park Dr., Livonia, Mich. Contact: Beth Zou, qzou@oakland.edu.

STLE Detroit Section: Lubricant Health Monitoring 2 (Speaker: Lloyd (Tex) Leugner, AGAT Laboratories), April 11, 6 p.m. (hospitality hour), 6:45 p.m. (dinner), 7:30 p.m. (speaker presentation), Hotel Blackfoot, 5940 Blackfoot Trail SE, Calgary, Alberta, Canada. Contact: Peter Neufeld, pneufeld@suncor.com.

APRIL 2016

STLE Central Illinois Section: Regulations Compliance/Cr Replacement, Conflict Minerals (Speaker: Chuong Dam), April 6, 5:30 p.m. (networking and dinner), 6:30 p.m. (speaker presentation), Golden Corral, 3525 N. University St., Peoria, Ill. Contact: Allison Labraaten, labraaten_allison@cat.com.

STLE Northern California Section: Lubrication Fundamentals and Fluid Management Seminar, April 7, 8 a.m. to 5 p.m. Red Lion Hotel Oakland International Airport, 150 Heggenberger Rd., Oakland, Calif. Contact: Robert Mills at (510) 242-4275 or email stle.norcal@gmail.com.

STLE Canton Section Education Course: Lubrication: Composition, Applications and Condition Monitoring, March 24, University of Akron, 302 E. Buchtel Ave., Akron, Ohio. Contact: Paul Shiller, paul.shiller@uakron.edu.
STLE LOCAL SECTION MEETING CALENDAR

STLE Cleveland Section: Topic TBD (Speaker: STLE President Dr. Martin Webster, ExxonMobil), April 13, 5:30 p.m. (registration and networking), 6 p.m. (dinner), 6:45 p.m. (speaker presentation), Shula’s 2, 6200 Quarry Ln., Cleveland, Ohio. Contact: Leah Morris, lmorris@elcocorp.com.

STLE Chicago Section: Social Outing, April 16, 5:30-9:30 p.m. Join the Chicago Section for a night of great food and laughs at Second City Theater, 1616 N. Wells St., Chicago, Ill. Show time is 8 p.m. at the main stage. Dinner will be before the show at Topo Gigio Ristorante, 1516 N. Wells St., Chicago, Ill. Fee is $55 per ticket and is open to the first 50 participants. Sign up at www.chicagostle.org.

STLE Hamilton Section: Topic and Speaker TBD, April 19, 5:15 p.m. (hospitality hour), 6:15 p.m. (dinner), 7:15 p.m. (speaker presentation), The Scottish Rite Club of Hamilton, 4 Queen St. South, Hamilton, Ontario, Canada. Contact: Chris Webb, cwebb@hydrafab.com.

STLE Pittsburgh Section: Topic and Speaker TBD. April 19, 5:30-8 p.m., Atria’s Restaurant, 1374 Freeport Rd., Pittsburgh, Pa. Fee is $31 and includes appetizers and desserts. Contact: Walter Sloan, Walter.Sloan@sbc.com.

STLE Detroit Section: Commercial Vehicle Transmission Fluids (Speaker: Donna Mosher, Eaton Corp.), April 20, 4:30 p.m. (registration), 5 p.m. (speaker presentation), 6 p.m. (dinner), Powers Court Building, Green Glass Building, 17199 N. Laurel Park Dr., Livonia, Mich. Contact: Beth Zou, qzou@oakland.edu.

STLE Philadelphia Section: Automotive Seminar: GF-6 and PC-11, April 21, 12-4 p.m. This education seminar features an update on two new engine oil specifications. Sandy Run Country Club, 200 E. Valley Green Rd., Orelan, Pa. Contact: Stephanie Johnston, sjohnston@harrymillercorp.com.

STLE Northern California Section: Marine Lubricants (Speaker: TBD), April 27. Time and location TBD. Contact: stle.norcal@gmail.com.

2016 ICMCTF CONFERENCE

The International Conference on Metallurgical Coatings and Thin Films (ICMCTF) is the premier international conference focused on thin-film deposition, characterization and advanced surface engineering, bringing together scientists, engineers and technologists from academia, government laboratories and industry—thereby merging cutting-edge research with real-world applications. The conference will be held April 25-29 at the Town and Country Hotel in San Diego, Calif. (USA).

ICMCTF 2016 is organized in eight concurrent technical symposia, as well as six topical symposia addressing experimental, theoretical and manufacturing issues associated with the development of new coating materials and processes and evolving approaches to scale-up for commercial applications.

In addition to the technical program, the conference features a two-day industrial exhibition, which is open to the public, showcasing the latest in equipment, materials and services used for the deposition, monitoring and characterization of coatings and thin films. Short courses and focused topic sessions (FTS) also will be offered.

For more information, visit www2.avs.org/conferences/icmctf/.

RELIABLE PLANT CONFERENCE

The Reliable Plant Conference serves the machinery lubrication, oil analysis and reliability professionals workshops, learning sessions and case studies covering today’s trends, technologies and issues. The conference will be in Louisville, Kentucky, April 5-7, 2016, at the Kentucky Convention Center. Register early and save at http://conference.reliableplant.com.
Speakers wanted!

OilDoc is continually seeking speakers with interesting case studies, personal expertise and new ideas to contribute to the program. Speaking at the OilDoc Conference provides a number of company and individual benefits:

- Build your company’s name recognition and image.
- Convince the attendees that your company is a leader in the lubricant industry – you/your company will be subject of expert discussions.
- Gain increased status and credibility within the industry by appearing in official conference documents.
- Distinguish yourself as an expert in your relevant specialist area(s).
- Benchmark and gauge your performance against market players and competitors.
- Attract the attention of high potential employees and promising partners.
- Take advantage of the reduced participation fee of only 190 EUR + VAT

Main topics

- **Condition Monitoring – Online, On-Site, Offline**
  - Gears • Rotating machinery • Rolling and plain bearings • Special applications ...
- **Fluid Management – Innovative & Sustainable**
  - Lubrication management tasks • Plant lubricant selection • Fluid care technologies • Handling and storage techniques • Lubrication equipment ...
- **Lubricants – Latest developments**
  - Base oils • Additives • Lubricating greases & pastes • Bonded coatings • Solid lubricants • Dry lubrication ...
- **Tribology – Research targeting Experience**
  - Friction and wear • Materials, surface engineering, contact mechanics • Hydrodynamic and elasto-hydrodynamic lubrication • Minimal quantity lubrication ...
- **Lubricants – Design to Application**
  - Engines • Gas engines • Gears • Hydraulics • Bearings • Turbines • Wind energy plants • Compressors ...
- **Metal working and forming lubrication**
  - Water based & water free fluids • Multifunctional lubricants • Minimum quantity lubrication • Modular systems ...
- **Lubrication in Special Environments**
  - Environmental & health aspects of lubrication • Vacuum lubrication • Biodegradable fluids • Food grade lubricants • Fire resistant lubricants ...
- **Functional fluids – Everything but lubrication**
  - Insulating oils • Heat transfer fluids • Corrosion protection • Cleaning agents ...

Call for Papers

Deadline: April 30, 2016

www.oildoc-conference.com
I was extremely pleased to see this latest revision of a time-tested reference. When I first entered the world of tribology and lubrication engineering in 1981, one of the key references was Lubrication Fundamentals. This book was largely written and edited—but with the help of many—by J. George Wills of Mobil Corp. in 1980 and has stood the test of time. It also is a key reference in STLE’s Body of Knowledge—a listing of key books, courses, Webinars, etc., that codify our current understanding of this broad, multidisciplinary field—for preparation for the Certified Lubrication Specialist™ (CLS) exam. The initial edition was succeeded by the second in 2001 by Don M. Pirro and A.A. Wessol of ExxonMobil. This second edition was a great improvement and update of our understanding. Now we are fortunate enough to have yet another update and expansion. It also is a key reference in STLE’s Body of Knowledge—a listing of key books, courses, Webinars, etc., that codify our current understanding of this broad, multidisciplinary field—for preparation for the Certified Lubrication Specialist™ (CLS) exam. The initial edition was succeeded by the second in 2001 by Don M. Pirro and A.A. Wessol of ExxonMobil. This second edition was a great improvement and update of our understanding. Now we are fortunate enough to have yet another update and expansion. The third edition, written by Pirro, Martin Webster and Ekkehard Daschner, is like its predecessors and should be on the desk of those in our industry who are responsible for understanding the basics of lubrication in automotive and industrial applications.

Lubrication Fundamentals, easily readable by both lubricant sales and plant maintenance people, provides a sound foundation of knowledge on what lubricants are, how they work, many of the applications where lubricants are used and the factors affecting lubrication in these applications. Much has happened in our field over the years. This new book does an excellent job of codifying the very basic concepts in concise, readable English and adds some of the nuances of our expanding knowledge. I think the key strength of this book is its breadth. No matter what practical problem or what the reader wishes to learn more about, this book is an ideal place to start. Indeed, for most subjects, the book contains all you need to know.

The layout of the now 22 chapters of the book begins with a history of lubricant usage and a chapter on base stock production and application, followed by a logical progression of chapters describing lubricant products including an update on environmental lubricants. There are a series of chapters on various industrial and automotive applications describing the lubricants used and what makes each of those applications unique from a tribological perspective. Toward the end there are very practical chapters on the lubricant impact on energy efficiency in mechanical systems, lubricant storage and handling and dispensing of lubricants, with best practices for lubricant conservation and machinery reliability, and then concludes with a final new chapter on how to maintain lubricants in-service, which includes both testing as well as reconditioning techniques.

Additionally there are two more new chapters on the growing renewable energy application of wind turbines, the impact of lubricants on energy efficiency and best practice guidelines on establishing an in-service lubricant analysis program.

Some of the notable updates concern energy efficiency and—in the automotive area—API, SAE and ACEA engine oil specifications, descriptions of new engine oil tests and impact of engine and fuel technology trends on engine oil.

In summary I think this book is, as were its predecessors, a key foundation reference that any serious practitioner in our field should have—and read. While not written like a typical textbook, it could easily fit into the course materials used in some of the new undergraduate programs arising in our universities.
LUBRICATION, MAINTENANCE AND TRIBOLOGY

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Staying visible in your profession

These 14 recommendations will improve your industry visibility.

HAVE YOU ASKED YOURSELF LATELY what it will take to achieve your ultimate career goals? In all likelihood your goals will change many times throughout the course of your career. Accomplishment of these goals is an ongoing, challenging and dynamic process and is dependent upon a number of factors.

Hard work, success and determination go a long way in helping achieve career goals, but you also need to be visible by keeping professionals in your field aware of who you are, what you have done and what you want to do. Staying visible is akin to consistently marketing yourself within your industry, including to your current employer.
There are numerous benefits to be gained from heightened visibility. You will potentially:

- Receive more job opportunities
- Earn faster promotions
- Increase your monetary value
- Increase the size of your network
- Reconnect with old contacts
- Be found easier via searches on Google
- Be viewed as an expert and thought leader in your field
- Raise the status and visibility of your employer
- Earn additional honors and awards
- Raise industry awareness of your background, interests and goals
- Be offered STLE leadership and presentation opportunities.

With the advancement of the digital age, there are more and more ways to maintain a high level of visibility for yourself within your field. Examine yourself to see where you can improve your industry visibility. Here are my top recommendations.

1. **Get connected and keep your network active.** Networking comes in many forms and is a primary avenue to enhanced visibility. The foundation of a plan to heighten professional visibility is to have a solid and broad network that you keep in touch with regularly. Keep your name in front of others, emphasize that you value the relationship, offer assistance and information and ask for career assistance when needed. Building your network can be done through phone calls, emails, in-person contact and through LinkedIn (the best social media site for professionals). Connect as much as possible with industry leaders and executives who may be more likely to offer you valuable career guidance.

2. **Attend trade shows and conferences.** The STLE Annual Meeting & Exhibition, which frequently draws in the range of 1,500 attendees and 90 exhibitors from around the world, is an example of an excellent conference venue to achieve high visibility among a great number of peers. It is an opportunity to conduct business in one location with many fellow lubricant industry professionals. Education and networking are top reasons that individuals attend conferences. Take advantage of this venue by participating in education programs and social functions, actively networking and taking on leadership and volunteer roles.

3. **Attend industry meetings.** Attending industry meetings and technical sessions, often held monthly, is an outstanding method to stay visible among your peers in the best possible way: in person. Such meetings usually consist of a social hour and dinner, which allows plenty of time to network, discuss career developments and industry news and exchange ideas and information. If you attend such meetings frequently enough, you will build close relationships where you can rely upon others for career guidance and reciprocate when others need your assistance.

4. **Volunteer.** Numerous opportunities exist to volunteer in technical societies such as STLE. At the local section or national level, you can join a committee or become an officer. You can chair a session or help with planning at a technical conference. With each of these volunteer roles, you will expand your networking opportunities. You also will develop close relationships where you might gain ideas for career advancement or even obtain a specific job opportunity. Overall you will gain visibility and recognition for your time commitment and dedication to the industry as well as for your specific knowledge and leadership capabilities.

5. **Get published.** Having a technical article or professional column published in a print or digital magazine, newsletter or other venue will provide you with a great deal of recognition among your peers. If you have not previously been published, offer your writing talents to your employer, industry leaders and technical societies in your field. Your expertise will likely be welcomed. You also will gain positive recognition from being quoted and assisting with article content in publications such as TLT and other industry magazines. If you’re a researcher, peer-reviewed journals like Tribology Transactions and Tribology Letters will raise your profile.

6. **Give presentations.** STLE provides many opportunities to present at local and national levels including annual meetings, technical conferences, education programs, Webinars and section meetings. Your efforts will be noticed by many professionals, even those who have not listened to your presentation. Most important, you will be recognized as an expert in your field and an individual who gives back to the industry. Once you begin to make successful presentations, you will receive regular offers to present, especially if you include yourself in the STLE speaker database.

7. **Maintain a LinkedIn profile.** About 94% of employers utilize LinkedIn to support recruitment efforts, and 79% of employers have hired someone through LinkedIn, according to a 2014 survey by Jobvite. LinkedIn has more than 380 million members in more than 200 countries and is the predominant social media site focused on professional careers. There is much information you
can display about yourself in your LinkedIn profile, including (1.) availability for employment, (2.) experience, (3.) skill set, (4.) strengths, (5.) accomplishments, (6.) certifications, (7.) personal characteristics, (8.) passion for your work, (9.) career goals and recommendations, (10.) awards, (11.) volunteer efforts, (12.) connections, (13.) career goals and (14.) contact information. Whether you are actively job searching or simply looking to maintain career visibility, do not pass up the opportunity to gain wide industry exposure through a LinkedIn profile.

8. **Participate in LinkedIn discussion groups.** STLE, with more than 5,000 current group members, is one of many lubricant industry related groups you can join on LinkedIn. Participating in or starting a discussion within a group is an excellent way to express your views and prove yourself to be a thought leader in your field. Post and respond to inquiries and news items to further increase your visibility. Create and build your own group to substantially increase your visibility level.

9. **Use Facebook, Twitter and other social media.** Facebook and Twitter are among the largest social networking sites to offer valuable professional networking opportunities, albeit less than LinkedIn. According to a 2014 survey by Jobvite, 66% of employers utilize Facebook to support recruitment efforts while 26% of employers have hired someone through Facebook. Also 52% of employers utilize Twitter to support recruitment efforts while 14% have hired someone through Twitter. On Facebook you should (1.) include your professional history in your profile, (2.) post and respond to content and (3.) find networking connections at specific companies. On Twitter you should (1.) build your personal brand and (2.) network by creating content and being followed. Since over half of employers who use social networking sites have found content causing them not to hire a candidate, do not post negative, controversial, religious or political material.

10. **Maintain a personal Website.** There is a tremendous amount of information that can be included on a personal Website that will convey to the industry who you are, what you have done and what you want to do. For starters it is a success in itself to put together a professional Website that will be viewed and admired by your peers. If you are actively job searching, post your full resume, list of accomplishments and recommendation letters. In addition, include links to your LinkedIn profile, Twitter and Facebook accounts and select publications and presentations.

11. **Manage a personal blog.** Creating your own blog would be an invaluable resource to greatly increase your personal visibility and would be a big asset toward obtaining job leads if you were searching for a new opportunity. It would keep you in constant communication with professionals in your field. However, keep in mind that managing a blog requires a huge time commitment.

12. **Achieve honors and awards.** Giving 100% effort and going the extra mile toward completing tasks successfully will naturally lead to recognition, honors and awards. These honors will typically be displayed and/or presented in places such as your resume, LinkedIn profile, personal Website, employer newsletters and Websites, trade publications, industry meetings, conferences and various press releases. This is the type of visibility to aim for: the kind that not only keeps your name out there but shows your peers that you are dedicated to your work and have been highly successful.

13. **Promote your business.** Keep your name visible in the industry through your own business if you are currently (1.) running a company, (2.) actively consulting, (3.) an independent sales representative or (4.) between positions. If you are unemployed you are effectively running a full-time business with the mission to find the right long-term career opportunity. In this case it is more important than ever to promote yourself through networking, social media and job boards. If you manage a business be sure to keep the industry aware of major developments such as new (1.) hires, (2.) contracts, (3.) products or innovations, (4.) purchases and alliances and (5.) expansions. Accomplish this ideally through press releases in major publications as well as through social media.

14. **Post your resume on job boards.** If you are actively or semi-actively searching for a new position, maximize industry exposure and cover as many bases as possible by posting your resume on sites such as CareerBuilder, Monster, STLE and LinkedIn. If your search is confidential, leave out information that could easily reveal your identity such as contact information and employer names. It is generally safe to openly display your professional experience on LinkedIn since it has become standard practice to do so. Even if you are satisfied with your current job, it may be a good idea to post your resume on job boards to learn about the types of opportunities that are available for your background.

In summary, work toward reaching your career advancement potential by maintaining high industry visibility for your knowledge, skill set, experience, accomplishments, strengths, career goals and motivation.
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ON CONDITION MONITORING

Jack Poley

LAST COLUMN, I PRESENTED THREE REQUIRED INFORMATION PIECES IN ORDER for an intelligent agent (IA), domain knowledge-infused expert system:

1. The component name (I.D.), a unique designation for the lubricated asset (the sump) being monitored
2. The sample date (no date, no trending)
3. The component type (diesel, gas turbine, gear set, etc.).

Let’s revisit the conceptual difference between equipment and component once more. The equipment houses the component and the component hosts the lubricant (or other fluid being tested). You may prefer different labels—well and good—but if so, it’s essential you still translate your terms correctly to the IA data template so that appropriate tables of boundaries and commentary are availed. Figure 1 shows some relationships between equipment and component.

Notice that some equipment like plant is strictly conceptual, but it’s important to recognize that relationship to the sampled component. The important thing is to differentiate properly.

Note as well that a top drive (the principal drilling apparatus on most drill rigs these days) is a sub-equipment in effect. Most every top drive has a gear set (the main drive) plus a hydraulic and, often, seals. Multiple sample points therefore exist and must have separated records. It would be slightly wrong using our dictionary for this article to call it a sub-component since we’ve already postulated that components house the lubricant or other fluid. In this case I suggest the proper thing to do is violate the rule we posited and create an exception, calling the top drive a sub-equipment but treating the top drive’s individual sumps as components called Top Drive Gear, Top Drive Hyd, etc., until all sumps sampled are accounted for. Also note that you’ll still need to identify these components as simply gear (and type of gear if you know: Helical, Pelatoid, Herringbone) and the hydraulic (and type if you know: axial-piston, gear, vane, etc.). Then you will have everything sorted out.

Yes, this is a semantics exercise, but it’s important you conduct it correctly when you set up or redress your database. As I warned early on, there is a bit of work and some tedium, mostly paying close attention to detail that is necessary to have something close to an idealized, pristine database. I hope by now you know why I’m pressing so hard with this notion. Here’s a hint: $$.

Occasionally the component is stand-alone, i.e., it belongs to no plant or recognizable equipment. However, it could be in a group of transformers that are part of a specific grid configuration, i.e., are clustered near each other, creating a logistical equipment.

I gave some examples of component types; however, Figure 2 is a more thor-
ough list, though there might always be a component that requires its own unique component type designation. I have found this list to be >99% complete thus far. We may have created as many as five (if that) new component types in the last three or four years.

It stands to reason: The component is the key to good evaluation. So one should always aim to provide as much information as possible as to a component’s classification. And by the way, it’s also a good key to help the lab guide one to the best test package possible. Labs often have difficulty rendering incisive evaluations when samples enter the door labeled crudely: diesel engine, compressor or hydraulic, and nothing else—not an MFR, not a sump size. (You wouldn’t be so quick to recommend a drain on a 5,000 gallon sump, would you?)

Sampling should not be an exercise in inadvertently misleading an evaluator. On the other hand, I’ve always advised evaluators never to guess the sub-classification of, say, a hydraulic system. About all one can do when limited to such basic nomenclature, even if one is using an IA, is state: Wear is normal, abnormal, very high, severe and lube is or is not suitable for continued use; fluid needs to be drained (and filtered, if applicable, also changed); or fluid needs cleaning or polishing, though we’re not sure what the contamination limits might be. We would take a middle-of-the-road approach perhaps. One surely should not mention axial pistons or vanes because one just doesn’t know.

We’ll conclude the database construction/redress next article.

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**Table: Component and Equipment Types**

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>COMPONENT</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulldozer</td>
<td>Transmission</td>
<td>One of five possible components in the bulldozer</td>
</tr>
<tr>
<td>Plant #2</td>
<td>Compressor</td>
<td>The plant is an equipment analog, housing components</td>
</tr>
<tr>
<td>Plant #2</td>
<td>Steam turbine</td>
<td>The plant is an equipment analog hosting numerous pieces</td>
</tr>
<tr>
<td>Ocean-going ship</td>
<td>Steam turbine</td>
<td>A vessel has numerous components supporting its work</td>
</tr>
<tr>
<td>Offshore drilling rig</td>
<td>Compressor</td>
<td>Offshore rigs are a form of plant</td>
</tr>
<tr>
<td>Offshore drilling rig</td>
<td>Top Drive Gear</td>
<td>The Top Drive has at least two sumps: gear set and hydraulic</td>
</tr>
<tr>
<td>Offshore drilling rig</td>
<td>Top Drive Hyd</td>
<td>The Top Drive has at least two sumps: gear set and hydraulic</td>
</tr>
<tr>
<td>Over-the-road tractor</td>
<td>Differential</td>
<td>A tractor–trailer has several components</td>
</tr>
<tr>
<td>Off-road haul truck</td>
<td>Differential</td>
<td>A haul truck has several components</td>
</tr>
<tr>
<td>Transformer</td>
<td>Transformer</td>
<td>Stand-alone: Equipment and component are one and the same</td>
</tr>
</tbody>
</table>

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**Figure 1** | Relationships between equipment and component.

**Figure 2** | Examples of component types.

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The correct industrial gear oil

Viscosity grade and speed are among the determining factors when making a selection.

Industrial gears operate in many different environments whether indoors or outside. Conditions can be hot, cold, wet, dry, dusty and/or with variable loads. The latest gearboxes often are smaller and made from lighter weight materials, but they can be pushed to transmit more power while also being more durable and reliable. Plant managers expect higher performance, less downtime and more productivity to improve profits.

Smaller gearboxes mean less oil to lubricate and protect gears. Coupled with higher loads, this leads to higher oil temperatures and more rapid oxidation. Oxidation harms industrial gear oils because it can form sludge that can shorten both oil and gear life. Constant gear rolling and sliding also produces friction and heat. In addition, contaminants such as water and dust can compromise a gear system.

Many factors need to be considered when selecting an industrial gear oil.

The appropriate viscosity grade might be found in the equipment maintenance manual. But the manual may not exist or the operating conditions may not be under the manufacturer’s recommendations. A gear oil’s viscosity is primarily chosen to provide a desired film thickness between interacting surfaces at a given speed and load. Because it is difficult to determine the load, this is assumed and the determining factor becomes speed.

One of the most common methods for determining viscosity is the American National Standards Institute (ANSI) and American Gear Manufacturers Association (AGMA) standard ANSI/AGMA 9005-E02. Assumptions are made about the load, viscosity index and the pressure-viscosity coefficient of the lubricant, and these are combined with the type of gear set, gear geometry, operating temperature and the speed of the slow speed gear.

Highly viscous oils generate heat from internal fluid friction and also may consume more power to turn the gears. Less viscous oils can flow more easily through the filtration system. Contaminants are removed effectively, reducing the possibility of gear and bearing damage and increasing equipment life.

Next comes the type of gear oil: rust and oxidation (R&O) inhibited, extreme pressure (EP) or compounded. The gear lubricant type that best fits a given application will be determined by the operating conditions. R&O gear oils generally have good chemical stability, demulsibility, corrosion prevention and foam suppression. They are used in gearboxes operating under relatively high speeds, low loads and with uniform loads but do not perform well or prevent wear under boundary lubrication conditions.

EP gear oils contain additives that enhance their film strength or load-carrying ability by preventing adhesive wear under boundary lubrication conditions. In less severe applications, antirust additives may be used to provide wear protection under boundary lubrication conditions. Conditions that generally require EP gear oils include heavy loads, slow speeds and shock loads.

High-quality mineral base oils typically have higher pressure-viscosity coefficients than common synthetic oils, giving greater film thickness at given operating viscosities. However, many synthetic base oils have greater inherent resistance to oxidation and thermal degradation, making them preferable for applications with high-operating temperatures and/or allowing extended service intervals. Synthetic gear oils can perform better at low ambient temperatures if they have a high viscosity index and low pour point. They may be more suitable for a wider range of ambient temperatures eliminating the need for seasonal oil changes. Some synthetic oils also may offer greater lubricity, which reduces friction in sliding contacts.

Water can creep into a gearbox in several ways, potentially leading to corrosion. Gear oils should have good demulsibility properties so that any water can separate quickly. The ability to rapidly drain water from the system helps extend the life of both the gearbox and the oil.

When choosing a gear oil, ask the supplier if it is approved or recommended by the equipment manufacturer. Also ask for performance information against the international or national specifications. The fluid should be delivered clean and water-free so it will perform at its best. It’s very important to conduct used oil analysis as recommended by the supplier to determine when the oil may need maintenance or replacing.

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